Name of the Deptt. : Irrigation Department, Punjab

A Manual of Administration

APPENDIX – F
PREFACE

The first edition of Manual of Irrigation Practice was published just before the Partition. Since the Partition, activities of the Irrigation Branch, Punjab, have expanded manifold and besides canal works, they encompass design and construction of high dams, power houses.

The first volume of Manual of Irrigation Practice concerning Specifications was issued in the year 1956. An endeavour was made to publish Volume No. II early but the same got delayed up to 1963, as the writing of chapters entailed a considerable volume of work. This Manual presents useful data for the guidance of engineers in the Department.

A few chapters still remain to be completed. But keeping in view the urgency and need of young engineers, the chapters so far completed have been included in the Manual of Irrigation Practice. The remaining chapters, however, will be added as and when complete.

Chief Engineer,
Irrigation Works, Punjab,
Chandigarh.
CHAPTER 1.
Definitions

CONTENTS.
Definition of terms used in connection with irrigation Glossary of vernacular terms.
CHAPTER I

Definitions*

Aeration  ... (1) The process of mixing air or other gases with water, sewage, etc.
          (2) The process of relieving the effects of cavitation by admitting air to the section affected.

Acre foot  ... A unit of volume used in irrigation practice. It means the volume of water required to
            cover an area of one acre, to a depth of one foot. It amounts to 43,560 cubic feet. It
            will be noticed that a cubic yard is equal to 1,98 acre feet (ordinarily taken as 2).

Acre inch  ... Is 1/12 of acre foot defined above (and is almost equal to one-cusec hour).

After bay  ... The tail-race of a water power plant, a pond or reservoir at the outlet of the turbines.

Angularity correction ... The correction to be made to an observed velocity when the direction of the current
                        is not exactly at right angles to the discharge section line.

Apron  ... A floor or lining of concrete stone, etc., to protect a surface from erosion, such as the
          pavement below weirs, falls or at the toe of a dam.

Aqueduct  ... A channel, in which water flows with "free" surface, constructed to carry water above
           the natural surface level.

Area-Assessed  ... The area irrigated, on which water rates are levied (generally the same as area
           matured).

Area-Cultivated  ... Land which is under crop or fruit trees or has been under crop or fruit trees in
           the previous three harvests.

Area—Culturable commanded  ... That portion of the cultivable irrigable area which is commanded by flow irrigation.
<table>
<thead>
<tr>
<th>Area</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culturable lift</td>
<td>That portion of culturable irrigable area which can be irrigated by lift.</td>
</tr>
<tr>
<td>Discharge section</td>
<td>The area of the water-way of a channel at the discharge section line, this is always expressed in square feet.</td>
</tr>
<tr>
<td>Flow irrigation</td>
<td>Area which can be irrigated from the source of water, by flow under gravity alone.</td>
</tr>
<tr>
<td>Gross</td>
<td>The total area within the extreme limits set for irrigation by a project, system or channel.</td>
</tr>
<tr>
<td>Gross commanded</td>
<td>That portion of the gross irrigable area which is commanded by flow irrigation.</td>
</tr>
<tr>
<td>Gross irrigable</td>
<td>The gross area less such areas within irrigation limits as may be excluded, for any reason, for irrigation by the project, system or channel.</td>
</tr>
<tr>
<td>Gross lift</td>
<td>That portion of gross irrigable area which can be irrigated by lift.</td>
</tr>
<tr>
<td>Irrigated</td>
<td>The area to which water has been applied.</td>
</tr>
<tr>
<td>Lift Irrigation</td>
<td>Area of which the level is too high to allow of irrigation by flow from the source, but which can be economically irrigated by water raised to the necessary level at some point in the supply system.</td>
</tr>
<tr>
<td>Matured</td>
<td>The area irrigated upon which crops have matured.</td>
</tr>
<tr>
<td>Non-perennial</td>
<td>The area served by a non-perennial canal.</td>
</tr>
<tr>
<td>Outlet</td>
<td>The unit of area, in irrigation practice for final distribution. It is the area served by the individual outlet. The village area may be divided into several outlet areas or alternatively an outlet area may consist of portions of several villages. Its boundaries are, or should be, defined by the configuration of the ground, whereas village boundaries are not so limited.</td>
</tr>
<tr>
<td>Ar</td>
<td>Definitions</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Area—Perennial</td>
<td>The area served by a perennial canals.</td>
</tr>
<tr>
<td>Area—Reclaimed</td>
<td>The area irrigated for which water rates are remitted owing to failure of</td>
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<tr>
<td></td>
<td>crops to mature or for other reasons.</td>
</tr>
<tr>
<td>Arid</td>
<td>A term applied to lands or climates that lack sufficient water for</td>
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<td></td>
<td>agriculture without irrigation.</td>
</tr>
<tr>
<td>Backwater curve</td>
<td>A form of the surface curve of a stream of water caused by an obstruction</td>
</tr>
<tr>
<td></td>
<td>in the channel such as a weir.</td>
</tr>
<tr>
<td>Baffle</td>
<td>A cross wall or a set of vanes or some other device placed in a channel to</td>
</tr>
<tr>
<td></td>
<td>effect a uniform distribution of velocities across the section.</td>
</tr>
<tr>
<td>Barrage</td>
<td>A weir equipped with series of sluice gates to regulate the water surface</td>
</tr>
<tr>
<td></td>
<td>level above them.</td>
</tr>
<tr>
<td>Base, base days or</td>
<td>The number of days in a crop. In the Punjab it numbers 183 for irrigated</td>
</tr>
<tr>
<td>period</td>
<td>162 for irrigated.</td>
</tr>
<tr>
<td>Bed load</td>
<td>Silts, sand, gravel or other detritus rolling along the bed of a stream.</td>
</tr>
<tr>
<td>Berm</td>
<td>1. The space left between the upper edge of a cut and the toe of an</td>
</tr>
<tr>
<td></td>
<td>embankment.</td>
</tr>
<tr>
<td></td>
<td>(2) A horizontal strip or shelf built into an embankment to break the</td>
</tr>
<tr>
<td></td>
<td>continuity of an otherwise long slope.</td>
</tr>
<tr>
<td>Blocks</td>
<td>Obstructions set in the path of high velocity water to dissipate energy and</td>
</tr>
<tr>
<td></td>
<td>prevent scour.</td>
</tr>
<tr>
<td>Breach</td>
<td>This term is applied to a large channel taking its supply from the main</td>
</tr>
<tr>
<td></td>
<td>canal but whose functions are the same, viz., the supply of water to</td>
</tr>
<tr>
<td></td>
<td>distributaries.</td>
</tr>
</tbody>
</table>
Bucket wheel. The revolving portion of a current-meter driven by the force of the current and whose revolutions are an indication of the velocity of that current.

Caisson. A chamber, usually sunk by excavating within it, for the purpose of gaining access to the bed of a stream of other body of water. If the chamber is closed on top and the water excluded by air pressure, it is called a pneumatic caisson.

Canal. An artificial channel constructed to convey appreciable quantities of water.

Canal-Inundation. This term is ordinarily applied to a canal with or without some form of head regulators, dependent upon the surface level of the water in the river for its supplies. It follows that inundation canals will only run when the supply in the river rises to a level which permits of feeding the canal.

Canal-Intermittent. A canal designed to irrigate only when demand arises and usually takes its supply from a storage or reservoir.

Canal-Irrigation. A canal constructed primarily for conveying water from the source of supply to areas in which it can be used for irrigation.

Canal-Navigation. A canal whose primary object is transport by water. In a purely navigation canal the flow of water is reduced to a minimum.

Canal-Weir controlled. A canal taking its supply from a river at whose head the works are of a nature which permit control of the water level of the source of supply.

Capacity. (1) When applied to a channel, the authorized full supply discharge.
Ca

DEFINITIONS

(2) When applied to a reservoir or tank the gross capacity is the quantity of water stored between bed level and the level of the cill of the waste weir.

(3) When applied to an outlet, the outlet capacity is the discharge passed by the outlet when the channel is running at authorised full supply discharge.

Capacity curve. The graph of the volume of reservoir, tank, etc., as function of elevations. The capacity of reservoir can only be defined by reference to some definite elevation.

Capacity factor. The ratio of the mean supply to the authorised full supply or capacity.

Note:-(i) If it were possible to run a canal system at full supply discharge or closed, then the capacity factor and time factor would be the same.

Note:-(ii) Owing to rotational working, branches and distributaries do not run for the same number of days as either the main canal or each other.

Note:-(iii) The volume of discharge of a channel is given in days-days by the sum of the daily discharges for the period in question. It is equal to the:

(a) average discharge multiplied by the number of days the canal is in flow, or

(b) mean discharge multiplied by the number of days in the crop.

Capacity-Flood absorption. Is the capacity of a reservoir between high flood level and the normal reservoir level, provided for the absorption of floods.

Capillarity. In a soil, arises from the fine interstices between the particles and results in the raising of the contained water above the free water level.

Capillary water. Water held above the water table in soil by capillary force.

Cavitation. A condition where in a vacuum to any degree exists as a result of flowing water complete cavitation obtains when the pressure within the affected part is reduced to that of the vapour pressure of the water.
**MANUAL OF IRRIGATION PRACTICE**

**Centrifuge moisture equivalent**
- Is the moisture content of the soil when subjected to a centrifugal force of one thousand times the force of gravity for one hour.

**Channel—Irrigation**
- (Commonly known as water course). A small channel taking its supply from a Government channel but owned and maintained by the cultivators.

**Channel—Non-perennial**
- A channel which is designed to irrigate during only part of the year, usually the "kharif" or summer season.

**Channel—Perennial**
- A channel which is designed to irrigate all the year round.

**Cistern**
- A pool of water maintained to take the impact of water overflowing a dam, chute, drop or other spillway structure.

**Clay**
- According to the American standard, this represents soil particles under .005 mm. diameter. The standard adopted by the International Society of Soil Science, however, lays down the limit as particles under .002 mm. diameter.

**Co-efficient of discharge**
- Ratio of observed (actual) to the theoretical discharge.

**Co-efficient of roughness**
- A factor in the Kuturr, Manning, Bazin, and other formulae expressing the character of a channel as effecting the friction slope of water flowing therein.

**Cooker dam**
- A barrier built in water so as to form an enclosure from which water is pumped to permit free access to the area within.

**Cohesion**
- In a soil, is the resistance of particles against motion because of their stickiness. Cohesion is high in clays, but may be very low in silt and is entirely lacking in sand.

**Colloids**
- Soil particles smaller than .001 mm. diameter.

**Commutator**
- The portion of a current meter containing the electrical contacting device for indicating single revolutions of the bucket wheel.
Co

DEFINITIONS

Compaction

.. Compaction is one of the methods used in the consolidation of stabilised earthwork and consists in the application of load at the top of an unconsolidated or partially consolidated layer of a graded mixture which contains enough granular material to provide for mechanical interlocking. The load is readily transmitted vertically and causes consolidation through out the thickness of the layer. The soil is rolled in relatively thin layers and, as a rule, in a moistened state, but neither thickness of layers nor the moisture content is critical. (See Densification)

Compressibility

.. In a soil, is the degree of resistance to change in volume under the pressure of heavy loads.

Contraction

.. The extent to which the cross sectional area of a jet or nappe is decreased after passing an orifice, weir or notch.

Control point

.. A "free" fall, so designed that the water surface level above it bears a fixed relation to the discharge passing. The level is usually fixed with reference to the authorised fall supply discharge.

Crest

.. (1) The top of a dam, dyke, spillway or weir, frequently restricted to the overflow portion;

.. (2) The summit of a wave, peak or a flood.

Crop ratio

.. The crop ratio, or kharif rabi ratio is defined as the ratio between the areas anticipated to be irrigated in these two crops.

Current meter

.. The device for determining the velocity of flowing water by ascertaining the speed at which a stream of water rotates a vane or a wheel.

Cusec

.. The unit of discharge used in irrigation practice and means a rate of flow of one cubic foot per second.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cusec day</td>
<td>A unit of volume used in irrigation practice and means the volume of water resulting from a discharge of one cusec for one day (24 hours). It amounts to 86,400 cubic feet of water and is equal to nearly two acre-feet.</td>
</tr>
<tr>
<td>Cut-off</td>
<td>A wall, color, or other structure intended to reduce percolation of water along otherwise smooth surfaces or through porous strata.</td>
</tr>
<tr>
<td>Cut-off trench</td>
<td>An excavation in the base of a dam or other structure filled with relatively impervious material to reduce percolation.</td>
</tr>
<tr>
<td>Dam</td>
<td>A structure erected to impound water in a reservoir or to create hydraulic head.</td>
</tr>
<tr>
<td>Dam—Arched</td>
<td>A curved dam, convex upstream that depends on arch, or arch and cantilever action for its stability. The load is transferred by the arch to the canyon walls or other abutments.</td>
</tr>
<tr>
<td>Dam axis</td>
<td>The axis of an arch dam is a vertical cylindrical surface which pierces through the top of the dam at the upstream face.</td>
</tr>
<tr>
<td>Dam-Buttress</td>
<td>A masonry structure which carries the water load from the impervious deck on the upstream face through buttresses or counterforts to the foundation.</td>
</tr>
<tr>
<td>Dam-Debris</td>
<td>A barrier built across a stream or channel to collect debris such as sand, gravel, silt, drift wood.</td>
</tr>
<tr>
<td>Dam-Flat deck</td>
<td>This type of dam is made of a flat reinforced concrete slab, which transmits water pressure to a series of parallel buttresses which rest directly on the foundation or upon a concrete slab resting on the foundation material.</td>
</tr>
<tr>
<td>Dam-Gravity</td>
<td>A dam which depends, for its stability, entirely on its weight. It may be straight or slightly curved in plan.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
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</tr>
<tr>
<td>Dam-Gravel fill</td>
<td>It is an embankment composed of gravel or shingle with the downstream part made of relatively coarse material, and the upstream, or water side part made of finer gravel and sand.</td>
</tr>
<tr>
<td>Dam-Hydraulic fill</td>
<td>A dam composed of earth, sand, gravel etc., sluiced into place, generally the fine materials are washed towards the centre for greater imperviousness.</td>
</tr>
<tr>
<td>Dam-Multiple arch</td>
<td>This type of dam consists of a series of inclined arches supported by buttresses. The load on the upstream face is transmitted by the archer to the foundation through the buttresses.</td>
</tr>
<tr>
<td>Dam-Overflow</td>
<td>A dam designed to be overtopped in floods.</td>
</tr>
<tr>
<td>Dam-Rock filled</td>
<td>It is a modified form of the earth dam using rock of all sizes to provide stability and an impervious membrane on the upstream side to provide water-tightness.</td>
</tr>
<tr>
<td>Dead storage level</td>
<td>See Level—Dead storage.</td>
</tr>
<tr>
<td>Delta</td>
<td>As expression used in irrigation practice to mean the depth of water that would result over a given area from a given discharge for a certain length of time. Alternatively, delta may be defined as the total volume of water delivered divided by the area over which it has been spread.</td>
</tr>
<tr>
<td>Demand</td>
<td>(1) At the outlet—The cultivators' water requirements.</td>
</tr>
<tr>
<td></td>
<td>(2) At the head of a channel—The sum of all useful discharges required, plus total losses.</td>
</tr>
<tr>
<td>Demand factor</td>
<td>When applied to an electric installation Demand factor of a system or any part thereof is the ratio of the maximum demand of the system or part thereof to the total connected load on the system or part thereof under consideration.</td>
</tr>
</tbody>
</table>
Densification

Is one of the methods used in the consolidation of stabilised earth-work and consists in the application of such a load as penetrates the unconsolidated material and compacts the layer from the bottom upwards in order that the material shall be consolidated uniformly throughout its thickness without stratification. For densification the soil is deposited in layers of specified thickness and at a particular moisture content (See compaction).

Density-Soil

The density of a soil is its weight per unit volume. A soil which, consists of solids and pores has two densities that of the mass termed "bulk" density and that of the solids termed "absolute" density.

Depression

In a semi-module, the depth below supply level of some point of a semi-module fixed by its hydraulic such that as supply level varies, a constant co-efficient multiplied by the correct power of that depth gives the discharge.

Depression ratio

The ratio between the depression and the height of the opening of an orifice outlet.

Direction float

A standard metal float carrying a small flag used for indicating the direction of flow of a river so that the angle that direction makes with the discharge section line at an observation point may be measured.

Direction peg line

The line parallel to the discharge section line on which the direction pegs are located.

Direction pegs

The points through which rays from the observation points pass when converging on the pivot point.

Discharge

The rate of flow at a stated site, i.e. the quantity of water passing in unit time.

Discharge section line

The line along which depths and velocities of water are measured between two points located one on each bank of a channel.
Distributary—Major  (Commonly known as a distributary) A Government channel taking its supply from a main line or branch, the function of which is to supply water to minor distributaries and outlets.

Distributary—Minor  (Commonly known as a minor) A small Government channel, usually taking its supply from a major distributary, the function of which is to supply water to outlets.

Distributary—Sub-minor  (Commonly known as sub-minor) A Government channel off-taking from one already defined as a minor.

Diversity factor  The diversity factor of any electrical transmission system, or part of a system, is the ratio of the sum of maximum power demands of the sub-divisions of the system, or part of a system, to the maximum demand of the whole system, or part of the system under consideration measured at the point of supply.

Divide wall  A long wall which separates the weir proper from the underdrains.

Drainage  The natural lines of depression in an area through which storm waters escapes to the river.

Drainage cut  An artificial channel, deliberately excavated on a line which is not naturally a drainage, for the disposal of storm water.

Drift  The distance in feet a discharge boat travels down-stream with the current whether anchored or not during the time taken to make a velocity observation.

Drowning ratio  The ratio of the tail water elevation to the head-water elevation, when both are higher than the crest, the overflow crest of the structure being the datum of reference. The distances upstream or downstream from the crest at which head-water and tail-water elevations are measured have not been standardized but should be such that the levels are not in the influence of the work.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant discharge</td>
<td>Is the discharge which controls the meander length and breadth. It appears to be slightly in excess of bank-full stage.</td>
</tr>
<tr>
<td>Duty</td>
<td>When applied to a channel the area irrigated during a base period divided by the mean supply utilised in cusecs.</td>
</tr>
<tr>
<td>Duty on capacity</td>
<td>The full supply factor obtained by a canal system or channel after it has been opened for irrigation.</td>
</tr>
<tr>
<td>Energy gradient</td>
<td>The slope of energy line with reference to any plane.</td>
</tr>
<tr>
<td>Energy head</td>
<td>The elevation of the hydraulic grade line at any section plus the velocity head of the mean velocity of the water in that section. The energy head may be referred to any datum or to an inclined plane such as the bed of a conduit.</td>
</tr>
<tr>
<td>Energy line</td>
<td>A line joining the elevation of the energy heads of a stream. The energy line is above the hydraulic grade line a distance equivalent to the velocity head at all sections, along the stream.</td>
</tr>
<tr>
<td>Escape</td>
<td>A channel through which surplus or excess water may be removed from a canal to a drainage.</td>
</tr>
<tr>
<td>Fall</td>
<td>A work designed to secure the lowering of the water surface is a channel and the safe destruction of the surplus energy.</td>
</tr>
<tr>
<td>Feeder</td>
<td>A channel constructed primarily to convey water from one source of supply or system to another.</td>
</tr>
<tr>
<td>Field moisture equivalent</td>
<td>The minimum moisture content at which a drop of water placed on a smooth surface of the soil will not be immediately absorbed, but will instead spread over the surface and give it a shiny appearance.</td>
</tr>
<tr>
<td>Flexibility</td>
<td>The ratio which the rate of change of discharge of the outlet bears to the rate of change of discharge of the supply or parent channel.</td>
</tr>
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</tr>
<tr>
<td>Float run</td>
<td>The fixed distance over which surface float is timed.</td>
</tr>
<tr>
<td>Flow-Critical</td>
<td>Is that state of a stream, either momentary or sustained in which the energy of flow is a minimum for the discharge, passing the channel section through which the discharge passes.</td>
</tr>
<tr>
<td>Flow-Hyper critical</td>
<td>Flow at velocities greater than the critical.</td>
</tr>
<tr>
<td>Flow-sub-critical</td>
<td>Flow at velocities less than the critical.</td>
</tr>
<tr>
<td>Flow-Uniform</td>
<td>A constant flow or discharge, the mean velocity of which is also constant. Uniform flow is also referred to as 'steady uniform flow'.</td>
</tr>
<tr>
<td></td>
<td>It is an ideal condition that can only be approximated in fact. If the velocity of the constant discharge varies, the flow is defined as 'steady non-uniform'.</td>
</tr>
<tr>
<td>Flow-Turbulent</td>
<td>That type of flow in which any particle may move in any direction with respect to any other particle and in which the head loss is approximately proportional to the second power of the velocity. (Sometimes designated as 'sinuous flow or tortuous flow')</td>
</tr>
<tr>
<td>Flume</td>
<td>A constricted waterway.</td>
</tr>
<tr>
<td>Free-board</td>
<td>(1) The distance between the designed full supply level and the top of the sides of an open channel or masonry work left to allow for wave action, floating debris, or any other condition or emergency without over-topping the banks of the channel or sides of the structure.</td>
</tr>
<tr>
<td></td>
<td>(2) When applied to a dam, it is the distance from the top of the dam to the water surface in the reservoir during maximum flood conditions.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Fore-bay</td>
<td>A reservoir or pond at the head of a penstock or pipe line.</td>
</tr>
<tr>
<td>Full supply factor</td>
<td>The area proposed to be irrigated in a project during the base period divided by the authorized full supply discharge of the channel at head.</td>
</tr>
</tbody>
</table>
| Note               | (i) The full supply factor is assumed for purposes of project making in the light of experience.  
| Note               | (ii) Once a project is opened for irrigation, the full supply factor attained is usually known as the duty or capacity. |
| Gauge discharge curve | The curve resulting upon the plotting of discharges against equivalent gauges. |
| Gauge line         | The line across a channel, passing through the permanent gauge in a fixed direction. |
| Gauge line pillars | The masonry landmarks fixing the position of the gauge line.               |
| Gauge—Permanent   | The constancy whose position is never changed and against which the height above sea level of water surface levels are recorded in feet. |
| Gauge—Temporary   | Any temporary gauge fixed for the purpose of recording water surface level above sea level. |
| Glacis             | The sloping floor below and in continuation of the raised crest of a weir. |
| Government channel | A canal or channel which is owned, maintained, and operated exclusively by Government. |
| Gravel             | Soil particles retained on a 10 mesh sieve, which has openings 2 mm. in diameter. |
| Groyne             | A spur constructed with more permanent materials.                          |
| Guide bank         | The embankments forming the upstream and downstream approaches of a weir. The nose of a guide bank is heavily armoured to withstand river action. |
DEFINITIONS

**H**

**Head**

1. The height of water above any point or plane of reference, used also in various compounds, such as energy head, entrance head, friction head, static head, pressure head, lost head, etc.

2. The term is usually applied to the control work constructed at the offake of a channel subsidiary to a main canal.

**Head—Available working**

The minimum difference between supply and delivery water levels available.

**Head—Energy**

See Energy head.

**Head—Gross**

When applied to a dam—The gross head is the total fall or difference between the elevation of water surface in the diversion pond and that in the lower end of the tail race.

**Head—Minimum modular**

The difference of water level or pressure between supply and delivery sides, which is the minimum necessary to enable a module or semi-module to work as designed.

**Head—Net**

When applied to a dam—Net head is the gross head less all losses in the conduit and tail race. (Losses within the turbine casings, the turbines and the draft tube are not included in the conduit losses, being accounted for in the turbine efficiency).

**Head race**

A channel leading water to a water-wheel a forebay.

**Head—Static**

See Static head.

**Headworks**

The works constructed at the off-take of a main canal. It includes the weir on a river, the dam at storage site, etc.

**Hydraulic gradient**

The slope of hydraulic grade line. The slope of the surface of water flowing in an open conduit.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrograph</td>
<td>The curve resulting from the plotting of discharges against each day of the year.</td>
</tr>
<tr>
<td>Hydraulic jump</td>
<td>The sudden and usually turbulent passage of water from low stage below critical depth to high stage above critical depth during which the velocity passes from hyper-critical to sub-critical. It represents the limiting condition of the surface curve where in it tends to become perpendicular to the stream bed.</td>
</tr>
<tr>
<td>Hydraulic mean depth</td>
<td>The right cross sectional area of a stream of water divided by the length of that part of its periphery in contract with its containing conduit; the ratio of area to wetted perimeter.</td>
</tr>
<tr>
<td>Hydraulic mean radius</td>
<td>The right cross sectional area of a stream of water divided by the total length of its periphery.</td>
</tr>
<tr>
<td>Irrigant</td>
<td>Is the total requirements of discharge at any place. It includes the discharges actually used for irrigation as well as absorption losses in between the delivering site and the place where irrigation is actually done.</td>
</tr>
<tr>
<td>Infiltration</td>
<td>The percolating flow of ground water into a drain, gallery, or other underground conduit.</td>
</tr>
<tr>
<td>Inlet</td>
<td>(1) A surface connection to a drain.</td>
</tr>
<tr>
<td></td>
<td>(2) A structure at the diversion end of a conduit.</td>
</tr>
<tr>
<td></td>
<td>(3) The upstream end of any structure through which water may flow.</td>
</tr>
<tr>
<td>Intensity—Annual</td>
<td>The term is applied to the percentage of the cultivable irrigable area irrigated during the year. The project intensity is the annual intensity aimed at in the project.</td>
</tr>
<tr>
<td>Invert</td>
<td>The floor, bottom or lowest part of the internal cross-section of a conduit.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Irrigation</td>
<td>The artificial application of water to arid land for the purpose of growing crops.</td>
</tr>
<tr>
<td>Irrigation requirements</td>
<td>The quantity of water, exclusive of precipitation that is required for crop production. It includes economically unavoidable wastes.</td>
</tr>
<tr>
<td>Irrigation Sub-soil</td>
<td>Watering plants by applying the water below the ground surface.</td>
</tr>
<tr>
<td>Irrigator</td>
<td>One who applies water to land for growing crops.</td>
</tr>
<tr>
<td>Leach</td>
<td>To remove alkali from soils by abundant irrigation (combined with drainage, if possible).</td>
</tr>
<tr>
<td>Lead</td>
<td>Is a distance between two lakes?</td>
</tr>
<tr>
<td>Level—Accretion of levels</td>
<td>Converse of degradation or retrogression of levels. A rise in specific levels of the river section at any site.</td>
</tr>
<tr>
<td>Level—Dead storage</td>
<td>It is the water level below which a reservoir is not depleted in order that the minimum designed head for hydro-electric generation is not reduced. The capacity below this level is reserved for silt deposit.</td>
</tr>
<tr>
<td>Levels—Degradation of</td>
<td>A reduction of specific levels at any site which has originated at that site or worked downward from a site higher up.</td>
</tr>
<tr>
<td>Level—Regime gauge reading of</td>
<td>The level or the gauge reading of the water surface for a given discharge, during a period of time when the channel is in permanent or temporary regime.</td>
</tr>
<tr>
<td>Levels—Retrogression of</td>
<td>A reduction of specific levels which has in general, worked upstream from the site of a similar reduction of specific levels lower down.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Levels</td>
<td>The gauge reading or level of the water surface at any particular site for a given discharge.</td>
</tr>
<tr>
<td>Specific gauge reading of</td>
<td>A water surface, also its elevation above any datum, gauge, height, stage.</td>
</tr>
<tr>
<td>Level—Water</td>
<td>Is the width with which a river has ranged within historic times.</td>
</tr>
<tr>
<td>Limits of oscillation</td>
<td>A protective covering over all or over a portion of the perimeter of a conduit, or reservoir to prevent seepage losses, to withstand pressure or resist erosion. Conduits are sometimes lined to reduce friction or otherwise improve conditions of flow.</td>
</tr>
<tr>
<td>Lining</td>
<td>Is that moisture content expressed as a percentage of the weight of oven-dried soil at which the soil will just begin to flow when lightly jarred. At this stage cohesion and internal friction are practically zero.</td>
</tr>
<tr>
<td>Liquid limit</td>
<td>It is the ratio of the average load to the peak load. In each case the interval of maximum load and the period over which the average is taken should be definitely stated such as a &quot;half-hourly monthly&quot; load factor.</td>
</tr>
<tr>
<td>Load factor</td>
<td>The weight and cord attached to it used for determining depths at observation points where it is impossible to use a sounding rod.</td>
</tr>
<tr>
<td>Log line</td>
<td>Losses from a canal or reservoir on account of evaporation and percolation or see page.</td>
</tr>
<tr>
<td>Losses—Absorption</td>
<td>The sum total of losses of water by absorption, percolation and evaporation. The total loss in a channel may be defined as the difference between the discharge at head of a channel and the useful discharge, i.e., the sum of out let discharges.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
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</tr>
<tr>
<td>Main line</td>
<td>This term is applied to the principal channel of a canal system off-taking from a river or other source of supply.</td>
</tr>
<tr>
<td>Mean velocity position</td>
<td>The point lying between water surface and the bed of a channel at which the velocity is equal to the mean velocity.</td>
</tr>
<tr>
<td>Meter</td>
<td>Is a device for measuring quantities of water, passed or the rate of flow.</td>
</tr>
<tr>
<td>Meter-flume</td>
<td>The device for measuring discharge from the direct measurement of the depth of water flowing over it.</td>
</tr>
<tr>
<td>Module</td>
<td>Device for ensuring a constant discharge of water from one channel to another irrespective of the water level in each with in specified limits. This word is some times applied to what are really rateable modules which instead of ensuring a constant discharge aim at passing a discharge into the smaller channel which is in proportion to the supply in the parent channel.</td>
</tr>
<tr>
<td>Modular limits</td>
<td>The extreme values of any factors at which a module or semi-module ceases to be capable of acting as such.</td>
</tr>
<tr>
<td>Modular range</td>
<td>The range of conditions between the said limits, within which a module or semi-module works as designed.</td>
</tr>
<tr>
<td>MMH ratio</td>
<td>The ratio between the MMH and the depth of upstream water level on the crest of an outlet.</td>
</tr>
<tr>
<td>Marginal bund</td>
<td>An embankment constructed along the river at a short distance from the margin with the object of preventing inundation of the area behind the embankment.</td>
</tr>
<tr>
<td>Meander</td>
<td>Consists of two consecutive loops, one flowing clock wise, the other anti-clock wise.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>---------------------------</td>
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</tr>
<tr>
<td>Meander belt</td>
<td>Is the distance between lines drawn tangential to the extreme points of successive fully developed meanders.</td>
</tr>
<tr>
<td>Meander length</td>
<td>Is the tangential distance between corresponding points at extreme limits of successive fully developed meanders.</td>
</tr>
<tr>
<td>Meander ratio</td>
<td>Is the ratio 'meander width' to 'meander length'.</td>
</tr>
<tr>
<td>Meandering river</td>
<td>It follows a sinuous path due to natural physical causes not imposed by external restraint, and occurs where varying discharges and silt loads lead to curved flow and erosion of the banks.</td>
</tr>
<tr>
<td>Meander width</td>
<td>Is the amplitude of swing of a fully developed meander from midstream to midstream.</td>
</tr>
<tr>
<td>Nappe</td>
<td>A sheet or curtain of water flowing over a weir dam, etc. The nappe has an upper and a lower surface. A nappe is said to adhere if its lower surface is in contact with the face of the work.</td>
</tr>
<tr>
<td>Notch</td>
<td>A narrow fall whose crest is usually at or near the bed level usually without a gliss. In irrigation practice, notches are designed primarily to maintain the depth discharge relation of the canal at all stages of discharge.</td>
</tr>
<tr>
<td>Observation points</td>
<td>The points at segmented intervals along a discharge section line at which the velocities and depths are measured.</td>
</tr>
<tr>
<td>Ogee</td>
<td>The reversed curve of the face of an overflow dam.</td>
</tr>
<tr>
<td>Optimum moisture content</td>
<td>The moisture content at which the maximum density is produced by a specific degree of compacting.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------</td>
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</tr>
<tr>
<td>Outfall</td>
<td>The point where water flows from a conduit, the mouth of drains and sewers.</td>
</tr>
<tr>
<td>Outlet</td>
<td>The term used to designate the work which passes water from a Government channel to a water course.</td>
</tr>
<tr>
<td>Outlet—Direct</td>
<td>An outlet constructed in a main line or branch canal.</td>
</tr>
<tr>
<td>Outlet-Non modular</td>
<td>An outlet whose discharge is dependent on the levels both in the canal and in the water course.</td>
</tr>
<tr>
<td>Outlet-Pipe</td>
<td>An outlet whose construction involves the use of a simple pipe or pipes.</td>
</tr>
<tr>
<td>Outlet—Semi modular</td>
<td>An outlet of which the discharge is independent of the level in the water course, within working limits.</td>
</tr>
<tr>
<td>Pendant</td>
<td>A sheet metal disc bearing the observation point number and carried by the pendant wire.</td>
</tr>
<tr>
<td>Pendant wire</td>
<td>The wire exactly marking a section line and carrying pendants upon it to indicate the exact position of observation points.</td>
</tr>
<tr>
<td>Penta</td>
<td>The special commutator which indicates every fifth revolution only of the bucket wheel and is interchangeable with the commutator for indicating single revolutions of the bucket wheel.</td>
</tr>
<tr>
<td>Percolation</td>
<td>Movement of water through the interstices as through soil.</td>
</tr>
<tr>
<td>Pile line</td>
<td>A long line of inter-locked piles driven into the soil to form an impermeable cut off.</td>
</tr>
<tr>
<td>Pivot point</td>
<td>The point at a fixed distance from the discharge section line on to which rays from the observation points converge.</td>
</tr>
</tbody>
</table>
Pivot point layout: A geometrical lay out of points on one or both banks for the purpose of locating observation points in a river without direct measurement along the discharge section line.

Pivot point line: The line from the zero point of the discharge section line, passing through the pivot point.

Plastic limit: The lowest moisture content expressed as a percentage of the weight of the oven-dried soil, at which the soil can be rolled into thread 1/8" in diameter without showing signs of crumbling.

Plasticity index: The numerical difference between the liquid and the plastic limit. This shows the percentage in moisture content through which soil remains plastic.

Pocket: The under sluice pocket may be defined as the area adjacent to the head regulator bounded on one side by the flank and on the other by the divided wall.

Precipitation: The total measureable supply of water received directly from clouds, as rain, snow and hail, usually expressed as depth in inches in a day, month or year, and designated as daily, monthly or annual precipitation.

Priming: (1) The first filling of a canal reservoir or other structure that is, either the absolutely first, or the seasonally first.

(2) Starting the flow, as in a pump or syphon.

Pressure: Total load or force upon a surface, also appropriately used to indicate intensity of pressure or force per unit area.

Pressure sounder: The device for determining depths of water from the cubical measurement of water trapped within it due to the different pressures created at different depths.
<table>
<thead>
<tr>
<th><strong>DEFINITIONS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pr</strong></td>
</tr>
</tbody>
</table>
| Proportional moduling | The fitting of semi-modules on a supplying channel in such a manner that when supply fluctuates each off-take draws always a constant proportion of the supply.  
(1) Earthy material as a mixture of clay, sand, and gravel, placed with water to form a compact mass to reduce percolation.  
(2) To place such material. |
| Plant factor | (When applied to electric installation.) Plant factor (or capacity factor) is the ratio of the average load to the rated capacity of the plant. |
| Penstock | It is a closed conduit for supplying water under pressure to a water wheel or turbine. |
| Power Primary or Firm | (When applied to hydro-electric installation.) Is the minimum power that can be generated under the worst working conditions. |
| Power Secondary | (When applied to hydro-electric installation.) Any power generated over and above firm power due to variation of flow and head is called secondary power. |
| R | The machine incorporating a toothed wheel and a toothed rod to the bottom of which the Swivel and current meter are attached. |
| Rapids | (1) A term used by some writers for "cluete".  
(2) Swift and turbulent flow, without pronounced falls. |
| Rating | The term applied to the adjustment of the discharge of an outlet by altering the size of the orifice. |
| Reach | A comparatively short length of stream or channel. |
| Reconnaissance | A preliminary field examination of a proposed project. |
**Referring bench mark**  A masonry or other fixed point whose level above sea level is known and by reference to which the levels of gauges, etc., may be determined and thereby the water surface levels above sea level as read from those gauges.

**Regulation**  It is the process of distribution of supplies available in a river between different canals taking off it or between canals on a canal.

**Regulator**  A structure through which the discharge can be varied at will, also applied to a structure provided with means of varying the water surface level above it.

**Reservoir**  The lake impounded by a dam.

**Riparian**  Pertaining to the banks of a body of water; a riparian owner is one who owns the banks, a riparian right is the right to control and use water by virtue of the ownership of the bank or banks.

**River—Incised**  Is one which has cut its channel through the bed of the valley floor as opposed to one flowing on flood plain.

**Rotational working**  When the demand exceeds the available supply, recourse is had to a system known as Rotational Working. In sound irrigation practice every endeavour is made to run the distributory channels at the authorised full supply discharge or to close them entirely. This is possible in the case of some branches and most distributaries. Each channel takes a turn of full supply for a certain number of days, other channels being closed to admit of this. The unit period for which the channels run or are closed is known as a Rotational Turn.

**Run-off**  That part of precipitation that appears as flow in streams.
| Sand | According to the American standard, it is taken as particles of soil 0.05 mms. to 1 mm. diameter. The standard adopted by the International Society of soil science is, however, 0.2 to 2 mm. diameter. |
| Seconds pendulum | A small weight attached to a cord held "at a point 39" from the centre of gravity of the weight resulting in its swinging to and fro in exactly one second of time, irrespective of its normal swinging range of the circumferential length of the to and fro distance swing. |
| Segment | A specified length of the total discharge section line. |
| Sliding factor | Is the ratio of net horizontal force to net vertical load acting on a structure. |
| Sluice | (1) A conduit for carrying water at high velocity; (2) an opening in a structure for passing debris; (3) to cause water to flow at high velocities for wastage for purposes of excavation, ejecting, debris, etc. |
| Sensitiveness | The variation (per cent) of discharge of a semimodule for a tenth of foot variation of supply level. |
| Sensitivity | The ratio that the rate of change of discharge of an outlet bears to the rate of change in level of the distributory water surface, referred to the normal depth of the channel. |
| Setting | The ratio of the depth below F. S. L. of the crest of an outlet to the F. S. Depth of the channel at that point. |
| Shear friction—Factor of safety | The term is used to denote the factor of safety of a structure against failure by sliding, taking into consideration the shearing strength of the material of which the structure is constructed. |
Shrinkage limit... The moisture content expressed as a percentage of the dry weight of the sample at which the removal of additional water produces no further change in the volume of the sample. In other words, the amount of water required to fill the pores of a soil sample which has been dried to constant weight from a wet condition.

Shutter... When applied to a weir, a plate of steel or wood construction hinged to the crest. Shutters are used to regulate the level of the river above the crest. The size is limited by that which can be raised against a modest head by manual labour.

Side slopes... The slopes of the sides of a canal, dam or embankment; custom has sanctioned the naming of the horizontal distance first as 1.5 to 1 (or, frequently, 1:1) meaning a horizontal distance of 1.5 to 1 feet vertical.

Silt... (1) Water-borne sediment. The term is generally confined to fine earth, sand, or mud, but is some times broadened to include all material carried, including both suspended and bed load; (2) deposits of water-borne material, as in a reservoir, on a delta or on over flowed lands.

Slope gauges... Gauges fixed above and below a discharge section line for the purpose of determining the water surface slope through that discharge section line.

Soil... Finely divided material composed of disintegrated rock mixed with organic matter; the loose surface material in which plants grow.

Soils—Alkali... Soil that contains harmful concentrations of mineral salts.

Soil evaporation... Evaporation of water from moist soils.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sounding rod</td>
<td>The graduated pole with which depths of water are measured in feet at observation points.</td>
</tr>
<tr>
<td>Spillway</td>
<td>A passage for spilling surplus water; a waste-way.</td>
</tr>
<tr>
<td>Spur</td>
<td>In irrigation practice, a projection into a stream, provided with an armoured head; the head may be of various shapes.</td>
</tr>
<tr>
<td>Stability</td>
<td>In a soil, this may be defined as the resistance to natural flow, when loaded denoting its structural strength which depends upon the shear strength representing the combined effect of internal friction of the soil particles.</td>
</tr>
<tr>
<td>Standing wave</td>
<td>A term used in Indian practice incidental with hydraulic jump.</td>
</tr>
<tr>
<td>Static head</td>
<td>The total head without deduction for velocity head or losses; for example the difference in elevation of head-water and tail-water of a power plant.</td>
</tr>
<tr>
<td>Strike</td>
<td>The strike of a bed, fault or joint in a rock is the bearing of the line which a horizontal plane makes with the plane of the bed, fault or joint.</td>
</tr>
<tr>
<td>Submender</td>
<td>Is a small mender, contained within the banks of a perennial river channel. These are caused by relatively low discharges after the flood has subsided.</td>
</tr>
<tr>
<td>Submerged orifice</td>
<td>An orifice which in use is drowned by having the tail-water higher than all parts of the opening.</td>
</tr>
<tr>
<td>Sub-soil</td>
<td>The material lying below the surface soil, generally devoid of humus or organic matter.</td>
</tr>
<tr>
<td>Supply</td>
<td>Is taken to be supply utilized, that is supply entering the canal head less escapeage; in modern and efficient canal irrigation, there is practically no escapeage.</td>
</tr>
</tbody>
</table>
Supply — Available

- (1) In the river: The discharge passing at the moment
- (2) In a reservoir: The quantity of water stored in the reservoir above all of lowest sliures, or above the dead storage level.
- (3) At the head of a channel: The authorized share of the river discharge pertaining to a canal.
- (4) Other channels: The discharge flowing.

Supply — Authorized full or Designed full supply or Full supply discharge

Is the maximum discharge for which a channel or work is designed.

Supply — Average

- The average supply in a channel during a certain period is the sum of the daily discharges for at the head of the channel in that period divided by the number of days when the channel is in flow.

Supply — Mean

- The mean supply in a channel is the sum of the daily discharges at the channel head divided by the number of days in the base period.

Supply — Normal

- Is a term peculiar to the Satluj Valley Canals and denotes the discharge corresponding to 55 per cent of the Authorized Full Supply Discharge.

Supply — Share

- Is a term peculiar to the Bhakra Canals and denotes the discharge allowed to any particular channel according to the term of the agreement between the two parties, namely, Punjab and Rajasthan.

Supply — Utilised

- The supply entering a channel less any supply escaped. Sound irrigation practice requires practically no escape.

Surface float

- A wooden disc or other floating matter used for timing over a fixed distance in order to determine surface velocity.

Suspension rod

- The hand-operated rod used in shallow water instead of a Rack and Pinion.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swivel</td>
<td>The device fixed between current meter and its means of suspension, so that it may be free to swing in a horizontal plane.</td>
</tr>
<tr>
<td>Syphon</td>
<td>A term applied in irrigation practice to an &quot;inverted syphon&quot;, a tube or &quot;sealed&quot; channel constructed to carry water at a level lower than at which the open channel normally flows.</td>
</tr>
<tr>
<td>Syphon—Inverted</td>
<td>A tube tunnel or closed conduit for conveying liquid below an obstacle such as a river, canal, road or railway at or lower level than that it would flow with free surface.</td>
</tr>
<tr>
<td>Storage—Dead</td>
<td>The capacity of a reservoir below dead storage level.</td>
</tr>
<tr>
<td>Storage—Live</td>
<td>The capacity of the reservoir above Dead Storage Level.</td>
</tr>
<tr>
<td>Tail</td>
<td>This term is usually applied to the work constructed at the end of a channel for the distribution of the water thereat, e.g., tail cluster, tail regulator, etc.</td>
</tr>
<tr>
<td>Temporary gauge to permanent gauge</td>
<td>A temporary contrivance for measuring water surface level along the gauge line of a permanent gauge when that gauge itself is left high and dry, and fixed so that it measures as if it was the permanent gauge.</td>
</tr>
<tr>
<td>Time factor $^\text{T}$</td>
<td>The ratio of the number of days the channel is in flow to the base days.</td>
</tr>
<tr>
<td>Time lag $^\text{t}$</td>
<td>The allowance that has to be made for time required for the effect of change in indent at one site reaching another indenting site.</td>
</tr>
<tr>
<td>Tocwall</td>
<td>A shallow wall constructed below the foundation level to provide a footing for the pitching of the face of an embankment. When the sub-soil water level is high, the toe-wall takes the form of a series of shallow walls.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Turbulence</td>
<td>A state of flow where in the water is agitated by cross-currents and eddies, opposed to a condition of flow that is quiet or quiescent.</td>
</tr>
<tr>
<td>Trash rack</td>
<td>A grating, usually made up of M.S. Plates, provided at the entrance of a submerged outlet to prevent entry of debris, jungle, etc.</td>
</tr>
<tr>
<td>Tail race</td>
<td>The channel that leads water away from a turbine or water wheel.</td>
</tr>
<tr>
<td>Under- sluices</td>
<td>Under shot gates—in irrigation practice generally confined to the openings in the weir, adjacent to the canal head-regulator.</td>
</tr>
<tr>
<td>Uptick</td>
<td>The upward water pressure on the base of a structure.</td>
</tr>
<tr>
<td>Velocity</td>
<td>The rate at which movement occurs and usually expressed in feet per second.</td>
</tr>
<tr>
<td>Velocity—Central Surface</td>
<td>The rate at which the surface layer of water moves in the centre of a channel.</td>
</tr>
<tr>
<td>Velocity—Critical</td>
<td>The velocity in a stream corresponding to critical flow.</td>
</tr>
<tr>
<td>Velocity—Drift</td>
<td>The velocity in feet per second due to drift.</td>
</tr>
<tr>
<td>Velocity—Mean</td>
<td>The average rate at which all the layers of water move between water surface and the bed of a channel at specified distance from one bank.</td>
</tr>
<tr>
<td>Velocity—Modified</td>
<td>The velocity as observed after correcting for drift velocity and angularity.</td>
</tr>
<tr>
<td>Velocity—Over all mean</td>
<td>The average velocity of the discharge through a discharge sectional area, i.e.,</td>
</tr>
<tr>
<td></td>
<td>$\frac{Q}{A} = V$.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Velocity of approach</td>
<td>The mean velocity in a channel immediately upstream of a weir, dam, venturi throat, orifice, or other structure.</td>
</tr>
<tr>
<td>Velocity rod</td>
<td>A rod loaded with metal at one end so that it floats in a vertical position and on being timed through a float-run, gives the mean velocity of the water between water surface and the bottom of the velocity rod.</td>
</tr>
<tr>
<td>Velocity rod correction</td>
<td>The correction to be applied to a velocity rod velocity in order to convert it into mean velocity.</td>
</tr>
<tr>
<td>Velocity—Surface</td>
<td>The rate at which the surface layer of water moves.</td>
</tr>
<tr>
<td>Vena Contracta</td>
<td>The section at which the boundaries of a jet passing through an orifice or over a weir become parallel.</td>
</tr>
<tr>
<td>Wall—Breast or Face</td>
<td>When applied to irrigation practice, a wall generally of reinforced concrete or brickwork, immediately above the face of a submerged orifice.</td>
</tr>
<tr>
<td>Wall—Curtain</td>
<td>A cross wall built under the floor of a hydraulic structure with the object of dividing the work into suitable compartments, or to provide cut-offs.</td>
</tr>
<tr>
<td>Wall—Core</td>
<td>A wall of masonry, sheet-pilling, or puddled clay built inside a dam or embankment to reduce percolation.</td>
</tr>
<tr>
<td>Wall—Divide</td>
<td>See divide wall.</td>
</tr>
<tr>
<td>Wall—Flank</td>
<td>The retaining walls in continuation of abutments both upstream and downstream.</td>
</tr>
<tr>
<td>Wall—Tee</td>
<td>See toe-wall.</td>
</tr>
<tr>
<td>Water account</td>
<td>Is an account maintained of distribution of supplies between units of interlinked canals or different channels of one canal.</td>
</tr>
</tbody>
</table>
Water allowance

The outcome of all considerations of the duty of water, intensity, proposed crop ratio, water available, etc., is the fixing of the water allowance. Water allowance may be defined as the number of cusecs of outlets capacity, authorised per 1,000 acres of cultivable irrigable area. The water allowance, therefore, not only defines the size of outlet for each outlet area but also forms the basis for the design of the distributing channels in successive stages.

Watercourse

The term applied to an irrigator's channel taking its supply from a Government channel, from which fields are irrigated directly.

Water-logged

A condition of land where the ground water stands at a level that is detrimental to plants. It may result from over-irrigation, or seepage with inadequate drainage.

Water right

A legal right to the use of water.

Watershed

(1) The area drained by a stream or stream system.
(2) the divide between drainage basins.

Water-table

The upper surface of a zone of saturation in soil or in permeable strata or beds.

Weep holes

Openings left in retaining walls, aprons, linings, foundations, etc., to permit drainage, reduce pressure, etc.

Weir

A fall extending across a river or canal, usually provided with a raised crest and glacis.

Weir—Waste

The escape provided for the passage of surplus water from a reservoir or tank.

Weir—Cipolletti

A contracting measuring weir, in which the sides of the notch have a slope of 1 horizontal to 4 vertical, to compensate for end contractions.
<table>
<thead>
<tr>
<th>Weir—Drowned</th>
<th>A weir which in use has the tailwater level higher than the highest level with which a hydraulic jump is formed and by which the discharge is affected.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weir—Broadcrested</td>
<td>An overflow structure on which the sapper is supported for an appreciable length; a weir with a significant dimension in the direction of the stream.</td>
</tr>
<tr>
<td>Weir—Sharpcrested</td>
<td>A measuring weir with its crest at the upstream edge or corner of a relatively thin plate, generally of metal.</td>
</tr>
<tr>
<td>Wetted perimeter</td>
<td>The length of the wetted contact between a stream of water and its containing conduit, measured along a plane at right angles to the direction of flow; that part of the periphery of a cross-sectional area of the stream in contact with its container.</td>
</tr>
</tbody>
</table>

**GLOSSARY OF VERNACULAR TERMS**

**Banjar jadid or new fallow** and banjar qadim or old fallow

If for four successive harvests land which once was cultivated has not been sown it is classed as banjar jadid. If it continues to be uncultivated for the next four harvests it is classed as banjar qadim.

**Banjar qadim**

Also includes all culturable waste whether it has ever been under the plough or not.

**Bund**

An earthen embankment.

**Chak**

The block of land which an outlet irrigates.

**Chakbandi**

Is a comprehensive term. It covers the entire process of collection of data for working up details of gross, commanded and culturable commanded areas of channels as a whole or of individual outlets.

**Chak boundary**

Is the limit set for irrigation from any particular outlet.

**Colaba**

A pipe outlet in which the pipe is of earthenware.
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghair ummkin</td>
<td>This term is reserved for barren land, land under buildings, roads, streams, canals, tanks, etc. Sand or kollar comes under this category.</td>
</tr>
<tr>
<td>Khadir</td>
<td>River valley, low alluvial lands.</td>
</tr>
<tr>
<td>Khal</td>
<td>A watercourse.</td>
</tr>
<tr>
<td>Kharif</td>
<td>Summer crop.</td>
</tr>
<tr>
<td>Nakka</td>
<td>A cut in a watercourse to pass water to the fields.</td>
</tr>
<tr>
<td>Nikal</td>
<td>Is a term used in distribution of supply between different shareholders of an outlet. It is the amount of supply left in the watercourse in between the nakka in use and the nakka to be used next.</td>
</tr>
<tr>
<td>Rabi</td>
<td>Winter crop.</td>
</tr>
<tr>
<td>Rajbaha</td>
<td>Distributary channel.</td>
</tr>
<tr>
<td>Rakkar</td>
<td>Land with a low salt content but high pH values, i.e., an alkaline soil.</td>
</tr>
<tr>
<td>Sallab</td>
<td>Flood inundation.</td>
</tr>
<tr>
<td>Sem</td>
<td>Seepage</td>
</tr>
<tr>
<td>Shamilat</td>
<td>Village common land.</td>
</tr>
<tr>
<td>Tatil</td>
<td>The period of closure of an irrigation channel.</td>
</tr>
<tr>
<td>Zaid Kharif</td>
<td>Late summer crop.</td>
</tr>
<tr>
<td>Zaid Rabi</td>
<td>Late winter crop.</td>
</tr>
<tr>
<td>Zamindar</td>
<td>Land Owner.</td>
</tr>
</tbody>
</table>
# CHAPTER 2

## STANDARD NOTATIONS

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CHAPTER 2
STANDARD NOTATIONS

Introduction

2.01. The standard notations used in this Manual are reproduced in the following pages.

It is impracticable to devise a single notation which shall embrace all the subjects treated in this volume, without utilizing the same symbol twice. Moreover, a single symbol has acquired, by general usage, different meanings in connection with different subjects, e.g., in dynamics, 'a' is an acceleration, but in hydraulics of silt transport, 'a' is Lacey’s silt factor.

2.02. Separate notations are, therefore, indispensable. Confusion can be avoided by using the appropriate notation exclusively when dealing with a particular subject.

2.03. There are certain desiderata in any standard notation:

(a) Acceptance of usage—No violence should be done to a symbol which has general acceptance, e.g., g, the gravity constant; V, a velocity.

(b) Clarity—For this reason, capital letters should be used for the principal quantities, wherever possible, e.g., M, mass; D, depth.

(c) Uniformity—Using the same capital letter for the same class of quantity, a small letter may be added as a subscript to denote a particular one and also to indicate correspondence between two or more quantities. Hydraulics abounds in such examples. Thus:

Dc, Vc and Ec are all connected, as also are:

Dn, Vn and Sn
Dr, Vr and Sr.

(d) Simplicity—The fewest possible symbols should be laid down for any given class of quantity so as to permit the widest possible latitude for special cases.

2.04. Any standard notation requires periodic re-examination—the addition of some symbols and perhaps the modification of others. This will be done in future editions of this chapter.
2.05. Notes on the same subject by different officers, frequently use different notations, requiring constant reference to the table of symbols.

It is most desirable that these standard notations should be brought into general use, to facilitate perusal and comprehension, by different officers. In all references made to the Chief Engineer, the standard notation must invariably be employed.

2.06. The standard notations given below have been divided into three parts:—
(a) Hydraulics.
(b) Hydrology.
(c) Flow of water through subsoil.

2.07. Unless otherwise stated, units used are foot-pound-second.

HYDRAULICS

2.11. Preliminary definitions—

Steady flow is that state of flow in a stream, where the discharge across any defined section of the stream remains constant in respect of time.

Normal flow is that state of steady flow of a stream, where the fall of water surface corresponds to the consumption of energy by friction. It is stable. The principal symbols are subscripted with the letter 'n' to indicate this condition.

Regime flow is that state of stream, flowing in self-borne alluvium, where there is neither silt nor scour. Regime flow also postulates normal flow as a preliminary condition. The principal symbols are subscripted with the letter 'r' to indicate this condition.

Critical flow is that state of stream, either momentary or sustained, in which the energy-of-flow per unit mass of the stream is a minimum for the discharge passing and the channel section through which the discharge passes. It varies with the discharge passing. The principal symbols are subscripted with the letter 'c' to indicate this condition. It occurs somewhere in the stream in all cases of "free fall" discharge.

Note.—The small letters used above, viz., 'n', 'r' and 'c' should not be used for any other indication.

2.12. Constants—

- Arbitrary or experimental co-efficient.
- Lacey's "Silt factor".
The gravity constant.

\( E \) The constant in the “free fall” discharge formula.

Theoretically \( E = \sqrt{gH} \)

\( N \) The co-efficient of rugosity of channel.

Note: —Laxey has appropriated \( N \) to mean his “co-efficient of absolute rugosity”. To differentiate between other similar co-efficients, subscript initials may be used, where this is necessary.

\( W \) The weight of 1 cu. ft. of water.

2.13. Discharges—

\( Q \) The discharge in cubic feet per second (cusec) of a channel or work.

\( Q_A \) The absorption loss in a channel in cusecs.

\( q \) The discharge in cusecs per foot of width of a channel or work.

2.14. Energy.—

\( E \) The total energy expressed in feet head of water above a fixed datum. When plotted, this depicts the “total energy line”.

\( E_f \) The “Energy of flow” expressed in feet head of water above the bed. When the “total energy line” has been plotted, the “energy of flow” is depicted by the intercept between the bed line and the total energy line.

Note: —\( E \) and \( E_f \) are clearly dependent, the one upon the other, in relation to the bed of the stream.

\( E_c \) The minimum energy of flow for a given discharge \( Q \). In the case of stable stream-line flow, \( E_c \) connotes the existence of \( D_c \), \( A_c \), and \( V_c \), the critical depth, section and velocity.

Note: —In the above definitions of \( E \), \( A \), and \( V \), it is assumed that the velocity \( V \) is the same for all points in the critical section \( A \) of the stream. When curvature of the streamlines exists, the velocity is not uniform over the section: a redistribution of the energies takes place, and \( A \) may exist with a depth and velocity other than \( D_c \) and \( V_c \). The actual values can only be obtained when the law connecting velocity distribution and curvature is known.
H  The head or energy required to produce a velocity \( V \)

\[ H = \frac{V^2}{2g} \]

\( H_a \)  The head or energy equivalent to a velocity of approach \( V_a \).

\( H_w \)  The available working head, i.e., the difference in total energy levels between two sections.

\( H_m \)  The minimum working head required for modularity between two points.

\( H_L \)  The head lost between two points, due to all causes except destruction in a standing wave.

\( H_d \)  The head or energy destroyed in a standing wave.

Note: The symbols \( E \) and \( H \) are often interchangeable. The instances given above are special cases in which any use of a subscripted \( E \) is liable to cause confusion.

### 2.15. Velocities—

\( V \)  The mean velocity in feet per second of a stream at any given point.

\( V_a \)  The mean “Velocity of approach.”

\( V_n \)  The mean velocity of normal flow corresponding to \( D_n \).

\( V_u \)  The mean velocity of uniform flow.

\( V_r \)  The mean velocity of regime flow corresponding to \( D_r \).

\( V_c \)  The velocity of critical flow, i.e., the velocity assumed constant over the section—at which the energy of flow is a minimum (see definition of \( F_o \)).

\( V_o \)  Standard sill-bearing velocity, e.g.,

- Kennedy's \( V_o = 0.84D^{0.44} \) and
- Lacey's \( V_o = 1.155 \sqrt{FR} \)

Note: The term “critical velocity ratio” has been used in the past to define the velocity required to carry a silt charge other than Kennedy's standard sill. This is liable to cause confusion and the term “Kennedy's velocity ratio” should be used instead.

### 2.16. Dimensions—

\( L \)  The length of a channel or work measured along the center line parallel to the direction of flow between two points.
## Standard Notations

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_t</td>
<td>The length of parallel sides of the throat of a weir, flume, etc.</td>
</tr>
<tr>
<td>B</td>
<td>The length of a channel bed transverse to the direction of flow, i.e., the width.</td>
</tr>
<tr>
<td>B_e</td>
<td>The top or surface width of a stream.</td>
</tr>
<tr>
<td>B_t</td>
<td>The width of the throat of a weir, flume, etc.</td>
</tr>
<tr>
<td>D</td>
<td>The depth below the surface of a stream at a stated point.</td>
</tr>
<tr>
<td>D_n</td>
<td>The normal depth of stream a corresponding to V_n.</td>
</tr>
<tr>
<td>D_c</td>
<td>The depth of a stream corresponding to V_c (see definition of E_c).</td>
</tr>
<tr>
<td>A</td>
<td>The cross-sectional area of a stream at a stated point.</td>
</tr>
<tr>
<td>A_c</td>
<td>The cross-sectional area of a stream corresponding to V_c and D_c.</td>
</tr>
<tr>
<td>P_w</td>
<td>The wetted perimeter of a channel.</td>
</tr>
<tr>
<td>R</td>
<td>The hydraulic mean depth of a stream.</td>
</tr>
<tr>
<td>R_h</td>
<td>The hydraulic mean radius of a stream.</td>
</tr>
</tbody>
</table>

### 2.17. Miscellaneous

- **S**: The actual slope of the water surface at any given point.
- **S_n**: The actual slope of the water surface in the case of normal flow.
- **S_r**: The actual slope of the water surface in the case of regime flow.
- **S_b**: The actual slope of the bed of a channel at any given point.
- **S_e**: The actual slope of the total energy line at any given point.
- **S_en**: The slope of the total energy line in the case of normal flow.
- **S_er**: The slope of the total energy line in the case of regime flow.

**Note**: It should be noted that the slope S_e represents the loss of energy per foot run due to friction, etc. From this it follows that in cases of normal and regime flow only, \( S_e - S = b = S_n \) and \( S_r \), and the symbol S may be used to indicate any or all.
2.18. General formulae:

\[ V = \sqrt{\frac{2gh}{1}} \]
\[ E_r = D \div H \text{ (stream-line flow)} \]
\[ E_v = D_r + \frac{V^2}{2g} \quad \text{and} \quad D_r = \frac{V^2}{g} \]
\[ V_s = \sqrt{C \times R_s} \]

C being a variable, which in Manning's formula varies as \( R^{1/6} \). Thus:

\[ C = 1.49 \times R^{1/6} \]

Examples of special cases

2.191. Discharge through a triangular notch:

\[ Q = 4.28 \times C \tan \frac{Q}{2} \times h^{0.525} \]

Where \( C = 0.593 \) for \( Q = 90^\circ \)
2.192. Discharge through an orifice—
(a) drowned

Extra notation.
\( A_p \) is the area of the pipe or orifice
\[ Q = C_x A_p \sqrt{\frac{v}{2gH}}. \]
(b) Free fall

2.193. Discharge over a semi-modular weir or open flume—
There are two cases.
(a) When velocity of approach assists the discharge (weir).
(b) When velocity of approach does not assist the discharge.
In case (a), \( G+Q \) must be used but in case (b) \( G \) must be used.

\[ Q = K \cdot B \cdot (R)^{12} \]
\[ G + \frac{Q}{G} \]
\[ E_i = \text{or} - H_i \]
conditions.

\( H_i \) is the loss in head between the gauge site and "critical section."

\( H_n - H_i \) represents the loss in head between the critical section and the point where the downstream level is restored.

If \( H_n \) exceeds \( H_m \), the difference is destroyed in the standing wave. Hence \( H_n > H_m > H_i \).

2.194. Discharge through a pipe can open flume outlet.

Extra notation.

\( H_f \) is available working head between channel and watercourse surface levels.

\( H_m \) is the available working head between the channel and cistern surface levels.

\( H_{aw} \) is the available working head between cistern and watercourse surface levels. Then:

\[
H_f = H_{aw} + H_m
\]

\( A_o \) is area of orifice in diaphragm.

\( A_p \) is area of pipe.

Provided that \( H_{aw} \) exceeds \( H_m \). Then:

\[
Q = K \cdot B \cdot (G - H_m)^{1/2}
\]

If \( H_m \) may be neglected then:

\[
Q = K \cdot B \cdot (G)^{1/2}
\]

This neglects also velocity of approach to the weir. The two errors are in opposite sense and tend to cancel one another.

And \( Q = C \cdot A \cdot \sqrt{2gH_m} \)

and \( Q = A_p \cdot V_p \)

\[
V_p = \frac{Q}{A_p}
\]

This must be as low as possible to reduce friction but must be a non-silting velocity.
2.195. Discharge through an orifice semi-modular outlet—

Extra notation

Y is the elevation of the roof of the block above the crest.

Provided \( H_r \geq H_0 \), then a standing wave will form and

\[
Q = Y \times V \times \sqrt{2} g \times H_r \times C_s
\]

\[= 8.02 \ C_s \ Y \ B \ H_r \]

2.196. Conditions for a standing wave—

(a) Trough empty

Extra notation—

\( D_1 \) and \( V_1 \) are depth and velocity of hyper-critical stream immediately above the standing wave.

\( D_2 \) and \( V_2 \) are depth and velocity of sub-critical stream immediately below standing wave.

Then

\[
D_2 = D_1 + \sqrt{\frac{2V_1 D_1}{g}} + \frac{D_1^2}{4}
\]
(b) Trough loaded—

Extra Notation.

$D_1$: Depth of the load of static water on the hyper-critical stream.

$E_1$: Energy of velocity $V_1$.

Then

$$D_2^2 - D_1 (2D_2 + D_1) = 2q \frac{(V_1 - V_2)}{g}$$

**HYDROLOGY**

2.21. Area in square miles—

$A$: Total area of a catchment.

$A_e$: Effective area of a catchment.

$A_a$: That area for which dispersion is unily or that area which can be wholly covered by a storm and in which the intensity of storm does not vary.

$A_i$: Area covered by a particular storm.

$A_{i,i}$: Area between two isoyetals.

$A_{i,i}$: Area of influence assigned to a rain-gauge station.

2.22. Rainfall or precipitation in inches—

$P$: Mean annual total rainfall over a catchment.

$P_e$: Total annual rainfall over a catchment for any year.

$P_m$: Total monthly rainfall over a catchment for any month.

$P_i$: Total rainfall of a particular storm as recorded at a rain-gauge.

$P_{i,i}$: Mean annual precipitation between two isoyetals.

2.23. Run-off (for volumetric studies) in inches—

$R$: Mean annual total run-off from a catchment.

$R_e$: Total annual run-off from a catchment for any year.

$R_m$: Total monthly run-off from a catchment for any month.

$R_i$: Total run-off of a particular storm.
2.24. Discharges (for intensity studies) in cases—
Q

Maximum discharge from a catchment.

Q_o

Maximum discharge from a catchment on account of a particular storm.

Q_q

Maximum discharge from a catchment A_q.

q

Discharge per square mile of catchment.

2.25. Time in hours—
T

Inlet time.

t

An interval of time.

2.26. Temperature in degrees (Fahrenheit)—
\( ^\circ \)

Temperature in degrees (Fahrenheit).

\( ^\circ B \)

Mean annual temperature over a catchment.

\( ^\circ B \)

Mean monthly temperature over a catchment.

2.27. Miscellaneous—
L

Distance in feet of watershed from the stream along the line of flow.

B

Absorption into the soil in inches of depth per hour.

E

Evaporation in inches of depth per hour.

D

Total loss in inches per hour = E + B.

I

Intensity of rainfall.

I

Maximum intensity of rainfall.

S

Maximum slope of the catchment from the watershed to the drainage.

F

Reduction in inches due to rain initially held by trees, crops, and undergrowth.

Examples

To determine mean annual rainfall of a catchment—

(a) Isohyetal method—

\[ \frac{\sum P_n \cdot A_n}{\sum A_n} = \frac{\sum P_h \cdot A_h}{A} \]

(b) Weightage method—

Extra notation.

P_g

Precipitation at any rain-gauge station.

\[ \frac{\sum P_g \cdot A_g}{\sum A_g} = \frac{\sum P_g \cdot A_g}{A} \]

(c) The straight average method (for a large plain area)

\[ \frac{A_1 \cdot P_1 + A_2 \cdot P_2 + \ldots + A_n \cdot P_n}{A_1 + A_2 + \ldots + A_n} \]

Note: The total area is divided into sub-divisions, \( A_1, A_2, \ldots, A_n \) and \( P_1, P_2, \ldots, P_n \).

\( P_n \) represent the average rainfall for each sub-division.
2.282 Runoff formulae (Volume)—
(a) Vermuel formula—
\[ R = P - (11 + 0.29P) \times (0.35p - 0.65) \]
(b) Khosla's formula—
\[ R = P - \sqrt{C/2} + C \]
Extra notation:
\( C = 2 \) constant which allows for catchment characteristics, humidity, glacier contribution, etc., but not for absorption, evaporation and transpiration which are covered by the temperature factor \( \mu_2 \)

2.283 Maximum discharge from a catchment (intensity)—
(a) Ingles formula—
\[ q = \frac{7000A}{\sqrt{\nu A}} \] for fan shaped catchments,
\[ \text{And} \]
\[ Q = 7000 \times \sqrt{A} - 240 (A - 100) \text{ for an elongated catchment.} \]
(b) Khangar and Gulati's formula—
\[ Q = 650 \frac{A}{T} \left[ \frac{A_o}{\chi_o} \right]^m \]
Extra notation:
\( m \) Index of dispersion,
\( Z_{\text{max}} \) Maximum height of a theoretical hydrograph for a rainfall of maximum possible intensity in the catchment.

Flow of WATER THROUGH SOIL

2.31 Symbols—
\( H \) Head in feet or difference in water levels upstream and downstream of a weir.
\( P \) Pressure head in feet in a pressure observation pipe measured above the downstream water level.
\( P_C \) Pressure head at point C.
\( G \) Gradient, or rate of change of head.
\( G_e \) Exit gradient.
\( t \) Temperature in degrees Fahrenheit.
\( R \) Reynolds' number.
\( \eta \) Density of fluid.
\( \mu \) Viscosity = \( 0.0003716 \times 0.4712 + 0.01433t + 0.000882t^2 \)
\( v \) Kinematic viscosity = \( \frac{\mu}{\eta} \)
**STANDARD NOTATIONS**

Q  The discharge in cubic feet of a channel or work.

q  The discharge in cubic feet per foot of width of a channel or work.

f  Lacey's silt factor.

$\alpha$  Pressure head expressed as a percentage of the total head

\[ H = \frac{P}{H} \times 100 \]

Examples of special cases

2.321. Determination of exit gradient—

(a) Floor with pile at downstream end—

Extra notations

d  Depth of pile line below floor surface.

b  Length of impervious floor.

\[ L = \frac{b}{d} \]

\[ L = \frac{1 + \sqrt{1 + 4L}}{2} \]

\[ G_E = \frac{1}{d} \left( \frac{H}{d} \right)^{1/4} \]

Drawings and diagrams would be included here but are not visible in the text provided.
2.322. **Manual of Irrigation Practice**

(b) Floor with pile at downstream end with step—

\[
\begin{align*}
&d_1 \quad \text{Depth of pile line below upstream impervious floor.} \\
&d_2 \quad \text{Depth of pile line below downstream pervious floor.} \\
&L \quad \text{Length of impervious floor upstream} \\
&G_E = \frac{H}{\left( \frac{d_1 - d_2}{d_1 + d_2} \right)^2} \sqrt{K} \\
&\text{where } K \text{ is given by the equation.}
\end{align*}
\]

\[
\frac{\sqrt{1-K^2}}{K} \cdot \cos \theta = \frac{l}{d_1 - d_2}
\]

2.322. Pressures at different points one pile line or depressed floor)

(DEPRESSED FLOOR) (U/S and D/S floor at Same Level) (U/S and D/S floor at Different Levels)

Extra notations:

- \(d_1\) Depth of pile line below upstream floor.
- \(d_2\) Depth of pile line below downstream floor.
- \(L\) Length of impervious floor upstream.
- \(b\) Length of impervious floor downstream.
- \(\theta_A\) at junction of upstream floor and pile line.
- \(\theta_B\) at bottom of pile line.
- \(\theta_C\) at junction of downstream floor and pile line.
2.323. Mutual interference of piles—

\[ C = 19 \sqrt[\frac{d_1}{b^4}} \cdot \frac{d_1 + d_2}{b} \]

Extra notations.

- \( C \) the correction to be applied as percentage of head.
- \( b \) the distance between the two piles.
- \( d_1 \) the depth of pile whose influence has to be determined on the neighbouring pile of depth \( d_2 \).
- \( d_1 \) depth of pile on which the effect of pile \( d_2 \) is sought to be determined.
- \( b \) total floor length.

2.324. Depth of scour—

Kennedy

\[ D = 1.11 q \]

Lacey

\[ R = 0.7305 \left( \frac{2.67q}{3.8q} \right)^{\frac{1}{2}} = 0.9 \left( \frac{q^2}{r} \right)^{\frac{1}{2}} \]

- \( R \) depth of scour.
CHAPTER 4
THE "STANDING WAVE" OR "HYDRAULIC JUMP".

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CHAPTER 4

THE "STANDING WAVE" OR "HYDRAULIC JUMP".

INTRODUCTION

4.0. Before he can contemplate designing irrigation works large and small, the irrigation engineer requires an intimate knowledge of the principles underlying the phenomenon known as the "standing wave" or "hydraulic jump". This phenomenon is intimately bound up with the quantity designated "energy-of-flow", a brief study of which is necessary before discussing the standing wave.

ENERGY OF FLOW

4.11. When water flows in any channel, its energy is made up of potential energy, kinetic energy and pressure energy. The sum of these three is the total energy, but the sum of these three energies measured only above the bed line, is designated "energy of flow". This energy of flow is of vital importance in all hydraulic problems. It will be sufficient here to state that:

\[ E_f = D + \frac{v^2}{2g} \]  

Where these symbols have the meaning laid down in the standard notation, in Chapter 2 of this volume.

A full treatment of this important subject will be found in the bibliography which closes this chapter.

4.12. Consider a stream of water of discharge \( Q \), flowing in a smooth rectangular channel, of width \( B \).

Then \( q = \frac{Q}{B} \)

The depth \( D \) of the stream is inversely proportional to the velocity \( V \),

\[ D = \frac{q}{V} \]

One may assume any fixed value of \( q \) and assume a series of values for \( D \) and calculate the corresponding values of \( V \). The values of \( E_f \), the energy of flow, may be calculated from the equation (1).
One should plot these values of $E_i$ against $D_i$ for several values of $q$. He will find that each such curve is of the following form.

![Diagram showing $E_i$ against $D_i$](image)

This process has actually been done for values of $q$ from 1 case to 100 cases in a volume "Hydraulic Diagrams" Publication No. 4 of the Central Board of Irrigation and Power.

4.13 Attention of the person is invited to the shape of this curve, particularly the minimum point. This represents the minimum energy of flow required for each value of $q$. Unless this minimum value of $E_i$ is available, flow cannot continue, until the total energy line is raised sufficiently (by "headroom") to give the required minimum value. Such flow is termed "critical flow" and is violently unstable.

The state of flow to the left of this minimum point represents "hyper-critical" flow and to the right is "sub-critical".

The velocity at which the minimum energy of flow is generated is termed "critical velocity".

**The Standing Wave**

4.20. The person will now understand the definition of the "standing wave" or "hydraulic jump".

This phenomenon takes place when a jet of water moving with hyper-critical velocity meets a body of water moving at sub-critical velocity. At this point, a more or less abrupt change in velocity and depth takes place, accompanied by a loss of energy of flow.
.4.21. The original treatment of the standing wave problem is due to Belanger in 1838. He dealt with it on the basis of the simple dynamic principle that the rate of loss of momentum must be equal to the unbalanced force acting on the moving mass to retard its motion.

Fig. (ii)

The fundamental formula is:

$$D_2^x - D_1^x = \frac{2}{3} q (V_1 - V_2) \quad \cdots \quad (2)$$

the symbols having the same standard meaning as before.

.4.22. Recognition of the importance of this phenomenon was only gradual. Failure to recognize its existence was the cause of the original troubles on the falls of the Ganges canal when first opened. Even today the theoretical treatment is imperfect particularly on sloping glaces. Nevertheless our knowledge of this phenomenon is sufficient to enable us to design work with confidence and to make due allowance for the departure of practice from theory.

Theoretically the phenomenon takes place instantaneously. In practice surging and turmoil, accompanied by aeration, occur below the standing wave for a measurable distance and it is this single factor which gives rise to difficulties in practice and damage to works.

Again, in theory the hyper-critical jet flows freely and unobstructed until it reaches the point at which the standing wave should occur. In practice the standing wave invariably falls forward and covers the jet with a film of water of varying thickness which alters the characteristics of the standing wave itself. Here again, theoretical allowance can be made for such film or load of water, on a static basis. In practice, the “load” of water is in constant super-turbulent motion.

.4.23. One of the characteristics of the standing wave with loaded trough is that there are limits of discharge and drop below which the standing wave will not form at all. If the standing wave does not form, the surplus energy can only be destroyed in friction on the envelope. Where this occurs in an earthen channel, violent erosion and scour may take place.
4.31. All hydraulic phenomena are controlled by the concept known as the total energy line. Over a channel, this is really a theoretical surface which is represented on a section of the channel, by a line. This line represents with reference to a fixed datum, the total energy of every particle of water flowing in the section. The continuous fall from point to point of the total energy line represents the energy lost in friction by the flowing stream. There can be no other cause for a variation of this total energy line except in the solitary case of the standing wave which is represented by an abrupt drop in the level of the total energy line.

Variations in the bed or sides of a channel are accompanied by changes in velocities. These result in a change in position of the surface of the stream, but whatever these changes may be, the total energy of every particle of water in the stream is represented by the total energy line. A simple exposition of these principles is contained in "Fluming", C. B. I. Publication No. 6. The young irrigation engineer should make a careful study of these principles before he begins his study of the problem of the standing wave.

Theory for empty trough

4.40. To understand the problem of the standing wave, it is as well to remember that the loss in energy is brought about by a change in momentum due to a difference in pressures. For many years, it was necessary to work out each problem on these lines. C. B. I. Publication No. 6 mentioned in paragraph 4.12 also contains diagrams, loosely termed "Pressure plus Momentum" diagrams, for the quick graphical solution of standing wave problems; on these lines.

4.41. Belanger's basic equation (paragraph 4.21) can be recast to give the loss of energy in the standing wave. The fundamental equation is (see fig. iii).

$$H_L = D_1 - D_2 + \frac{q^2}{2g} \left\{ \frac{1}{D_1} - \frac{1}{D_2^2} \right\} \quad \ldots \quad \ldots \quad (3)$$

From any text book on hydraulics.

$$q = V \cdot D \cdot \sqrt{V \cdot D}$$

Whence

$$D = \frac{D_1^2 \cdot D_2}{2D_1 + D_2} \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

Combining these equations

$$D_1 \cdot D_2 (D_1 + D_2) = \frac{2q^2}{g} = 2D\Delta \quad \ldots \quad \ldots \quad (5)$$
This relationship is rigid and defines the depths (and therefore velocities) above and below a standing wave, in terms of \( q \), the discharge per foot of width of the channel.

4.42. These equations have been the subject of close study by many investigators. They have been reduced to dimensionless equations and plotted, for rapid solution of standing wave problems.

The quantity most usually defined in practice is the “drop” i. e., the difference in level between the total energy lines above and below the snubbing wave, designated \( H_L \). On this basis, the most useful form of curves for graphical solutions, is due to Blench. He depends on a discharge \( q \) and ordinates \( E \) see curves of equal \( H_L \).

**THEORY FOR LOADED TROUGH**

4.51. It was remarked in paragraph 4.22 that the hyper-critical jet is ordinarily covered by a film or “load” of turbulent water. The effects of this condition were studied by Blench and equations for the worst possible condition, i. e., maximum loading, when the trough in full of water were evaluated. These are:

\[
D_2^2 - D_1^2 (2D_1^2 + D_2) = \frac{2q}{g} (V_1 - V_2) \quad \ldots \quad (6)
\]

\[
H_L = D_L + D_1 - D_2 + \frac{q^2}{g} \left\{ \frac{1}{D_2} - \frac{1}{D_1} \right\} \quad \ldots \quad (7)
\]

\[
D_1, D_2 (D_2 - D_1) = \frac{2q^2}{g} = 2D_2^3 \quad \ldots \quad (8)
\]

where \( DL \) is the depth of the water load at the point where the standing wave forms.

Compare with equations (2), (3), and (5).

Precisely similar diagrams for “trough full” have been plotted. The first point to be noted is that for every value of \( H_L \) there is a limiting value of \( q \) beyond which a standing wave, will not form. This limitation is particularly important at low drops.
4.61. MANUAL OF IRRIGATION PRACTICE

The second point for observation is that for equal values of $H^2$ and $q$, the value of $H^2$ required, is invariably greater, for a "loaded" trough.

APPLICATIONS OF STANDING WAVES

4.61. The principal applications of the standing wave are in the design of:

(a) Falls.—It is the surest and most efficient method of destroying surplus energy.

(b) Measuring devices.—The value of $q$ is rigidly fixed by the minimum value of energy of flow. This may be measured on a gauge and needs certain corrections for velocity of approach, etc.

(c) Outlets.—A "standing wave outlet" is semi-modular because it is unaffected by the level downstream. So long as a standing wave forms, the discharge is dependent only on the value of the head on the outlet. The downstream level only determines the point at which the standing wave forms.

BIBLIOGRAPHY

4.71. The earnest person will find much additional information in the publications of the Central Board of Irrigation noted below:

No. 4 "Hydraulic Diagrams."
No. 6 "Fluming."
No. 7 "Standing Wave or Hydraulic Jump."
No. 10 "Irrigation Canal Falls."

Each of the above contains an extensive bibliography of the subject. The diagrams referred to, in paragraphs 4.42 and 4.51 will be found as plates VI and VII in C. B. I. Publication No. 7, and are now in general use in the Irrigation Branch, Punjab, and elsewhere, for the solution of all standing wave problems.
# CHAPTER 5
THEORY OF SILT TRANSPORT

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CHAPTER 5
THEORY OF SILT TRANSPORT
INTRODUCTION

5.0. Of all the technical problems which confront the Irrigation engineer, that of the transport of detritus by flowing water is probably the most important. Certainly it has occasioned an immense volume of literature and controversy, the end of which is not yet in sight.

KENNEDY'S THEORY

5.10. Prior to 1895 there was no organized system governing the design of channels which should be free from silting or scouring. In 1895 Mr. R. G. Kennedy of the Irrigation Branch, Punjab, published his theory of silt transport. This theory was based on observations extending over a number of years on channels of the Upper Bari Doab Canal which he considered to be in regime, i.e., to be neither silting nor scouring. In parenthesis, it should be recorded that since his retirement in 1906 these channels have widened themselves considerably due to the advance, downstream, of silt of coarser grades from the head works, on the Ravi river.

It is difficult to overestimate the value of Kennedy's work. He brought some semblance of order out of chaos and there is no question but that the Kennedy formula has been the means of permitting the vast expansion of irrigation system which has taken place in recent years in the Punjab.

5.11. Kennedy's formula is based on a simple but incomplete conception of the mechanism which sustains particles of silt in a stream of flowing water. He assumed that the vertical components of eddies supported silt particles and that the silt transporting power of a stream was dependent solely upon its mean velocity which controlled the eddies, and the depth which limited their effect. Kennedy concluded from the limited data then available, that the silt transporting power of a stream was unaffected by the width of the channel.

5.12. Kennedy was alive to the fact that different channels carried different grades of silt. As a first step, he defined the silt grade found in his observed channels on the Upper Bari Doab Canal, as unity. He measured the mean velocity of these channels and the average vertical geometric depth of water flowing therein on the bed, i.e., excluding side slopes. From these observations he derived the formula

\[ V_c = 0.54 D_{0.54} \] (1)

Where \( V_c \) is a mean velocity such that the channel neither silts nor scours. This \( V_c \) he termed "critical velocity". Since, however, this term "critical" is used more correctly in another connection, it is now customary to refer to it as Kennedy's silt bearing velocity.
5.13. The publication of this formula stimulated other observers to carry out similar observations on the channels in their charge. The following modifications of Kennedy’s equation were published subsequently.

\[
\text{Lower Chenab Canal } V_c = 0.95D^{0.5} \\
\text{Godavari, Western Delta } V_c = 0.67D^{0.5}
\]

(IA) (IB)

5.14. Channels bearing a different type of silt or a silt charge, naturally require a different velocity for the same depth. Kennedy defined these different silt burdens in terms of the ratio which the velocity required to carry the detritus bore to the \( V_c \) given by his formula. This ratio is now termed the “Kennedy velocity ratio” and was utilized to define the grade of silt and silt charge carried in the channel whose regime velocity differed from that given by Kennedy’s formula.

5.15. There are two outstanding defects in Kennedy’s theory, one of which was early recognized and for which Mr. F.W. Woods subsequently proposed an empirical correction: the second has only been recognized of recent years by Mr. Gerald Lacey, C.I. E., who is responsible for the Lacey theory now in common use in India and elsewhere.

Woods’ Normal Data

5.21. The silt carrying capacity of a stream is not independent of its bed width. This led to the formulation of Woods’ normal dat for the design of irrigation channels. These tables are empirical rules limiting and defining the bed widths of channels of varying discharges. For the ratios of bed width and depth given in these tables Mr. Lindley produced the formula

\[ B = 3.80D^{0.81} \]

5.22. In 1919 Lindley went further and stated that there was no reason why the silt charge should not control the bed width in the same way as it unquestionably defined the depth. If this should be admitted, he concluded that the volume of discharge and the amount of the silt charge uniquely determined the shape of the channel and its dimensions and slope.

Lacey’s Theory

5.31. In 1929 Lacey published his first paper on this subject in the proceedings of the Institute of Civil Engineers. His paper does not depend upon observations of any description carried out either by himself personally or under his control. The data upon which he founded his paper was simply all authentic and accepted data recorded by observers the world over. Lacey’s contribution to the theory of silt transport was not the result of profound consideration of this data, and the philosophic acceptance of the conclusions to which it pointed. But the whole of Lacey’s theory is rendered possible by his appreciation of a fundamental conception in hydraulics. Lacey held that a geometrical conception of depth was out of place when dealing with the forces generating a channel cross section, and moulding the boundary, or wetted perimeter, and that the depth \( D \), which appeared in all the formulae then existing, should, therefore, be replaced by the hydraulic mean depth \( R \). The effects of this flash of inspiration were immense.
5.32. Lacey proceeded to recalculate all available data on a basis of the equation

\[ V = KR^{0.5} \]

where \( V \) and \( R \) are the hydraulic mean depth. These he plotted on logarithmic scales (fig. 1) and secured a series of parallel straight lines equivalent to the formula:

4.5. Where \( V_e \) has the same significance as the Kennedy \( V_e \) in paragraph 5.12.
Obviously the constant represented the different silt grades or silt charges in the channels under examination. For many years the grade and charge of silt upon which Kennedy had founded his formula had been accepted as a standard. Lacey accepted this same standard, designated it \( f = 1 \) and produced the formula:

\[
V_v = 1.1547 \sqrt{fR}
\]  

(2)

It will be noticed that Lacey has taken his silt factor \( f \) under the root sign. In his own words, "It is preferable, to denote silt grade by a linear ratio, rather than by a velocity ratio, and for this purpose the silt factor \( f \) has been introduced by the writer".

5.33. Stimulated by the result of his substitution of \( R \) for \( D \), Lacey proceeded to test the Lindsey hypothesis. From such available data as was complete, he plotted the velocity \( V_v \) against the product of the sectional area \( A \) and square of \( f \) the silt factor pertaining to the particular channel. The resulting curve is shown in fig. (i) from which he secures the formula:

\[
A^f = 4.0 V_v^5
\]  

(3)

**GENERAL FORMULA**

\[
A^f = 4.0 V_v^5
\]

KENNEDY

LINDLEY

MADRAS (GODAVARI WESTERN DELTA)

(KISTNA WESTERN DELTA)

EGYPT

UNITED PROVINCES

SCOURING EXAMPLE

(FIG ii)

5.34. Lacey also eliminated \( f \) from the above two equations and produced the formula:

\[
P_v = 2.668 Q^3
\]  

(4)

Equations (2), (3) and (4) are the three standard Lacey formulae upon which is created the whole superstructure of the Lacey theory.
5.35. The Lacey formula can be cast in various useful forms as below.

\[ V_e = 1.1547 \left( \frac{Q}{A} \right)^{0.6} \left( \frac{R}{D} \right)^{0.2} \]  
\[ R = 0.75 V_e \]  
\[ D = 4.0 V_e \]  

Whence

\[ Q = 2.668 V_e^2 \]  
\[ R = 0.4775 \left( \frac{Q}{A} \right)^{0.5} \]  
\[ V_e = 0.141 \frac{P_v}{R} \]

5.36. Examination of these formulae shows that for a given value of the discharge \( Q \) and a given value of the silt factor \( T \), the dimensions of a regime channel are uniquely determined; that is to say, there is only one value of the velocity, the wetted perimeter and the hydraulic mean depth which will satisfy these equations. From this it follows that there is only one value of the slope which will satisfy the requirements of the above formulae.

**Lacey's Flow Equation**

5.41. Lacey now proceeded to tackle the flow formula. He accepted as his starting point, the basic Chezy formula—

\[ V = C \sqrt{R} \]

Many eminent hydraulicians have attempted to evaluate the "constant" \( C \). Kutter and Manning are the best known, but all assumed that the physical condition of the channel affected the value of this "constant". Lacey postulated that in alluvial channels, the coefficient of roughness was a function of the silt envelope and was independent of all other factors. This innovation was to lead to important results in the direction of simplification and accuracy.

In order to simplify study of the subject, it is necessary to establish relationships which are among the high-lights of the Lacey system.

5.42. Lacey pictures the hydraulic channel as the wetted surface, spread out on the horizontal plane, with the hydraulic mean depth erected thereon. Prototype and model may therefore be depicted as in fig. (iii).
Let the horizontal scale of the model be $\frac{X}{L}$ and the vertical scale be $\frac{1}{V}$.

Then the ratio $\frac{X}{V}$ is termed the "exaggeration" $E$ (i.e., the ratio between the vertical and horizontal scales).

Then, in the horizontal, $\frac{L}{L_1} = \frac{P_x}{P_{x1}} X$
in the vertical, $\frac{R}{R_1} = Y$

$E = \frac{X}{Y} = \frac{P_x}{P_{x1}} \frac{R_1}{R}$

But from equation (6)

$\frac{P_x}{R} = 7.11V$

$\frac{P_{x1}}{R_1} \frac{R_1}{V} = E$

Again, let $H_1$ and $H_{11}$ be the differences in levels between corresponding points on prototype and model, at the end of length $L$ and $L_1$, respectively.

Then

$\frac{H_1}{L} = \frac{S}{L_1}$

$\frac{H_{11}}{L_1} = \frac{S_1}{L_1}$

$\therefore \frac{S}{L_1} - \frac{S_1}{L_1} = \frac{L_1}{L} \frac{H_1}{L_{11}}$

$= Y \cdot \frac{1}{X}$

$= \frac{1}{E}$

$\frac{S}{S_1} = \frac{1}{E} = \frac{V_1}{V}$

This relationship is of vital importance in model experiments.
5.43. Returning now to the Chezy formula,

The velocity formula—

\[ V = \frac{C}{C_1} \cdot \frac{R^{\frac{1}{2}}}{R_1^{\frac{1}{2}}} S^{\frac{1}{2}} \]

or

\[ \frac{C}{C_1} = \frac{V}{V_1} \cdot \frac{R_1^{\frac{1}{2}}}{R^{\frac{1}{2}}} \frac{S^{\frac{1}{2}}}{S_1^{\frac{1}{2}}} \]

Substitute for \( S \) from equation (8)

\[ \frac{C}{C_1} = \frac{V^{\frac{1}{2}}}{V_1^{\frac{1}{2}}} \cdot \frac{R_1^{\frac{1}{2}}}{R^{\frac{1}{2}}} \]

But Lacey postulates that streams flowing in envelopes of the same silt (i.e., whose \( T \) value is the same) must have the same coefficient of absolute roughness \( N_0 \). Hence, for such channels, from equation (2)

\[ \frac{V}{V_1} = \frac{R_1^{\frac{1}{2}}}{R^{\frac{1}{2}}} \]

Substitute in equation (9)

\[ \frac{C}{C_1} = \frac{R_1^{\frac{1}{2}}}{R^{\frac{1}{2}}} \]

Therefore the \( C \) in the Chezy formula, when applied to Regime channels varies as \( R^{\frac{1}{2}} \).

Hence the Chezy formula may be rewritten

\[ V = k R^{\frac{1}{2}} S^{\frac{1}{2}} \]

or

\[ V = \frac{k_1}{N} \cdot R^{\frac{1}{2}} S^{\frac{1}{2}} \] (10)

Where \( N_0 \) is a true coefficient, a measure of the absolute roughness of the silt envelope.

5.44. Now the value of Kutter's \( N \) and Manning's \( N \) coincide at a depth of one meter. Lacey decided to retain this coincidence, familiar to all hydraulicians.
Then, (Manning)

\[
Y = \frac{1.4858}{N} R^{\frac{2}{3}} S^{\frac{1}{2}}
\]

\[
= \frac{1.4858}{N} (3.208)^{\frac{2}{3}} S^{\frac{1}{2}}
\]

\[
= (Lacey) \frac{K_1}{N_a} (3.208)^{\frac{2}{3}} S^{\frac{1}{2}}
\]

whence \[
K_1 = \frac{1.3458}{N_a}
\]

and \[
V = \frac{1.3458}{N_a} R^{\frac{2}{3}} S^{\frac{1}{2}}
\]

(11)

The above formula is strictly applicable to regime channels, but may be used freely as a substitute for either Kutter's or Manning's in non-regime alluvial channels or channels with rigid boundaries, rivers, etc., with improved accuracy and greater facility, by adjusting the value of \(N_a\).

5.45. It was remarked in paragraph 5.41 that channels in which the value of \(\kappa^2\) is the same, must have the same coefficient of roughness \(N_a\). The next step was to determine some relationship between \(N_a\) and \(\kappa^2\).

Form the authentic data at his disposal of channels in or near regime, Lacey calculated the value of \(N_a\) from equation (11) and the value of \(\kappa^2\) from equation (2).

The results are plotted in fig. (iv) from which he derived the empirical equation.

\[
N_a = 0.0225 \kappa^{\frac{1}{3}}
\]

(12)
This equation, while purely empirical in character, represents the statistical mean of observed results. It has been adjusted to ensure that when \( T = 1 \) (identical with Kennedy’s standard measure of silt, \( V = 1 \)), the value of \( V \) the \( N \) shall be 0.0225, the figure adopted by Kennedy in his work on regime channels.

Its value lies in its function as a connecting link between the regime equations and the flow formula. 5.46. The substitution of \( N \) in terms of \( T \), given by equation (12), in the flow formula equation (11) provides a formula connecting \( V, R, S, \) and \( T \) which can be cast in many forms, of which the following are most commonly used:

\[
V = \frac{1.3588}{N} \cdot R \cdot S^\frac{3}{2} \quad \ldots \quad (11)
\]

\[
V_0 = \frac{59.813}{T^3} \cdot R \cdot S^\frac{3}{2} \quad \ldots \quad (11a)
\]

\[
S = \frac{1}{1844.3} \cdot \frac{R^3}{Q^3} \quad \ldots \quad (11b)
\]

\[
V = 16.046 \cdot R^\frac{3}{2} \cdot S^\frac{3}{2} \quad (11c)
\]

5.47. Numerous other useful relationships can be obtained from Lacey’s formulae. For example, it can be shown that for all channels of the same absolute roughness, \( R^\frac{3}{2} \cdot S^\frac{3}{2} \) is a constant.

From equation (2)

\[
V = \frac{R^3}{R_1^3}
\]

From equation (11)

\[
V = \frac{R^3 \cdot S^\frac{3}{2}}{R_1^3 \cdot S_1^\frac{3}{2}}
\]

Hence

\[
\frac{R^3 \cdot S^\frac{3}{2}}{R_1^3 \cdot S_1^\frac{3}{2}} = 1
\]
5.48. Thus $R / S$ is a constant for all channels of equal silt factor $I$. The ideal silt transporting stream is one in which the discharge is fixed and constant; the silt charge is also constant and the envelope, regular and uniform, consists of incoherent self-borne alluvium. No such channel exists in nature. The discharge is always varying some times through extreme ranges: the silt charge varies with the season: the type of head and regime changes upstream of the channel offake, also affect the silt charge. All silt has some coherence and when clay is present may be anything but incoherent: grass will grow on the banks, or unerodible strata may check any tendency to scours. In short, the ideal channel to which the Lacey formulæ apply, does not exist. The Lacey regime is a knife edge and any departure from the ideal conditions postulated above, will result in a departure from ideal dimensions. The practical engineer, therefore, need not be surprised if he finds channels, approximately stable, with dimensions differing from those derived from the Lacey equations. But the initial construction and for a standard to which maintenance should be directed, the dimensions indicated by the Lacey equations are the safest guide available today.

There has been much controversy as to the precise nature of the quantity designed $I$. It is generally accepted that $I$ is an ominous factor embracing all considerations of quantity, shape, material and size.

Since no natural channel or even a canal will ever be found to conform strictly to Lacey’s regime, it follows that the values of $I$ derived from the slope equation (118) and from the velocity equation (122) never coincide. The difference between the two represents the divergence from regime, and is of utmost value to the discerning engineer.

**Diagram for Design.**

5.51. Simple as are the Lacey equations, their use involves an appreciable amount of calculation. Any body of calculations involves chances of error. To eliminate such error and to expedite the work, Mr. Lacey has provided two diagrams. In both these diagrams, the co-ordinates are divided logarithmically, to secure a suitable reduction of scale at higher values.

The first is entitled “Regime Dimension Diagram” and is usually provided in two parts:

(a) from 4 to 100 cases, and

(b) from 100 to 20,000 cases.

The curves are plotted from the regime equations assembled in paragraph 5.35.
5.52  THEORY OF SILT TRANSPORT

For known values of discharge \( Q \) and silt factor \( 'f' \), the wetted perimeter \( P \), and hydraulic mean depth are calculated. These are converted into bed-widths and depths for a corresponding trapezoidal channel with horizontal bed and \( \frac{1}{3} \) : 1 sides slopes. This section is the one most commonly used in the construction of irrigation channels.

The horizontal co-ordinate is the bed-width in feet and the vertical co-ordinate is the depth in feet. The values of the discharge and \( 'f' \) corresponding to these bed-widths and depths, are then plotted on the diagrams. The result is a series of curves varying from the horizontal to an inclination of about 40°, representing the values of \( 'f' \). Superimposed on this group are other lines of equal discharge varying from curves at about 45° to the horizontal to almost vertical at high value.

5.52. The second diagram is entitled "Regime Slope Diagram". The horizontal and vertical axes are similarly divided logarithmically. The discharge in cusecs is plotted horizontally and the slope per thousand is plotted vertically. The curves are plotted from the slope equation assembled in paragraph 5.46. The values of \( 'f' \) corresponding to the discharge and slope are represented by parallel straight lines inclined to the horizontal at about 25°.

5.53. From these two diagrams it is possible to determine the slope and dimensions of any channel, if two factors are known.

Every irrigation engineer should be in possession of these curves in the form of mounted wall diagrams, which should be his constant companion.

BIBLIOGRAPHY

5.9. The following is a bibliography of the important work which has been done on the transport of detritus by flow in water. It is arranged in chronological order, instead of the more usual alphabetical.


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6. Woods, F.W. Normal Data of Design for Kennedy Channels. (Published by Public Works Department, Punjab, Irrigation Branch).

7. Lacey, G. Stable channels in alluvium. (Institute of Civil Engineers Paper No. 4736). 1929.


17. Kalinske, A.A.  Suspended material transportation under non-equilibrium conditions. (Transactions American Geophysical Union, 1940, Part II). 1940.


24. Lase, E.W.  A partial bibliography on hydraulic engineering aspects of sediment transportation and deposition (Stencilled).

25. Saleh, Q.H.  Bibliography on silt and related subject (Typewritten).
CHAPTER 9

Masonry Works on Irrigation Channels

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CHAPTER 9

Cross Drainage Works.

INTRODUCTION

9.01 The alignment of the Irrigation Channels is selected on ridges or water sheds, so that generally no drains are necessary to be crossed by them. However, in an irregular and uneven country they have some times to cross the drains. Works necessary to dispose off the drains are called Cross Drainage Works.

9.02 There are several methods of calculating but the discharge of a drain or a stream in estimating the highest flood dis. The discharge of the Cross Drainage Works, so that, the one should be calculated by both the methods and serves as a check on the other.

1. Measuring the Cross Section estimating the mean velocity area and from the record of rainfall in the area, estimating of the maximum of the site of Cross Drainage Work.

2. The run-off that is are described briefly as below:

The two levels at the end of the stream are taken along the Cross Section of the torrent at right angle to the course of the stream and the area of the section below H.F.L. is calculated. Generally, the bed is live in the case of high velocity streams and it is necessary to give allowance for the scoping of the bed when calculating
Cross-sections from the levels taken when there is no flow in the stream.

(i) When the current is in flood, velocities are observed with the help of velocity rods or surface floats or a current meter.

The width of the terrace is divided into a convenient number of parts. Two wires 100' apart more are stretched across the stream in a straight reach. The divisions of the widths of the stream are marked on these wires. The time taken by a float or velocity rod to travel the distance along the centre line of each division is determined by a stop watch and from this the mean velocity of the water in each division is calculated. If the velocity is measured by a surface float, the mean velocity along a vertical line is taken as 4/5 of the surface velocity. It is more accurate if the mean velocity is measured in each segment with a current meter.

(ii) The area of each division and the mean velocity in the division being known, the discharge flowing through each division can be easily found viz. Thus if \( a_1, a_2, a_3, \) etc. are the areas of divisions and \( v_1, v_2, v_3, \) etc. are the respective mean velocities the total discharge of the stream is equal to \( a_1 v_1 + a_2 v_2 + a_3 v_3 + \ldots \ldots \ldots + a_n v_n. \)

An alternative method to work out the maximum flood discharge is described below:

(i) Take three cross sections of the stream at right angles to it, one at the site of the crest drainage work, the 2nd about 1000' U/S of the site of the crest drainage work and the 3rd about 1000' D/S of the work. Find the H.F.L. at each cross section either by observation or by local inquiry. These can be verified by the maximum flood marks. Calculate the area of each cross section up to H.F.L. and adopt the mean of the three areas for calculation purposes.

(ii) Measure the wetted perimeter of each cross section and calculate the hydraulic mean depth (H.M.D.)

\[
\text{H.M.D} = \frac{\text{Area of cross section}}{\text{Wetted Perimeter}} = \frac{A}{PW}
\]

Find the mean of the three hydraulic mean depths by dividing the sum of the H.M.Ds by three.
(iii) Find out the surface fall of water from the upstream cross section to the downstream cross section. This is determined by finding the difference in the H.F.Ls at the two extreme cross sections. Now, slope of the water surface is evidently the total fall divided by the distance between the sections.

(iv) Having known the mean area, A, the hydraulic mean radius, R, and the slope S, the mean velocity is calculated by the application of Manning's, Kutter's, or Bazin's Formula as given below:

(a) Manning's Formula.

\[ V = \frac{1.4858}{N} \times \frac{1}{S} \times \frac{A}{5} \]

Where \( V \) is the mean velocity, 
\( N \) is the co-efficient of roughness, 
\( R \) is the hydraulic mean radius = \( \frac{A}{PW} \), 
\( A \) is sectional area, 
\( PW \) = Wetted perimeter, 
\( S \) is water surface slope.

(b) Kutter's Formula.

\[ V = \frac{C}{R S} \]

Where \( V \) = mean velocity, 
\( R \) = Hydraulic mean radius = \( \frac{A}{PW} \), 
\( S \) = Slope, 
\( C \) = Co-efficient.

\[ 41.66 + 1.811 + 0.0028 \]

\[ = \frac{N}{S} \]

in ft units.

Following are the values of the co-efficient of roughness 'N' to be used in Manning's and Kutter's Formula.

0.025 Canals and rivers in earth in tolerably good order and regime.
0.030 Canals and rivers in bad order and regime.

0.035 Canals and rivers obstructed by detritus and in bad order and regime.

0.050 Torrents encumbered with detritus.

(c) Basin's Formula,

\[ C = \frac{1.25}{R} \times \frac{K}{R} \]

Where \( R \) = H.M.D. 

\[ K = \frac{2.35}{K} \]

Following are the values of \( K \):

- Clear smooth sides of wood, bricks, stone etc. \( K = 0.2 \)
- Dirty sides of wood, bricks, stone etc. \( K = 0.5 \)
- Sides of natural earth. \( K = 2.35 \)

(6) METHOD II.

The main data required for calculation of the flood discharge by this method is the determination of catchment area, the maximum rate of rainfall and runoff from the catchment area.

The catchment area should be found by planimeter from a contour survey map between the two water shed lines of a drainage. The maximum rate of rainfall is known by making a reference to the rainfall records of the last 30 or 40 years as available.

Run-off from a catchment area may be defined as the proportion of the water, out of the total rain, falling in the area of the catchment, running to drainage. It is evident that a portion of the rainfall seeps into the soil, another portion maintains the subsoil water current to the wells and springs and the rest flows to the streams. The run-off is dependent mainly on the following:

(1) The degree of porosity of the soil of the catchment area.
(2) The slope of the catchment area.

(3) Changes in the flow in the area such as roots of trees or other obstacles.

(4) The amount of evaporation.

(5) The character of the catchment area.

(6) The total area of catchment area.

The major factors that affect run-off from the catchment area are as follows:

(1) Intensity of rainfall.

(2) Duration of rainfall.

(3) Area of the catchment.

(4) Shape of the catchment.

(5) Slope of the catchment.

(6) Characteristics of the catchment.

As a result of several experiments made by the Engineers in the various localities, it is determined that the percentage of run-off varies from 2% to 70% according to the nature and characteristics of the catchment.

Having determined the catchment area, the intensity of rainfall and the percentage of run-off, the probable flood discharge can be calculated using the formula:

\[ Q = \frac{a \times d \times r \times 5200 \times 280}{60 \times 96 \times 260} \]

Where:
- \( a \) = catchment area in square miles.
- \( d \) = intensity of rainfall in inches per hour.
- \( r \) = percentage run-off.

The maximum flood discharge should be determined by the application of the following empirical formulas:

1. Dickson's Formula
   \[ Q = CM^{2/3} \]

2. Rynel's Formula
   \[ Q = CM \]
3. **Inglin**'s Formula

\[ Q = \frac{7000 \times M}{(M + A)} \]

**AND** \[ Q = \frac{7000}{A} - 240 (A+130) \]

for an elongated catchment.

The value of \( C \) which is a constant, depends on the catchment area and the intensity of rainfall. \( M \) is the area of the catchment in square miles.

Dicker's took \( C = 825 \), in cases where the rainfall was about 30 inches a year but he held that it might be applied where the rainfall varied from 24 to 50 inches. The formula takes no cognizance of the size of the catchment, nor of its declivity and provides no factor taking account of the variations in rainfall. The following statement shows the values of \( C \) in this formula with reference to some Indian rivers.

<table>
<thead>
<tr>
<th>River</th>
<th>Drainage area in Squ. Mem.</th>
<th>Maximum record</th>
<th>Coefficient in per cent per sq. min.</th>
<th>Average annual rainfall in inches</th>
<th>Dicker's Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tad</td>
<td>321</td>
<td>7200</td>
<td>242.5</td>
<td>726</td>
<td>1724</td>
</tr>
<tr>
<td>Krishna</td>
<td>253</td>
<td>11000</td>
<td>164.8</td>
<td>56</td>
<td>725</td>
</tr>
<tr>
<td>Godavary</td>
<td>721</td>
<td>8000</td>
<td>313</td>
<td>56</td>
<td>747</td>
</tr>
<tr>
<td>Ganges</td>
<td>2968</td>
<td>931240</td>
<td>34.9</td>
<td>53</td>
<td>147</td>
</tr>
<tr>
<td>Jamna</td>
<td>3846</td>
<td>138400</td>
<td>8.7</td>
<td>39</td>
<td>109</td>
</tr>
<tr>
<td>Hooghly</td>
<td>3679</td>
<td>180000</td>
<td>4.9</td>
<td>42</td>
<td>120</td>
</tr>
<tr>
<td>Coouly</td>
<td>1890</td>
<td>110000</td>
<td>4.8</td>
<td>46</td>
<td>148</td>
</tr>
<tr>
<td>Mahanadi</td>
<td>4509</td>
<td>126000</td>
<td>34.7</td>
<td>29 to 39</td>
<td>258</td>
</tr>
<tr>
<td>Betwa</td>
<td>959</td>
<td>70000</td>
<td>76.5</td>
<td>38 to 40</td>
<td>811</td>
</tr>
<tr>
<td>Bell Vads</td>
<td>2277</td>
<td>190000</td>
<td>54.7</td>
<td>50 to 60</td>
<td>382</td>
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<tr>
<td>Kanshe</td>
<td>1496</td>
<td>280000</td>
<td>61.4</td>
<td>50 to 60</td>
<td>530</td>
</tr>
</tbody>
</table>

The value of coefficient \( C \) suited to a particular tract should be deduced from measured maximum flood discharge from a known catchment basin.

Dicker's formula for the determination of the highest flood discharge for the design of the cross disjunct works on the Nangal Hydel Channel, and Bhakra Main Line Canal has been used. The value of \( C \) for the reach K.P. 0-25 to 0-60 Nangal Hydel Channel, has been taken as 1300 and below this reach it is taken as 1350. It may be noted that Nangal Hydel Canal is running just at or very near to the foot of the Shivalik Hills, therefore, higher values of \( C \) have been taken. The average...
annular rainfall in this tract is between 40 to 60 inches. It has been seen that the actual discharges observed in most cases fairly tally with those worked out from the above noted formula.

Ryves gives the following value of \( C \) for Madras.

\( C = \begin{cases} 450 & \text{within 15 miles of the coast.} \\ 560 & \text{for a tract 15 to 100 miles from the coast.} \\ 675 & \text{for limited areas near the hills.} \end{cases} \)

In addition to the above, there are many other formulae given by persons like Greenhill, in America & India. Out of these, the following formulae are noted for information and guidance.

G. Chantre Formula...

\[ Q = 640 \times R \times C \times M \]

Where \( Q \) = Maximum discharge in cubic feet per second.

\( R \) = Average rate of greatest rainfall in inches per hour for such duration as will allow of flood water flowing to the outlet from the farthest extremity of the catchment area.

\( C \) = A co-efficient.

In this formula, a good deal of experience and observation would seem necessary before value could be assigned to \( R \) and \( C \) but it possesses some advantage in the fact that it allows weight to actual rainfall of a definite time, a factor of importance which finds no expression in the other formulae.

Khangar & Guilhoti’s Formula.

\[ Q = 645 \frac{A_o \times Z_{\text{max}} - F \times \left(A_o\right)}{M} \]

Where \( A_o \) = Effective area of catchment.

\( A_o \) = That area for which dispersion is unity or that area which can be wholly covered by a particular storm and in which the intensity of storm does not vary.

\( M \) = Index of dispersion.
Cross Drainage Works

Z_{max} = \text{Maximum height of a theoretical hydrograph for a rainfall of maximum possible intensity in the catchment.}

\text{T =} \text{Event time.}

\text{F = Reduction in inches due to rain initially held by trees, crops and undergrowth.}

\text{TYPES OF CROSS DRAINAGE WORKS}

9.3

(a) Syphon.
(b) AQUEDUCT.
(c) Superpassage.
(d) Level crossing.
(e) Tunnel.

\text{Brief account and characteristics of each of the above Cross Drainage Works is given below:—}

(a) Syphon

9.31 When a stream passes under-nature a canal, such that the head way is insufficient, the bed of the stream is depressed below the normal level and the water passes in a tunnel underneath raising again on the other side; the cross drainage work, is called a syphon.

On the upstream side, in the approach channel, masonry and stone cut walls having side slope of 1:1 to vertical, are provided, for the easy approach of the channel to the tunnel of the syphon. In the bed flexible floor, consisting of loose stone filling 1.0 to 2.0 feet thick laid at the bed level of the torrent and cement concrete block 2'\times2'\times1.8' is provided. The flexible floor is followed by impervious sloping floor upon the mouth of the tunnel. Under the banks and canal bed, the tunnel barrels are of 1:2:4 R.C. Concrete or of plain brick masonry, or stone masonry having arched roof and level or inverted arched floor. The roof slab and the floor of the tunnel under the banks are sloping while they are level under the bed of the canal. Under the downstream bank the slope is reverse. The roof of R.C. Slab or the masonry slab is designed to bear safely the loads of the banks and of water column at top when the syphon is not working, as also against the uplift pressure of the water in the torrent passing through the tunnel of the syphon.
when the canal is closed and the syphon is working under the maximum flood conditions. The floor is designed to carry safely any load coming on it, as also against the uplift pressures of the sub-soil water underneath. Where the sub-soil water is above or near the floor level of the syphon, in the case of masonry syphons, an inverted arched floor should be provided to be safe against the uplift pressures. On the D/S side in the outfall channel, long masonry flared out walls are constructed to permit stream line expansion of water rushing through the tunnel of the syphon. The D/S flared out walls are similar in construction to the Upstream flared out walls. In cases where the fall available is more than the loss of head through the syphon, the extra fall is disposed of by providing a raised crest or hump just downstream of the tunnel of the syphon which is followed by a glace and a deep cistern. A cistern of suitable length and depth is necessary to kill the cistern extra kinetic energy. At the end of the cistern, flexible floor consisting of heavy cement concrete blocks (1:4:8) of size $3'\times 3' \times 3'$ are laid in situ over 6" thick shingle and generally followed by border stone placed in wire crates. This is necessary to take up the possible retrogression of the bed levels of the nullah and avoid damage to the D/S curtain wall and the flared out walls.

For the proper working of the syphon, a regular approach channel and properly graded outfall channel should be provided and maintained, otherwise, at the time of heavy floods, unnecessary heading up occurs on the upstream side resulting in heavy damage to the canal banks and flooding of the surrounding fields and village abadis. In the case of a very heavy torrent, guide banks on the upstream and downstream sides should be provided for training of the torrent and provision made for disposal of the flood water. The guide banks should be of adequate section and safe against a hydraulic gradient of 1:5 under the highest flood conditions. A possible afflux of ponding up of 1'0" to 2'0" should be allowed at the Cross Drainage works. A free board of not less than 0' should be allowed over the highest levels.

The guide banks should be faced with boulder pitching. 1.25' thick preferably in 2 layers, first layer of 6" flat stone and 2nd layer of 9" stone at end. The stone pitching to lie on the bed of suitable thickness and 6" shingle filling. A stone apron of suitable thickness and 6" shingle filling should be provided at the toe of the pitching to take up the possible scour, due to swift and concentration flow of
CROSS DRAINAGE WORKS

9.32

(b) AQUEDUCT

9.32 When a stream passes underneath a canal through a masonry structure, such that the headway is sufficient to permit the highest flood in the torrent to pass without any obstruction, the cross drainage work is called an Aqueduct.

The Aqueduct structure may either be of brick or stone masonry or of R.C. Concrete. The upstream and downstream flared out walls, floor, and downstream tisern etc are quite similar to those mentioned under item (a) Syphon. In the case of a masonry aqueduct, the structure mainly consists of an arched bridge with a platform at canal bed level and provided with two solid masonry retaining walls or earthen banks which retain the water flowing through the canal. For the sake of economy, the water way of an aqueduct is reduced to gain a velocity of about 8' to 10' per second. The arch of the aqueduct should be strong enough to safely carry the load of the water column in the canal as also any filling between the canal bed and crown of the arch and also of the earthen banks on the sides of the canal. The abutments and piers should be of adequate section to carry the load coming on the arches. The floor generally consists of inverted arch masonry to distribute the load evenly over somewhat shallow foundation. The inverted arch is also useful for taking up the upward water pressure on the floor. A masonry face wall on the upstream side as well as on the downstream side is constructed at each end of the aqueduct to retain the slope of the banks.

In the case of aqueduct, with a R.C. barrel, piers, abutments and floor can either be of brick or stone masonry or of R.C. Concrete (1:2:4). In the case of R.C. structure a suitable expansion joint should be provided in the barrel under the embankment portion, where the thickness of the top slab increases. To make the joint water tight, it should be filled with Shalimar's hot expansion jointing compound or any other suitable bituminous fill. For details of the joint,
9.33—9.34 MANUAL OF IRRIGATION PRACTICE

Reference is invited to Plate No. II, for Bassowal aqueduct at R. D. 57882.

(c) SUPPERPASSE

9.33 When the levels are such that a stream passes over a canal, the cross drainage work is termed a Supperpassage.

Description of the work: Supperpassage structure may either be of brick or stone masonry or of R. C. Concrete. Now-a-days R. C. Concrete, Superstructure is always preferred over a masonry structure, provided the cost of the former is not very high, due to the materials for concrete not being readily available. In this case, the upstream and downstream walls, floor and downstream cistern etc. are similar to those mentioned under item (a) Syphon. In the case of a masonry superpassage, masonry arches are provided with their crown at a bed level of the torrent. Massive side walls are constructed on sides of the torrent. In the case of R. C. concrete structure, and R. C. slab is laid at the bed level of the torrent or slightly higher if need be, over piers constructed in the bed of the canal. Side, walls including divide walls are constructed as retaining walls safe for the water pressure. The arches or the bottom slab of the trough are designed to carry safely load of column of water in the torrent coming over them. Piers and submains of suitable section are provided to be safe against the super-loads to which they are subject. In the case of a R. C. Concrete, Superpassage, expansion joints are provided at suitable intervals as shown in plate No. III.—Supperpassage R. D. 27256 of Nargal Hydel Channel.

(d) LEVEL CROSSING

9.34 When bed level of the stream and the canal are more or less the same at their junction, the cross drainage work is termed a level crossing.

In this case an inlet is required on the side from which the torrent is coming and an exit on the opposite side. This involves one regulator across the canal and one at the further bank across the exit of the drainage.
CROSS DRAINAGE WORKS

An inlet is needed rarely, as generally it is possible to dispose off the drainage in other ways than the level crossing, which is likely to disturb the regime of the canal and also prove costly due to the need for providing suitable controls at the inlet and outlet sides and perhaps a regulator in the parent channel if the discharge to be disposed off is considerable.

(c) INLET

9.35 When discharge of a torrent is small, its bed level is higher than the F.S.L. in the canal and the storm water is allowed to fall into the canal, the masonry structure is termed an inlet. This is done to avoid incurring heavy expenses for providing a costly superpassage. To avoid silting of the canal on account of muddy or shingle laden storm water entering into it, an inlet is usually avoided by providing a parallel drain along the canal and discharging it into another drain for which a cross drainage work has been constructed.

9.4 Instructions for Design:

For working out the design of a Cross Drainage Work, the following data must be made available.


(a) Canal.

Q i.e. authorized Full Supply Discharge.
Bed Width.
F.S. Depth.
W.S. Slope.
Bed Level.
F.S. Level.
Bank Level.

Normal Cross Section of the Channel showing N.S. Levels etc.

(b) Torrent.

Q i.e. the Highest Flood Discharge.
H. Flood level at the Central Line of the Canal.
9.42 MANUAL OF IRRIGATION PRACTICE

Crossing,
Deepest Bed R. L.

Slope—Actual W. S. Slope as observed under the Highest Flood conditions on the Up-stream and Down-stream of the work and also the average slope.

Longitudinal Section of the Torrent from about one mile Up-stream to about one mile Downstream of the central line of the canal crossing.

A few cross sections up to about 1000 feet Up-stream and about 1000 feet Down-stream of the Central Line of the canal crossing.

Calculations for the maximum flood discharge as observed.

Site Plan of the work site, showing course of the torrent one mile Upstream and one mile Downstream.

Contour survey plan showing limit of catchment area. Highest annual rainfall and intensity of Rainfall Geological Section at C. L. of the work. 50 to 100 feet Upstream and 50 to 100 feet Downstream for 15° to 25° below the lowest foundations.

Bed load in the bed of torrent whether there are boulders and shingle or shingle and coarse sand or coarse sand fine sand, silt etc.

The above data should be as accurate as possible, so that correct design may be worked out by the design Engineer.

9.42 II. Hydraulic Design.

(c) Approach and out-fall Channels.

Section of the approach and out-fall channels should be worked out according to Lacey's formulae. Having fixed the maximum flood discharge and available slope of the torrent bed under the Torrent Data, proceed as under.

Lacey's \( P_\text{w} = 2.87 \sqrt[3]{A} \)
When $Q$ is the Max. flood discharge

Find value of Lacey's "f" from the following formula: —

Formula.

$S = \left( \frac{Q^{1/3} \times f^{2/3}}{1844.3} \right)^{1/2}$

or $f^{2/3} = \left( \frac{1844.3 \times \frac{Q^{1/6} \times S^{1/2}}{3} \right)^{2/3}$  \hspace{1cm} (ii)

When $S$ in the bed slope as given under the data as per (i) above and "f" can thus be easily found.

Work out $V_0$ from the following formulae.

$V_0 = \left( \frac{Q}{1.8} \right)^{3/8}$  \hspace{1cm} (iii)

Find out value of $R$ (Hydraulic Mean Radius) from the following formulae.

$2 \times 0.7305 \times V
\frac{R = \frac{Q}{V}}{3}$  \hspace{1cm} (iv)

and $A = \frac{Q}{V}$

Where $A$: Sectional Area

To find out $B$ and $D$, i.e., Bed Width and Depth of Channel section.

$D = \frac{A}{2KR}$  \hspace{1cm} (\(v\))

and $B = \frac{A}{D}$  \hspace{1cm} (vi)

$K = 2 \left( \frac{1}{18}-1 \right)^{3/2} \times S$  \hspace{1cm} (vii)

Following are the values of $K$.

<table>
<thead>
<tr>
<th>Side Slope</th>
<th>S</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>0</td>
<td>2.0</td>
</tr>
<tr>
<td>One half to one</td>
<td>0.5</td>
<td>1.736</td>
</tr>
<tr>
<td>One to one</td>
<td>1.0</td>
<td>1.8284</td>
</tr>
<tr>
<td>1\frac{1}{2} to 1</td>
<td>1.5</td>
<td>2.105</td>
</tr>
</tbody>
</table>
In practice generally bed width is taken 0.8 of the $Pw$ worked out under (1) above.

In cases where the torrent has a deflected section with vertical or slightly sloping sides, the engineer should try to keep the same section, rather than to fix an arbitrary section derived from the above formulae. Generally, near the hills, as in case of torrents, crossing the Nangal Hydel Channel, bed width is not very wide as compared to that in plains.

It is seen that in many cases un-experienced Engineers try to adopt value of $T'$ without determining the size of silt particles or without reference to the bed load. To avoid this mistake it is essential to base the design on the actual bed slopes of the torrent and then find out value of Lacey's $T'$

For the proper functioning of a cross-drainage work, it is necessary that the approach and outfall channels should be maintained properly, otherwise due to settling on the downstream side, there is every likelihood of flooding of the land on the upstream side.

(b) Water-way.

Adopt suitable section such that velocity through the barrel does not exceed the critical velocity $V_c$ and actual loss of head should not be more than the fall available.

$$V_c = \frac{g}{D_c}$$

Where $q = \text{Discharge per foot}$.

$$Q = g$$

and $D_c = \text{Critical Depth}$.

$$D_c = 3.85 \sqrt{\frac{Q}{g}}$$

Where $g = 32.2$

Section of the barrels selected should preferably be in round numbers of feet.
(c) Loss of Head.

Loss of head may be provided as under.

(i) Due to convergence in the upstream flared out walls.

(ii) Due to friction in the upstream flared out walls.

(iii) Due to friction, through the barrel of the syphon etc.

(iv) Due to divergence in the downstream flared out walls.

(v) Due to friction in the downstream flared out walls.

Sum total of losses as per item No. (1) to (v) will be the total loss of head.

Various losses may be worked out from the following formulae:

(c) Loss of head due to convergence.

\[
\Delta h = 0.1 \left( \frac{v_2^2}{2g} - \frac{v_1^2}{2g} \right)
\]

Where \( v_1 \) is the velocity at the upper end of the flared out walls and \( v_2 \) is the velocity at the lower end.

(ii) Due to friction in the L/S approach.

From the given section in the approach between the flared out walls, calculate velocity at the upper end and at the lower end. Take mean of the two velocities by dividing the sum of the two velocities by two.

Similarly, work out mean sectional area and wetted perimeter i.e., \( F_w \) and find out average Hydraulic mean radius i.e., \( R \).

Now, average velocity and Hydraulic mean radius are
known then find out slope $S$ from the Mannings Formulae.

$$ V = \frac{1.4888 \times R^{2/3}}{n} \times S^{1/2} $$

$$ S = \frac{V \times S}{1.4888 \times R^{2/3}} $$

$$ S = \left( \frac{V \times S}{1.4888 \times R^{2/3}} \right)^{1/2} $$

Provide a splay of 2:1 for the Upstream flared out walls and find out length along the central line by taking the differences in width at the upstream end and at the downstream end of the flared out wall.

Loss due to friction will therefore be $L \times S$. Where $L$ is the length of flared out walls.

(iii) Loss of Head through the barrel due to friction.

Find out velocity through the barrel by dividing the total discharge by the sectional area i.e.:  

$$ V = \frac{Q}{A} $$

$$ R = \frac{A}{V} $$

Use Manning formula.

$$ V = \frac{1.4888 \times R^{3/2}}{n} \times S^{1/2} $$

and find out value of $S$. From the section of the canal work out length of the barrel.

.: Loss of Head in the barrel $= L \times S$

(iv) Loss of Head in the Downstream flared out walls. Due to divergence.

$$ = 0.2 \left( \frac{v_2^2}{2g} - \frac{v_1^2}{2g} \right) $$
CROSS DRAINAGE WORKS

9.42

(v) Due to friction.

As explained for the Upstream approach, Splay for the Downstream flared out walls is generally taken as 1 in 3.

Add together the losses as worked out under items (i) to (v). This will give total loss of head required for the working of a cross drainage work for the given discharge. This much loss of head should be provided to avoid heading up on the upstream side.

In case, the available working head is more than the above, as is usually in the torrents in their upper reaches in semi-mountainous tracts, surplus head can be disposed off by providing a suitable cistern, as explained later on.

(d) H. F. Levels and T. E. Levels.

Under the head data, H. F. L. at the C. L. of the crossing and W. S. Slope of the torrent are known. Find the total length of the work to Upstream end from the C. L. and thus find out the H. F. L. at the Upstream and of the work. Similarly find out the H. F. L. at the downstream end of the work.

Find out the head due to velocity of approach at the start of the upstream flared out walls at the end of the upstream flared out walls, at the end of the barrel on the downstream side and at the end of the downstream flared out walls as given below:

\[
ha = \frac{a^2}{2g}
\]

where \( v \) is the velocity.

T. E. L. at the Upstream end of the work

\[ = H. F. L. + ha \]

T. E. L. at the Upstream end of the barrel

\[ = T. E. L. \text{ at the upstream of the work minus losses in } \text{the upstream approach due to convergence and friction.} \]
9.42 MANUAL OF IRRIGATION PRACTICE

H. F. L. at the upstream end of barrel.  T. E. L. at the upstream end of the barrel minus ha at this section.

T. E. L. at the D/S face = T. E. L. at the upstream face minus loss of head through the barrel.

H. F. L. at the D/S face = T. E. L. at the downstream face minus 'ha' at this point.

T. E. L. at the downstream end of the barrel = H. F. L. at downstream end plus 'ha' at this point.

Insert Levels.

* At Upstream end of barrel = H. F. L. minus depth at U/Stream end.

At Upstream end of barrel, = T. E. L. at upstream end of barrel-H.

H may be worked out from the following formulae.

\[ Q = 2 \times B \times H^{3/2} \]

or \[ H^{3/2} = \frac{Q}{2B} \]

or \[ H = \left( \frac{Q^{2/3}}{2B} \right) \]

Where \( Q \) is the Highest Flood discharge.

and \( B \) = width of waterway upstream of barrel.

R. L. of bottom of slab = Ded R. L. of canal—

(thickness of R. C. concrete lining 0.3' plus thickness of R. C. Slab at top of barrel).
R. L. of bottom of floor under canal section = R. L. of bottom of slab-depth of water in barrel.

R. L. of crest of hump = T. E. L. at exits — H

Where \( H = \left( \frac{Q}{3 \times B} \right)^{\frac{1}{2}} \) (it is assumed that the fall is modular, i.e., a clear standing wave occurs downstream of the hump).

Where \( Q \) is the discharge,
and \( B \) is the width of crest.

Join this level with the slab under the canal bed in a slope and keep the crest 5.0 ft. away from the exit of barrel. It may, however, be seen that R. L. of crest of the hump should not be at a higher level than R. L. at 1/3rd depth of the barrel from the bottom of the slab, otherwise, there will be heavy silting tendency in the barrel.

R. L. of floor of cistern = T. E. L. at downstream end with 3 ft. for retrogression E ft.

E ft may be worked out from curves for the given value of H.L and Q.

\[ H.L = T. E. L. \text{ at exit} - T. E. L. \text{ at downstream with } 3 \text{ft. for retrogression.} \]

\[ q = \frac{Q}{B} \quad \text{Where } Q = \text{Total discharge.} \]
and \( B = \text{Width at crest.} \)

Length of Cistern = \( 4 \times E \) ft.

Downstream Glacier.
Find height of crest above R. L. of floor of cistern and call it \( Y \).
6.42 MANUAL OF IRRIGATION PRACTICE

Now work out distance X i.e. from downstream end of crest to the point of the end of glaize at R. L. of floor of cistern from the formulae given below:

\[ X = Y + \frac{q x \sqrt{4gH}}{g} \]

Where \( H \) is the depth at crest below T. E. L. at exit and \( q \) = discharge per foot \( Q/B \).

For plotting a suitable profile of the placs find out values of \( X \) for 1, 2, 3, etc. + Y ft. of depth below crest. The curve so plotted will give profile of downstream glaize.

**Upstream Approach**

Provide a spay of 2:1. Length of flared out walls, therefore, will be:

\[ L = 2 x \left( \frac{B \cdot H_t}{2} \right) = \left( B \cdot B_t \right) \]

Where \( B \) = Width at Upstream end of approach.

and \( B_t \) = Width at U/S of barrel including thickness of piers if any.

The flared out walls should have a side slope of 1:1 at the U/S end and a vertical face on the other end and should be laid in a curvature with a radius \( R = \frac{L \cdot \left(B-B_t\right)}{\left(B+B_t\right)} \).

At the U/S end the flared out walls should turn gently at right angle and end at a side slope of 1:5:1. The return should be laid in D. B. pitching 0.85 thick and should have a smooth profile wall at the end.

Sections of the flared out walls should be worked out at 1/16th length of the flared out walls from the graph (C. D. C. Drawing No: BC-111-24). In case there is a surcharge at the top of a flared out wall...
CROSS DRAINAGE WORKS

wall, detailed calculations should be worked out for finding out suitable section of the planks.

BED PROTECTION.

Provide a curtain wall at the U/S end of the U/S approach. Depth of curtain wall should be at least \( \frac{d}{3} + 1/8' \) where \( d \) is the F. S. depth in the approach channel.

On the U/S of curtain walls, bed protection should consist of brick hats, preferably Jama bricks hand packed, or boulders laid in trumorgen, with top at bed level of the approach channel and have thicknesses as given below:

- Upto 25 Cu discharge 6'
- 26 to 50 Cu 8'
- 51 to 100 Cu 1.5'
- 100 to 200 Cu 1.5'
- Above 200 Cu 2.0'

Length of loose protection in bed should be 5-0 ft. for discharge upto 200 Cu and 10 ft. discharge above 200 Cu.

Length of the impervious floor should be such that it leads to value of exit gradient (G. E) not more than 0.3. In the remaining length in between the U/S curtain wall and the impervious floor, find scour depth with the following formula:

\[
\text{Scour depth } R = 0.5 \left( \frac{-q}{f} \right)^{\frac{3}{2}}
\]

where \( q \) is discharge per foot at U/S end

\( f \) = Lacey's Silt factor.

Scour depth = 1-5 R is straight reach of the drainage.

Taking depth in channel = \( D \)

Then scour below the bed

Level of the drainage = \( 1.5R - D \)
Assume thickness of bat filling and work out width, as in the case of apron of guide bank. Total quantity of stone should be equal to 4.5 (1.5 R.D).

For large works, it is not necessary to provide pneu impervious floor in the entire length of the U/S approach. Length of impervious floor should be reduced to the extent that value of G.E. is within the safe limits up to 0.3. In the remaining length in between the U/S curtain wall and the impervious floor, provide bed blocks 2' x 2' x 1.5 of 1:4:8 cement concrete laid on 6' shingle /walling underway. The blocks should have joints 4 inches wide and filled with shingle passing through 3/4" and retained on 5/8" screen. Where shingle is not easily available, graded brick ballast maximum size 3/4" may be used.

In case of small works pneu impervious floor should be provided in the entire length of U/S approach.

**Downstream Expansion.**

Provide a spacy of 3:1, Length of downstream expansion.

\[
L_e = 3 \times \left( -\frac{B-B_t}{2} \right)
\]

The expansion should be in a curve with Radius of expansion.

\[
R = L_e + \left( -\frac{B-B_t}{R} \right)
\]

Where \( B = \) width of expansion on the downstream end, \( B_t = \) width at the downstream of exit including thickness of piers if any & \( L_e = \) Length downstream expansion.

**Bed Protection.**

Depth of D/S curtain wall at the end of the impervious floor should be at least \( \frac{d}{2} + 1 \) where \( d \) is the depth of channel of the downstream.
CROSS DRAINAGE WORKS

Just downstream of the curtain wall, provide cement concrete (1:4:8) bed blocks 3" x 6" x 2" laid on 1" thick shingle filling underneath. The cement concrete blocks should be followed by loose protection of boulders laid in crungettes as explained in case of U/S bed protection. In case of large works, 20ft length of loose boulder protection generally suffices. In case of small works cement concrete blocks may be omitted.

Thickness of loose stone protection should be kept as explained in the case of U/S bed protection.

IMPERVIOUS FLOOR.

Provide adequate length of impervious floor and check the same against exit gradient. The safe value of exit gradient for alluvial permeable soil should be taken as 1:3.

THICKNESS OF FLOOR.

Determine the thickness of floor for the maximum uplift pressure, caused at any point under the maximum pressure head available. In case of a supergassage maximum pressure head may be determined under the highest flood conditions, while for a synclise or an Aqueduct, the maximum pressure head will occur when the canal runs. Full supply and the terrain is dry.

Assume Hydraulic Gradient 1 in 4 for well compacted clay soils and 1 in 5 for uncompacted normal good soils and work out pressure head at various points along the profile of the floor.

Take effective pressure head equal to 5% of the pressure head available at a point in case of lined channels and 75% for unlined channels.

Determine thickness of floor at any point by dividing the effective pressure head so obtained by G - 1, where G is the specific gravity of the material used for the construction of the floor and add 0.23 to the thickness of floor obtained to allow for wearing etc. For large works keep minimum thickness of floor = 1.65" i.e. one ft concrete and 0.85" pucca
Just downstream of the curtain wall, provide cement concrete (1:4:8) bed blocks 3" x 4" x 2" laid on 1. 0" thick shingle filling underneath. The cement concrete blocks should be followed by loose protection of boulders laid in trusses as explained in case of U/S bed protection. In case of large works, 20 ft length of loose boulder protection generally suffices. In case of small works cement concrete blocks may be omitted.

Thickness of loose stone protection should be kept as explained in the case of U/S bed protection.

IMPEVIOUS FLOOR.

Provide adequate length of impervious floor and check the same against exit gradient. The safe value of exit gradient for alluvial permeable soil should be taken as .3.

THICKNESS OF FLOOR.

Determine the thickness of floor for the maximum uplift pressure, caused at any point under the maximum pressure head available. In case of a superpassage, maximum pressure head may be determined under the Highest Flood conditions, while for a syphon or an Aqueduct, the maximum pressure head will occur when the canal runs, Full supply and the torrent is dry.

Assume Hydraulic Gradient 1 in 4 for well compacted clay soils and 1 in 5 for uncompacted normal good soils and work out pressure head at various points along the profile of the floor.

Take effective pressure head equal to 6 % of the pressure head available at a point in case of lined channels and 75% for unlined channels.

Determine thickness of floor at any point by dividing the effective pressure head so obtained by G - 1, where G is the specific gravity of the material used for the construction of the floor and add 0.25" to the thickness of floor obtained to allow for wearing etc. For large works keep minimum thickness of floor = 1.65" i.e. one ft concrete and 0.85" pucca.
9.42—9.43 MANUAL OF IRRIGATION PRACTICE

Cement Masonry and for average or small works keep thickness of floor or as 1.4 ft., i.e. one foot concrete and 0.4 ft. paces masonry.

Note:—In cases where the pressure head available is very large, say 25 ft. or more it will be found un-economical to provide such a heavy thick floor. In such cases, other alternatives should be determined to reduce the thickness of floor of a Cross Drainage work to a reasonable limit.

On the Nangal Hydel Channel under such extraordinary circumstances R.C. Concrete lining 6" thick, 80 ft. to 90 ft. on the Upstream and Downstream sides of the cross drainage work has been provided in the canal to increase the length of the Hydraulic Gradient line and thus reduce the pressure head under the floor. Since the ordinary concrete lining 1 : 2 : 6 in canal has not been considered impervious therefore R.C. Concrete lining which is considered impervious has been provided to increase length of Hydraulic Gradient. All such works have stood quite safe so far.

9.43. The following example will make the above observations clear.

Floor Thickness and Exit Gradient—

Golconda Distributory U/S.

P. S. L. in the parent channel (Rajasthan Canal) = 675.48

Assuming 1 in 5 drop in the hydraulic gradient through the bank, the hydraulic gradient level at the breast wall,

\[
\frac{31 + 9.43 + 23.00 + 1.5}{50} = \frac{675.48}{5} = 667.67
\]

Bed Level (Floor) ... = 684.83
Therefore head of water acting = 2.84 ft.
Length of floor = 37.5 ft.
Assume a depth of curtain wall = 8.4 ft.
Assuming 2° inverted filter consisting of 10° concrete, block and 10° graded shingle—

d effective = 3.4 - 2.0 = 1.4 ft.

Therefore L = b/d
= 37.5/1.4
= 26.8

\[ L = \frac{1 + \sqrt{1 + 4\lambda^2}}{2} \]

\[ \lambda = \frac{1 + L}{2} \]

Approximately,

\[ \text{i.e.,} \quad 27.8/2 \quad = 13.9 \]

New GE = 2.84

\[ \alpha = 0.177 \quad \text{which is} \quad \alpha \]

Hence safe.

U/S Curtain wall:—
Assume 4:6 depth of curtain wall.

Therefore \[ \frac{1}{\alpha} = 4 \]

[\[ \psi_c_1 = 100 - 29.0 = 71.0 \% \]
[\[ \psi_d_t = 100 - 29.0 = 70.0 \% \]
[\[ \psi_c_1 - \psi_d_t = 9.0 \% \]

Correction for floor thickness—

\[ = \frac{9.0 \times 3.4}{4} \quad = 6.75 \% \]

Corrected \[ \psi_c = 71.0 + 6.75 \quad = 77.75 \% \]
D/S curtain walls—

1/D = \(\frac{3.4}{37.5} = 0.091\)

\(\phi/E = 26.7\ %\)

\(\phi \ D = 18.5\ %\)

\(\phi \ E = 8.2\ %\)

Correction for floor thickness—

\(\text{Corrected } \phi \ E = 26.7 - 3.62 = 23.08\%\)

Say = 23.1\%

H. G. L. U/S = \(664.83 + 2.84 \times 77.75\ %\) = 667.03

H. G. L. D/S = \(664.83 + 2.80 \times 23.1\%\) = 665.34

Proposed head U/S = 667.03 - 660.86 = 6.17 ft.

Now providing 3’0’ thick floor, which will take pressure head = 3 \times 1.16 = 3.48

Therefore balance head = 2.69’ = 168 lb. per sq. ft.

B. M. = \(\frac{168 \times 7^{2}}{12} = 8250\) lb. inches,

\(f = \frac{M/Z}{12} = 12 \times 36^{2} = 2 \times 36^{2}\)

Therefore \(f = \frac{8250}{2 \times 36^{2}} = 3.18\) lbs/sq. inches.

\(\phi = 20\) lb/sq. inches.

Hence safe.

This 3’0’ will be taken up to 18’0” and 2’0”, for the next 10’ and 1’0”, for the rest.
Therefore \( \lambda = \frac{1}{2} \cdot \frac{5}{3} = \frac{5}{6} \), which is < 0.8.

\[ \text{Length of line} = 674.48 - 668.88 = 5.6 \text{ ft} \]

Provide 3 ft deep curtain wall and deduct 2 ft for the depth of trench fill.

\[ \text{Effective depth} = 179.39 + 6 + 5.49 = 190.87 \text{ ft} \]
H. G. Ls. and floor thickness.

U/S curtain walls:
Assume 5'0 deep curtain wall—

\[
\begin{align*}
1/L &= 5'0/54'02 = 0.0927 \\
\phi C_1 &= 100 - 37'0 = 73\% \\
\phi D_1 &= 103 - 18'7 = 81.3\% \\
\phi D_2 - \phi C_1 &= 8'3\% \\
\end{align*}
\]

Correction for floor thickness

\[
8.3 \times 4 \div 3'0 = 8'65
\]

Therefore corrected \( \phi C_1 \)

\[
73 + 8'65 = 79.68\%
\]

D/S Curtain walls:

\[
\begin{align*}
1/L &= 3'9 \div 54'20 = 0.0723 \\
\phi E &= 24\% \\
\phi D &= 16.75\% \\
\phi E - \phi D &= 24 - 16.75 = 7.25\% \\
\end{align*}
\]

Correction for floor thickness

\[
7.25 \times 1.5 \div 3'9 = 2'79
\]

Therefore corrected \( \phi E \)

\[
24'0 - 2'79 = 21'21\%
\]

H. G. L. U/S

\[
663.36 + 5'61 \times 79'65 \% = 667.83
\]

H. G. L. D/S

\[
663.36 + 5'51 \times 21'21 \% = 664.55
\]

Proposed head at the U/S end of the curtain walls

\[
667.83 - 667'04 = 10'79
\]

Provide 4'0' concrete, proposed head equivalent

\[
4'64'
\]
Therefore balance = 6'15 ft. of water = 384 lbs. Say

\[
\text{Bending moment} = \frac{390 \times 7^2 \times 12}{12} = 19100 \text{ in lb}
\]

\[
\text{Therefore } t = \frac{M}{x}
\]

\[
\text{Therefore } x = \frac{bd^2}{6} = \frac{12 \times 48^2}{6} = 19100
\]

\[
= 2 \times 48^2 = 415 \text{ Lbs./sq. in ches.}
\]

\[
\angle \leq 20 \text{ lb.}
\]

\[
\text{Hence safe.}
\]

At 17'-0' from the U,S, curtain walls—

\[
\text{H. G. L.} = 654.55 + \frac{3.28 \times 37.02}{54.02} = 666.79
\]

\[
\text{Floor level} = 657.04
\]

Therefore proposed head = 9'75

Proposed head equivalent for 4' concrete = 4'64

Therefore balance = 5'11 ft. of water = 319 lbs. say 320 lbs.

\[
\text{Span at 17'-0'} = 7 + \frac{25 \times 17}{62.5} = 15'6''
\]

\[
\text{say 14'0''}
\]

\[
\text{Bending moment} = \frac{320 \times 14^2 \times 12}{12} = 62700 \text{ inch lbs.}
\]
\[ \text{Stress } f = \frac{M}{2} \]

\[ = \frac{62700}{2 \times 48^2} = 13.66 \text{ lbs/sq. inches.} \]

\[ \angle 20 \text{ lbs/sq. inches.} \]

Hence safe.

At 5.42 ft. from the DJS curtain walls:

\[ \text{H. G. L.} = \frac{664.55 + \frac{228 \times 5.42}{540}}{2} \]

\[ = 664.55 + 0.33 = 664.88 \text{ say} \]

Floor level = 663.36

Therefore proposed head = 1:52

Therefore floor thickness = 1:52/1:16 = 1:31

say = 1:57

The above assumption of assuming the floor as ratta is valid in view of the concrete laid and placed and flared out wall constructed on it.

2. There is possibility of water standing over the cistern making it over safe.
CHAPTER 10
OUTLETS

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CHAPTER 10

OUTLETS

INTRODUCTION

10.01. An outlet may be defined as a device at the head of a watercourse which connects it with a distributing channel. In America it is termed a "turn-out." Its importance lies in the fact that while the distributing channel is under the management and control of Government, or a public organisation in charge of a canal system, the internal working on a watercourse is, in general, managed by the cultivator or cultivators whose lands are irrigated by the watercourse. This device, therefore, must be such that it not only passes a known and constant quantity of water, but must essentially be a measure of the discharge.

10.02. As long ago as 1906, Mr. Kennedy in Irrigation Branch Paper No. 12 (published in Edinburgh) noted the following main desiderata for the design of an outlet:

- "(a) To keep the discharge automatically constant as adjusted, and indicated, however much (within working limits) the water levels may vary in the distributory channel, or in the water course, or in both at once.
- (b) To allow of slight variations in the discharges as adjusted, so as to avoid the need of constantly removing and replacing the outlet, whenever the discharge must be somewhat altered.
- (c) To work with low 'heads' as well as high-down to three inches or so.
- (d) To be free from derangement by silt or weeds.
- (e) To be light, portable, easily removed and replaced elsewhere.
- (f) To be cheap and durable, with no complicated mechanism.
- (g) To be all closed in and immune from outside interference or derangement in working.
- (h) To be capable of being opened or closed off entirely by the cultivators from outside.
- (i) To indicate from outside when the working head is insufficient to give the full discharge, and, therefore, also the necessity for clearance of the watercourse.
- (j) If so desired and adjusted, to work as a module, only within certain limits of level in the feeder; above and below these limits to give proportionately increased or decreased discharges.

*This chapter is essentially an abstract of Punjab Engineering Congress Paper No. 264—1944.
10.03 Manual of Irrigation Practice

(This is with special reference to farmer’s canals, where each man is entitled to a proportion of the whole available supply).

(k) Floods in the distributary to be passed off by increased discharges through the outlets, so as to avoid damage.

(l) When the distributary supply is very low and inadequate, it will be more or less proportionally distributed to all outlets, those with very high command not being allowed to draw off all the water there is.

(m) Discharges to be provided for may be anything between half and four cusecs, with possible duplication above the latter figure."

10.03. It will be realized that it is impossible to obtain all the conditions detailed above in one type. The following conditions, however, must necessarily be complied with by any device of this nature:

(a) An outlet must be strong and should not have moving parts liable to derangement or requiring periodic attention.

(b) Interference by the cultivator must be difficult, and, if made, should be readily detectable.

(c) The outlet should draw its fair share of the silt carried by the parent channel.

(d) If possible for the outlet to work efficiently with a small working head. The larger the working head the higher the water level required in the parent channel and the higher the cost of the distributary system.

(e) The cost should not be high.

10.04. Outlets may be divided into three classes:

(a) Modular outlets or modules are those outlets whose discharge is independent of the water levels in the distributary and the watercourse within reasonable working limits.

(b) Semi-modular outlets or semi-modules are those outlets whose discharge, although depending on the water levels in the parent channel, is independent of the water levels in the watercourse, so long as the minimum working head required for the working of the semi-module is available.

(c) Non-modular outlets are those outlets whose discharge is a function of the difference in levels between the water surface in the distributing channels and the watercourse. Variations in either affect the discharge.
10.05. The following are some of the important terms used in connection with the working of outlets:

**Flexibility**—The property of an outlet to vary its discharge with the change in the discharge of the distributing channel is studied by calculating its flexibility.

Flexibility (F) is defined as the ratio, the rate of change of discharge of the outlet bears to the rate of change of the discharge of the channel.

\[ F = \frac{dq/q}{dq/Q} \]

Sensitivity (S) is the ratio that the rate of change of discharge of an outlet bears to the rate of change in level of the distributory water surface referred to the normal depth of the channel. Thus sensitivity

\[ S = \frac{dq/q}{dH/D} \]

The sensitivity of a module is zero. The larger the variation in the discharge of a particular outlet for the same rise or fall in the water level, the higher its sensitivity. It can be shown that normally S > 3F/3.

**Sensitivity**—Sensitivity (to be distinguished from sensitivity, defined above) is the fractional increase (or decrease) of outlet supply per 0.1 rise (or fall) in channel surface. This can be easily derived from sensitivity by dividing S by 10D which gives sensitivity.

\[ S = \frac{S}{10D} = \frac{F}{6D} \]

**Efficiency**—The minimum working head necessary for an adequate working of the outlet is a measure of its efficiency. The efficiency of an outlet may be defined as the ratio of the head recovered to the head put in. The smaller the working head required for the outlet, the greater is its efficiency.

**Minimum modular head ratio**—This is defined as the ratio between the minimum modular head and the depth of water in the channel over the crest of the outlet.

**Some Important Types of Outlets.**

10.11. Apart from a cut in the bank of a distributory the simplest and the oldest known type of outlet is a pipe outlet. To start with, it was an earthenware pipe (colaba) placed in the bank of the distributory at bed level. Later on, it was provided with face and tail walls of masonry and embedded in concrete. The earthenware pipes were gradually replaced by rectangular, wooden and masonry barrels. The steel or cast iron pipe was brought into the field at a subsequent stage and the Hume pipe is the most recent addition.
The discharge of a pipe or barrel outlet is given by the formula:

\[ q = C \times A \times \sqrt{2gH} \]

If the outlet has a free fall, \( H \) is measured from the centre of the pipe or barrel to the full supply level in the distributary (\( H_0 \)). If it is drowned, i.e., discharge into a watercourse in which the water level is above the top of the barrel, then \( H \) is the difference in the water level in the watercourse and the distributary (\( H_w \)).

If the outlet has a free fall, the discharge through it is independent of the water level in the watercourse and under these conditions, it is semi-modular.

10.12. In this type of outlet a pipe from the distributary leads into a cistern or 2 or 3 ft. square, at the other end of which is fixed a cast iron or stone orifice of the correct dimensions required for the authorized discharge of the outlet. While the pipe is fixed at bed level, the orifice can be fixed at a higher level to ensure semi-modularity, if obtainable. If, however, the orifice is submerged it functions in the same manner as the non-modular pipe outlet.

The main advantages in the use of this type are the ease in adjustability, low cost, and a constant co-efficient of discharge.

10.13. The open flume outlet is simply a smooth weir with a throat constructed sufficiently to ensure a velocity above the critical and long enough to ensure that the controlling section remains with in the parallel throat at all discharges up to the maximum. A gradually expanding flume is provided at the outlet to obtain the maximum recovery of head. The entire work is built in brick masonry, but the controlling section is generally provided with cast iron or steel bed and check plates. There are various forms of the open flume outlet which differ from each other only in details. For further particulars of the various types reference may be made to Punjab Engineering Congress Paper No. 264.

The discharge of an open flume outlet is given by the formula:

\[ q = KB_0 \times C^{1/2} \]

As the width of the open flume outlet is comparatively small the value of the co-efficient \( K \) is assumed to be less than the theoretical value 3.09 on account of additional frictional losses in narrow flumes. The co-efficient remains constant for varying heads over the crest so long as the minimum modular head required is available. A visual test of the outlet taking its authorized discharge under full supply conditions is provided by the presence of a standing wave below the outlet. So long as a steady standing wave forms, the discharge through the outlet is independent of the water levels in the watercourse.

For \( B_0 \) of 0.2' to 0.3':

\[ K = 2.90 \]

For \( B_0 \) of 0.3' to 0.4':

\[ K = 2.95 \]

For \( B_0 \) more than 0.4':

\[ K = 3.0 \]

In practice \( B_0 \) is never kept less than 0.2'.
Adjustability can only be secured by dismantling one side wall and either raising or lowering the crest, or by reducing or increasing the width of the flume by rebuilding the side wall at the required distance. In other words an adjustment means practically a reconstruction.

Proportionality (F = 1) can be secured by keeping the crest of the outlet at 0.9 of the depth of the channel. If the cill is kept higher than this, the outlet becomes more flexible, i.e., hyper-proportional, and if lower, it tends towards rigidity. With a fall in the F. S. level, the flexibility would increase and with a rise in the water level it would decrease.

It may be taken as axiomatic that the higher the crest of the outlet compared with the bed level of the distributary, the less is its lift drawing capacity. In practice, the width of the outlet is limited to a minimum of 0.2 ft. and, as such, it often becomes necessary to raise the crest of the outlet much above the bed level. The table below gives the minimum discharges for which an open flume outlet can be designed at bed level of the distributary for varying full supply depths. (B = 0.2', K = 2.90)

<table>
<thead>
<tr>
<th>D (ft)</th>
<th>1.0'</th>
<th>1.5'</th>
<th>2.0'</th>
<th>2.5'</th>
<th>3.0'</th>
<th>3.5'</th>
<th>4.0'</th>
</tr>
</thead>
<tbody>
<tr>
<td>q (cfs)</td>
<td>0.58'</td>
<td>1.07'</td>
<td>1.64'</td>
<td>2.29'</td>
<td>3.01</td>
<td>3.80</td>
<td>4.64</td>
</tr>
</tbody>
</table>

From the above, it will be apparent that except for small channels it is seldom possible to place the crest of an open flume outlet at bed level of the channel.

The working head required in an open flume outlet with a 1 in 5 gliss and side walls spaying at 1 in 5 is 20 per cent of the depth of water above the crest of the outlet. Further, as it is perfectly possible to construct the crest of the outlet high, these outlets can work with just a fraction of the head on the outlets. This is their chief merit.

This type of outlet is most suited to:

(a) tail clusters,
(b) proportional distributors.

At tail clusters, they are useful in distributing the supply proportionately and in easily absorbing any excess that reaches the tail. The low working head required also avoids undue raising of the F. S. level in the channel.

As a proportional distributor, the open flume affords an opportunity of inserting a control point with a minimum loss of head. The cills of all the off takes are pitched at the same level and proportionality secured by adjusting the widths of the off takes. Generally the cill level is kept such that the weir
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crest extends right across the distributary channel, to reduce the working head and also to reduce the action below the work.

Experience has proved that a design of this nature does not cause silting above the work, except when low supplies are run for considerable periods. Such silt as may be deposited under these conditions is swept away soon during high supply.

Another advantage of this type of design is that the water surface at the control point is relatively steady during small fluctuation in supply.

The main disadvantage is that in many cases the open flume outlet is either deep and narrow in which case it is easily blocked or is shallow and wide, in which case it is hyper-proportional and also fails to draw its fair share of silt.

To overcome the defect of a high flexibility, a roof block corresponding to the plate in the Stoddard-Harvey outlet is sometimes fitted in the gullet of an open flume. This device enables the open flume to start working as an orifice, as soon as the roof block comes into action. The most suitable position and shape of the roof block is under determination. The latest orders on the subject are to fix the roof block such that its upstream face is at a distance of G seven the parallel throat from the crest, its bottom to be at a height of 0.7G above crest and its upstream bottom corner rounded to a radius of 11' 6.

10.14. An orifice semi-module consists essentially of an orifice provided with a gradually expanding flume on the downstream side. The critical velocity is exceeded in the orifice and the discharge is thus independent of the water levels in the watercourse. The type most commonly adopted is the one evolved by Mr. Crump.

"Structurally, it may be regarded as a long throated flume with a roof block, capable of vertical adjustment, introduced into the upstream and of the parallel throat. With the roof block removed the O.S.M. differs from the flume module only in regard to the length of the throat. It belongs, however, to the orifice type of flexible module and may be regarded, from this point of view, as a modification of the Harvey-Stoddard (Original) outlet." The upstream and downstream approaches of the O.S.M. are not much different from those of open flume outlet.

Modularity in an O.S.M. is ensured by the formation of a standing wave, and so long as the wave is steady and remains clear of the exit of the orifice the discharge co-efficient does not alter. The roof block is so shaped that the jet is made to fill the exit of the orifice and jet contraction is suppressed. Also by extending the parallel throat to a distance H below the exit, curvature
of the jet is avoided, thereby ensuring a uniform velocity distribution over the section of the jet. Thus discharge is dependent on $VH^{1.5}$ and the discharge formula is given by $q = 7.3B \cdot Y^2 \cdot H$.

Adjustability is secured by raising or lowering the roof block. This is fixed by a couple of bolts which in turn are secured from tampering by a masonry key. This key can be broken out, the roof block adjusted and the key rebuilt with in a few hours at the cost of a few rupees without injury to the rest of the work. This is one of the important advantages that this form of outlet has over the open flume.

The flexibility of this outlet depends just like the pipe outlet on the relation of $H_y$ to $D$. Proportionality is secured when the bottom of the roof block is submerged below the full supply level by 3/10 of the depth of water in the channel.

Mr. Crump's design aimed at keeping $H - Y$ thus fixing the crest at a setting of 6/10 of the depth. Thus his design aimed at exact proportionality and that is why called Adjusted Proportional Module (A.P.M.).

As experience was gained of the working of Mr. Crump's A.P.M. (the term A.P.M. should be applied only to Mr. Crump's original design with crest at 6/10 setting), it was found that channels fitted with A.P.M. silted up badly. The same device, therefore, was used with the crest lowered to 9/10 h setting, at bed level or even below it to improve the silt draw.

As already stated this type of outlet is instantaneously proportional when the bottom of the roof is built at 6/3 of the distributable channel F.S. depth. With a rise in the F.S. level the flexibility which is equal to 3/10, $D/G$ is reduced and the outlet becomes sub-proportional. Similarly, with a fall in the F.S. level the flexibility is increased and the outlet becomes hyper-proportional.

When the outlet is set near bed level, with a rise in the F.S. level the value of $D/G$ is reduced and the outlet tends to move further from proportionality in the direction of rigidity. A fall in the F.S. level similarly increases the flexibility and the outlet moves towards proportionality.

With the outlet set at bed level, the flexibility remains constant at 3/10.

When it is set near the bed, it is one of the best forms of outlets to adopt except at tails which have to work as safety valves in case of any temporary excess and at control points where heading up may be required frequently.

The MMH required for an O.S.M. as given by the formula*

$$MMH = 0.82 \frac{H - B}{2}$$

has been found, in practice, to be accurate for values of $B$, up to 0.4' and for

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value of G as required in practice. The simpler formula \( MDH = 0.75 \) H, is also fairly approximate.

10.15. It has been stated above that it is not possible to place the crest of the open flume outlet at or near bed level on account of the undesirability for practical reasons of constructing open flumes with \( B \) less than 0.2. Similarly, on account of the limitations imposed by the available working head it is not possible to place the crest of O.S.M. outlets at or near bed level. Both the types are frequently so designed that their crest level is considerably above the bed of the channel. This is particularly true in the case of large distributaries.

With a high sitting it is not possible for these semi-modules to take their fair share of the sill charge in the distributary. As such, various devices have been put forward in the past to enable these outlets to draw more silt than they normally do. The Bend outlet of Khan Bahadur Sheikh Minhaj-ud-Din, the sill extracting S.M.M.O. of Mr. Haigh, and the nozzle outlet of Mr. Guan which were attempts in this direction are described in the Punjab Engineering Congress Paper No. 264.

10.16. The Scratchley type described in paragraph 10.12 of this chapter Pipe-Cum-Semi-Module, with its orifice working free fall is the simplest type among the pipe-cum-semi-modules. If the orifice does not work free fall, it can be replaced by a semi-module, i.e., an open flume or an A.O.S.M., which would require comparatively less working head for modularity.

At its upstream end the pipe-cum-semi-module comprises a pipe taking off from a channel and opening into a tank about 3 feet square on the other side of the bank. In the downstream WALL of the tank is fitted a semi-module which may be a pipe working free fall, an open flume with its crest at any suitable level, or an A.O.S.M. set anywhere above, at or below the bed level of the distributary.

The discharge of the outlet will be equal to the discharge of the semi-module fixed at its lower end. But the head for calculating the discharge should be measured from the water level in the cistern below the pipe. There is bound to be some loss of head through the pipe, but the size of the pipe or barrel can be made sufficiently large to reduce this loss of head to a bare minimum subject, of course, to such a velocity in the barrel as is enough to pick up the silt from the bed of the distributary.

With regard to silt drawing capacity, this outlet has a great advantage over other devices. By placing the upstream end of the pipe below bed level, at bed level or at any height above the bed level, complete control can be obtained over the silt induction by the outlet, at the expense of loss of head in the pipe which can generally be reduced to about 0.1' for most cases. In the case of deep channels the pipe can be placed slanting w.h its upstream
end at or below the bed level of the distributary as required, at a slope of about 1 in 12. The tank downstream of the pipe need not thus be built deeper than necessary for the design head over the semi-module. As the silt induction into the outlet depends only on the position of the inner end of the pipe with respect to the bed, the crest of the outlet can be placed at any level so that the loss in head through the pipe can be more than counterbalanced by a possible higher setting of the outlet.

This device thus gives a considerable range of flexibility. The position of the barrel does not affect either the discharge or the proportionality and the barrel can be raised or lowered depending on the requirements of the silt draw.

The other advantages possessed by this type are:

(a) A high degree of immunity from interference due to the certainty of early detection.
(b) Large range of modularity.
(c) Low consumption of head particularly with an open flume.
(d) Cleanness when built in wide tanks.
(e) Ease of adjustment even with the channel running.

This type of outlet can be used with advantage for outlets which work in Kharif only and not in rabi. The pipe can be placed with its bed above the rabi full supply level and since the head over the crest is to be measured in the tank, the design of the outlet is simple enough. No water will get into the tank until the water level in the distributary rises above the rabi full supply level.

10.17. As already defined, a module is a device, through which only a fixed quantity of water will be passed (within working limits) irrespective of the changes in the water level on the supply or the delivery side.

Modules are of two kinds: one having moving parts and the other without moving parts. The former are generally expensive and not simple to design and construct. They are liable to disarrangement on account of silt and weeds in flowing water and on account of rusting of moving parts. As such they have little practical value for use on large irrigation works.

Of the modules without moving parts the following are the important types:

(a) Gibb's module.
(b) Khanna's rigid O.S.M.
(c) Glaister's rigid flume module.
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The Gifford's module has been tried and found to be successful in many respects and the other two types are still in an experimental stage. For a detailed description of these three types reference may be made to the Punjab Engineering Congress Paper No. 254.

10.18. Apart from the Dethridge meter no self-contained volume measuring device has been evolved so far. A description of the Dethridge meter and other possible means of measuring the volume of water supplied through an outlet will be found in the Punjab Engineering Congress Paper already referred to.

ESSENTIAL CONDITIONS FOR SELECTING OUTLET TYPES

10.21. The supply levels in a distributing channel vary considerably for various reasons. There may be variations in the discharge run on account of varying demand or there may be changes in slope due to seasonal variations or due to faulty design. Again frequent closing and opening of channels on account of rotational running creates additional problems. The outlet requirements for these varying conditions may be indicated briefly as below:

(a) Temporary variations in discharge require proportionate outlets to deal with the excess or distribute the deficiency.

The needs of reclamation require the use of outlets of low flexibility so that outlets other than those in which additional supply is to be passed do not take any discharge above their authorised capacity.

(b) Seasonal variations in slope require the use of outlets of low flexibility. This would apply more to the tail reaches of channels where the F.S. level is appreciably affected by local soil movements.

(c) Faulty design can be corrected only in part by the use of outlets of zero or low flexibility. This should not, however, be taken as indicating a method of avoiding the necessity for remodeling. Considerations of faulty design should be ruled out when deciding upon the type of outlets to be employed. The problem can only be solved by intelligent design and to drag the consideration in, when selecting out types, renders intelligent selection impossible.

(d) Rotational running indicates the use of outlets of high flexibility at the head reach of a channel. This is opposed, however to (b) and (c) above.
10.22. The difficulties created by the periodic or permanent changes in slopes from any reason whatsoever can be eliminated to a large extent by the introduction of control points in a distributing channel. A control point (already referred to in paragraph 8.435) is so designed that the water surface level above it bears a fixed relation to the discharge passing. This level is independent of the varying silt charge in the channel and of any faults that may exist in the design of the section or slope of the channel. It varies only with the discharge and so long as the authorised discharge is passing the water level immediately above the control point (in practice up to about 1,000 feet, upstream) is the same as designed. Thus those outlets which are fixed within a short distance of the control points will pass their authorised discharges even if the silt charge varies or the design of the channel is faulty. And if the outlet is designed as an O.P. with its crest at the same level as the crest of the control point, proportionality can also be secured.

A control point can only be constructed at the loss of some head in the distributing channel. When ever a fall is otherwise necessary, it should be so designed that it works as a control point. Control points can be introduced in an existing channel by raising the water levels upstream provided the command from the parent channel is not reduced to such an extent that the distributary is unable to take its due share of the supply.

The larger the number of control points on a channel, the more efficient is its working. A warning is necessary, however, that control points should not be introduced by flattening the slopes in the distributing channel as this would induce silt trouble and consequent silting below the control points which may render them non-modular. A minimum drop of 9° may generally be regarded as essential for the efficient working of a control point.

Where control points cannot be introduced, it is necessary to design outlets in such a manner that they are least affected by temporary or permanent changes in the regime of channels.

10.23. In paragraph 10.03(c), it has been stated that one of the essential conditions to be satisfied by an outlet is that it must draw its fair share of the silt carried by the parent channel. It may be remembered that water is continually percolating through the wetted perimeter in the entire length of the distributary. The steady reduction of the total discharge on this account is not accompanied by a proportional removal of the silt charge with the result that on a distributary the silt load, if it does not deposit in the head reach, actually increases as the water progresses further down the system, unless the outlets in the head reach are so designed that they draw a large proportion of the silt charge in the channel. In a distributary system the absorption generally varies from 10 to 15 per cent. The silt charge in the water so lost must be removed by the off-taking outlet. In other words if the silt charge in a channel is 100 per cent, the off-taking outlet
power of the outlets should be 110 per cent to 115 per cent. to enable them to draw their share of the silt charge.

The silt draw in an outlet depends on the following factors.

(a) Position of entrance relative to the silted bed.
(b) Shape of entrance.
(c) Velocity through the outlet near its upstream end.
(d) Inclination of the pipe in the case of a pipe outlet.

No extensive observations have so far been carried out to determine the absolute or relative merits of the various types of outlets for silt conduction. Arbitrarily, the lower the setting of the outlet the better the silt draw off. There is a general belief however, that pipe outlets draw off more silt than any other type of outlet set at the same level.

A watercourse should be given only as much silt as it can carry depending on the slopes available in it and the low silt induction capacity on some outlets should be compensated for by giving more than their due share of silt to other outlets, where conditions of command permit, this being done.

When it is not possible to dispose of all the silt brought into a channel through its outlets on account of constantly poor command on most of the outlets the only solution is to raise the full supply level in the channel or alternatively to provide a silt selective head so that the total quantity of silt entering the channel is reduced.

Attention is here invited to paragraph 10.16 in which a description of the pipe-sum-semi-module is given. This useful device offers complete control over the silt induction of outlets.

10.24. Without entering into the details of this controversy it may be stated here that experience has shown that proportional distribution of supplies by outlets is neither necessary nor feasible. Proportional distribution is necessary among the different channels of a distributary system but its application to outlets creates serious difficulties in the working of the system. The requirements of the cultivator do not make it necessary to adopt this method of distribution except on some channels where the conditions of supply are peculiar (See paragraph 10.41). On all other channels rigidity should be aimed at.

10.25. Every semi-module requires a minimum working head, and if it is not available the outlet cannot draw its authorised discharge.

The minimum modular head required for an outlet is generally a function of the setting of the outlet, and as it is necessary to set the outlet with its
OUTLETS

10.31. The use of a module is limited to direct outlets on a branch
channel subject to variations in supply, or above stop dams where
heading up of supplies is necessary for feeding other channels,
or for some special reasons where no fluctuation in the discharge of an
outlet is to be permitted. On a distributory system the number of modules
should not exceed a small percentage of the total, as by their very nature
modules cannot absorb any fluctuations in the parent channel, and thus the
cannels would be either flooded or would run dry in the tail reach.

10.32. Semi-modules, if properly designed, can be made to distribute
more or less equitably variations in the supply of distributory.
If, however, the discharge in a distributory does not alter, but
there is a change in the water level due to siltage, the semi-modules in the head
reach draw a bigger share of the discharge and the tails run short. The
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design of semi-modules, therefore, should be such that they are least affected by changes in the regime of the channel.

On account of the immunity from variations in discharge with varying water levels in the watercourses the semi-modules are the best class of outlets to be used in practice.

10.33. Non-modal outlets should be avoided as far as possible.

Non-modal outlets are justified only when the working head available or the discharge of the outlet is so small that a semi-modal outlet cannot be designed.

The use of non-modal outlets (pipe-outlets) is indicated for all temporary outlets and for outlets on a new canal system in the first instance.

10.34. At present Gibb's module is the only module about which sufficient information exists to enable a proper design to be worked out. The module is, however, liable to tampering and special safeguards are necessary to prevent this. The other two devices—Kishore's and Ghafour's modules—are also useful but further investigation of their working is required before they can be generally adopted.

10.35. The best non-modal outlet is the Scrutonley type which has, under working conditions, a constant co-efficient of discharge and tampering of which is easily detectable. The height of the office should be a full number of brick courses 3", 7½", etc., The width may be varied to suit the discharge. The sill and top of the office should be of stone or precast concrete blocks. The co-efficient for discharge should be 6.4 in the formula:

\[ q = 6.4A \sqrt{Hw} \]

10.36. Any type of the open flume or the O.S.M. may be used, and in the selection of the particular type for any situation, the following factors should be considered:

(a) Maximum rigidity possible with the working head available.
(b) Silt conduction.
(c) Immunity from tampering.
(d) Ease of adjustment.
(e) Cost.

The use of the open flume outlet should, as far as possible be restricted to reaches above control points. For all other situations the O.S.M. is a better type.

Where the bank section is heavy or it is necessary for proper silt conduction to draw off water from the distributary at a level lower than that of the crest, a pipe-out-semi-module is to be preferred.
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10.41. The supply available in these canals is so short in the critical growing and maturing periods that it has been found necessary to run these channels with, what is called, normal supply for certain important periods in the agricultural rotation. This normal supply is 85 per cent of the full supply. The design of outlets on these channels should, therefore, be such that they take their proper share of the discharge both at full supply and at normal supply, in other words, it is necessary to design the outlets on these systems as proportional outlets.

10.42. The following are the three types of proportional outlets which are suitable for use on these canals:

(a) An open flume outlet having its crest at 0.9D and having an available working head of not less than 0.4D will draw proportional discharge at both full and normal supply conditions in a channel.

(b) An O.S.M. with its H = 0.4D and an available working head of not less than 0.4D will draw proportional discharge at both full and normal supply conditions in a channel provided G does not exceed 0.69D.

(c) An O.S.M. with G = 0.75D and Y = H, will draw its due share of discharge at full and normal supply levels. In the latter case, it works as an open flume. The working head required in this case is also 0.4D.

10.43. It will be seen that a working head of 0.4D is required for the design of outlets with the required conditions. An examination of the available working heads of outlets on the Sutlej Valley Canal shows that whereas conditions very considerably a substantial number of outlets do not possess a working head of 0.4D. It will thus be recognized that whereas it is possible to design a large number of outlets such that they would work proportionally under both full and normal supply conditions the number of those that cannot be so designed is considerable.

10.44. For purposes of design, therefore, the outlets on a non-perennial distributary on the Sutlej Valley Canals may be classified as follows:

(a) Outlets that can be designed to work proportionally under both full and normal supply conditions. Such outlets must have an available working head of not less than 0.4D.
(b) Outlets that cannot be designed as class A, but have sufficient working head to be modular at full supply conditions. Such outlets are those that have a working head of 0.2D to 0.4D.

c) Outlets other than those included in class A and B. Such outlets have very poor command, i.e., less than 0.2D.

After the outlets of a distributary have been classified as above and before proceeding with the design of outlets, an attempt should be made as explained in paragraph 10.25 to see if any of the outlets classified B cannot be converted into class A or those classified C to class B or A. For successful distribution it is essential that the number of outlets of Classes B and C should be reduced to a minimum.

10.45. The type of outlets that should be adopted for each class is as follows:

(I) Class A.—For this class of outlet which can be designed to draw correct discharge at both normal and full supply conditions, the following type should be adopted:

(a) An open flume outlet with crest set at 0.9D, provided B, does not work out to less than 0.2\(^2\).

(b) If in (a) above B, works out to less than 0.2\(^2\), an O.S.M. set at 0.75D may be designed such that the value of H. ranges from 0.375 to 0.43 D.

(c) If an O.S.M. outlet as above cannot be designed for a particular discharge then an O.S.M. set at 0.69D may be designed satisfying the condition H. = 0.43D.

(II) Class B.—For this class of outlet, it is not possible at present, to arrange for proportional working at both full and normal supply conditions. The best type of outlets for this class would be either:

(a) an open flume with H equal to five times the working head available, or

(b) an O.S.M. outlet set at 0.75D with H, from 0.375D to 0.43D, whichever of the two would give a lower setting, so as to enable the outlet to draw some discharge at low supplies.

(c) In case the width B, of the open flume outlet works out to less than 0.2\(^2\) or it is not possible to design and O.S.M. according to (b) above for the particular discharge then the outlet should be designed as an O.S.M. with crest at 0.69D, provided it could work modularly under full supply conditions.

(III) Class C.—For this class of outlet which has a working head of less than 0.2D, it is not possible to design an outlet of the semi-modular type.
The only outlet possible is of the pipe or office type and the best type is the Scratchley outlet.

The working head H, to be adopted for purpose of design; of the outlet should be the average of working heads observed during the time of keen demand (1st to 15th September) for a period of 10 days. A fair proportion of those working heads should be personally checked by the Sub-Divisional Officer (by surprise visits, if possible).

10.46. When water level in a distributary rises above designed full outlet capacity the outlet draws a high percentage of excess. To guard against this, all open flume outlets whether of class A or B should be fitted with roof blocks.

10.47. The outlets proposed above will have a high setting and will not draw their due share of the silt charge in the distributary. To overcome this difficulty all outlets of class A and class B should be of the pipe-cum-semi-module type.

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CHAPTER 13

Embankments

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### 13.10 Embankments

Embarkments are usually not in irrigation practice for the following purposes:

(i) **River embankments**—Upstream of weirs or barrages for river control (called marginal banks) and/or for flood protection.

(ii) **Shanks of armoured spurs**—In certain cases fairly long shanks have to be provided for "T" head or other similar types of spurs.

(iii) **Limiting embankments of silting tanks.**

The considerations which enter into the design, construction, consolidation and maintenance of all these types of embankments are very nearly the same. River embankments are dealt with in the following paragraphs. The special considerations regarding limiting embankments of silting tanks are briefly mentioned in Chapter 16, paragraphs 15.41 to 15.44.
13.11 A river embankment should—

**Essential requirements**

(a) be high enough to prevent its being overtopped by an extreme flood, i.e. it should have enough free board,

(b) have a thoroughly consolidated section sufficiently wide to prevent water percolating through it and causing it to slip,

(c) have a width of base able to support the superstructure, and to prevent creep, and

(d) have its slopes protected against guttering by rain and erosion by wind and wave-lap.

13.12 In the interest of safety consistent with economy, the embankment should be aligned on the highest land available but care should be taken not to traverse ground which is impregnated with salts, much cracked, or intersected by numerous channels. The neighbourhood of villages should also be avoided, if possible, as their proximity generally means heavy trespass.

13.13 Embankment section depends upon the height of the bank, the nature of its material and foundation, and the way in which the embankment is to be formed. Of these, the last named is the only condition which can be varied.

The top of the bank should be given a slight slope to facilitate drainage towards the land side, so as to diminish the tendency of the water side slope to gutter during rainfall.

The width of an embankment should be sufficient to permit of frequent inspections. Hence, even when 8' width would suffice from hydraulic considerations, 12' to 16' width should be provided to permit of inspection by car.

*Water side slope*—1:2 to 1:3.

*Land side slope*—1:2 or flatter, depending on the material; usually for banks composed of sand or sandy loam a hydraulic gradient of 1 in 4 to 1 in 5 is sufficient, while it may be 1 in 3 for banks composed of good clay.
An embankment is considered to be safe against a hydraulic gradient, if the hydraulic gradient line is covered by about 2 feet depending on the nature of the material.

13.14 Free board is required as a measure of safety against overtopping, and to provide for any settlement which may occur. A free board of 5' for river works is usually recommended.

13.15 The following forms of protection are recommended to be adopted where protection against erosion is deemed necessary. The type of protection to be used will depend on the extent and severity of water action.

(a) Pitching — Stone or brick.

(b) Pitchi, farash or sarbanda pitching or mattresses to protect against wave-lap.

(c) Kila spurs, at right angles to the embankment, consisting of two rows of kila, 2' apart centres, with brushwood filled in between to protect the embankment from damage by parallel flow.

Dimensions of aprons for armoured banks and spurs are given in chapter 6, "River training and control".

CONSTRUCTION.

13.21 Slips and leakages take place as a rule only at considerable intervals, and their occurrence is due either to bad foundations, bad material or insufficient compaction or to a combination of these defects. River embankments generally consist of inferior soil, and the more carefully is the soil compacted, the safer will the embankments be.

Specifications regarding earthwork in chapter 38th should be strictly followed. Where compaction is ordered, it should be in accordance with Chapter 38th.

13.22 As a rule the soil which exists close to the site of the embankment is used in order to avoid excessive lead, as otherwise the expense of construction will be greatly increased.

The most satisfactory embankments have been found to be made of sand, as sand is insoluble in water, is not affected by deliquescent salts, is exactly of the same character throughout,
and although it settles quickly when wetted, always sinks uniformly and never has a leakage plane. Moreover, rats can not burrow into it.

If the heating is of sand, the cover of good earth should always be given to protect it from being blown away by winds.

13.23 As far as possible borrow pits should not be excavated on the land side, as these they increase the infiltration head acting on the embankment by the extent of their depth, and tend to cause the embankment to leak. Nor should borrow pits be continuous, as otherwise they may lead to the formation of scour channels. Borrow-pits should be set out regularly so as to obtain the maximum amount of material from the area under excavation.

13.24 When sand is not available and the embankment has to be made of loam or sandy loam, wetting earth for it is advisable, if possible, to flood the borrow-pits area to be covered by the next day’s borrow-pits. The depth of flooding required so as to obtain the optimum moisture content in the depth of layer to be removed the next day will vary with the soil and can be easily ascertained by experiment and experience.

Sinking sand pumps for this purpose, or leading water even from long distances is well worth the trouble, owing to the better compaction possible and absence of clods in wet earth-work.

Settlement allowance as specified in Chapter 38.0 should invariably be given.

13.25 When neither sand for construction of the embankment nor water for wetting soil are

Rolling for consolidation available, a thorough consolidation in 6" of dry earth comprising layers must be done in the dry, whereby the embankment all clods of earth are crushed into intimate and regular contact with each other.

Ramming is not enough for crushing the clods completely which can be done effectively only by heavy rollers. Hence when an embankment is to be constructed of dry earth, each layer (which should be of the greatest length practicable) should be rolled, until all clods are flattened.

13.31 New river embankments whether made of sand or wet earth or of dry earth have to be watched during the first one or two years after construction as protection against breaches. An embankment made of bone-dry earth is very
susceptible to breaches due to its low dry bulk density and consequent settlement on wetting.

In reaches where river water is likely to touch the embankment, gangs for day and night watching should be engaged for patrolling the slopes, watching leakages and closing them as they appear.

At night the watchmen should carry lanterns with them.

13.32 An embankment which has come against water for the first time is likely to settle. Puddling the river slope. Special patrols should be employed to puddle the slope of such embankments. This will result in the slope flattening out. As the river drops, the embankment should be repaired to its proper top width.

Where it is possible to regulate the rise of water level (for example, in case of embankments upstream of headworks), it should be specially arranged well in advance of the flood season, in order to ensure proper staunching of the embankments. The rise of pond level should be restricted to about 3 ft a day after water has come in contact with the embankment and may be reduced to 0.5 ft per day as the highest flood level mark is approached. Pond level should be regulated by means of small gauges erected for the purpose at the dangerous sites.

MAINTENANCE.

13.41 Maintenance of embankments is carried on throughout the year, by gangs, the Maintenance by gangs strength of which will be different for the flood season and for the low supply season. The gang men have to watch the embankments and to prevent trespass. They should also do petty repairs, such as filling rat holes, making up hollows, repairing rain cuts, rooting out rank vegetation on the side slopes and for a distance of 2 feet from the toe of the embankment. They have also to look after plantations, etc., etc. As the river side slopes need protection from wave lap and the land side from gattering, grass growth on slopes is to be encouraged.

13.42 Special estimates are sanctioned to keep the embankment up to proper section and to increase it when considered necessary. Such work is done when ordered by competent authority.

13.43 Road crossings should be made 12 feet wide, and Road crossings with longitudinal ramp slopes up and down the embankment of not less than 1 in 6 for
cattle and in 20 for cart traffic. Where a cattle path or a road crosses at right angles, the ramp slope should start at least 10 feet from each of the core lines, to preserve the top width of bank from being reduced by traffic.

13 44 Where an embankment runs through an arid Protection areas, sunbaked tracts, grass will not grow on it, and wave action on its base will cause surface water to erode greatly from wave wash. To protect it, *pithi*, *farash* or *sarkanda* mattress as described in chapter 14 9 should be provided.

In reaches, where water is available and plantation would grow, *pithi*, *sarkanda*, *kibel* or willow should be planted for a width of about 100' in front of the toe of embankment as the existence of such plantations breaks the force of the waves.

Only grass should be allowed to grow on the side slope below high flood level on the river side.

Between high flood level and the top of the bank a line of shade trees should be planted.

On the land side slope a line of shade trees should be planted near the top and at the toe of the embankment, between these two lines of trees on y grass should be allowed to grow.

If jungle growth is permitted on the side slopes of an embankment it is impossible to trace leakages.

13 45 When an embankment has to be raised, the new earthwork should be built on the upstream or embankment river side of the embankment where it will be pressed on to the old bank by water pressure. The old slope should first be carefully “concaved” to receive the new earthwork.

13 46 Leaks should be stopped from the upstream side by cutting off the penetrating water at its source. If practicable, cracks should have good earth worked into them by chisel-pointed poles, but if the presence of water against the bank prevents this, the leakage should be stopped by a cover of good earth thrown over it. Subsequently in the dry season the defective part should be cut out and properly re-made.

Leakages have been closed by throwing sawdust, bran, powdered dung, etc., just upstream of them. The stuff is carried by water into the leaks, where it swells and stops the leaks.
When a breach takes place, it is invariably accompanied by deep scour at the breach site. The only possible method, therefore, of closing it is to make a ring bund, well outside the breach site. Earthwork is begun from both sides after selecting the alignment. A row of stakes intertwined with jungle, precedes the earthwork in order to prevent the latter from being washed away. Earth is deposited on the upstream side of the row stakes.

For closing the final gap in the ring bund, a sufficient number of sand filled bags along with sufficient quantity of earth is kept in reserve at both ends of the gap to enable the final closure to be done with a rush.

After the ring bund is completed, the gap in the embankment should be made up, with a wider top width and a higher top level to allow for subsequent settlement. The ring bund should preferably remain as additional protection.
CHAPTER 14

Induction Canal Heads

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CHAPTER 14

Inundation Canal Heads

14-0 Inundation canals do not have any weirs or barrages introduced across the river to control its supplier and feed the canals. These canals, therefore, obtain supplies from open cuts in the bank of the river or the creeks, which are called "heads". Whenever the river is high, these "heads" begin to flow and with long experience such a high technique has been developed that many "heads" remain in flow even during the winter season, when the river is low. The supply received in the heads is taken through a "supply channel" to the head regulator of the canal, where the discharge entering the canal is controlled and the balance escaped back into the river. This head regulator is usually a masonry work and is placed at a safe distance from the main river, so that it cannot be damaged by river action. Beyond the head regulator the inundation canal is very much the same as an ordinary non-perennial weir controlled canal. This chapter describes the various factors that enter into the selection of the site and the design of inundation canal heads only.

14-1 Inundation canals are more successful in those River behaviour reaches of a river where the variation in water-level is comparatively small. The extra cross section required for flood discharge is provided either by the spread of water over a wide bed or erosion of the deep channel. Such action can take place in alluvial reaches and the best example is that of the river Indus in Dera Ghazi Khan and Muzaffargarh Districts. The main river stream meanders considerably in its wide bed. Various theories have been put
forward regarding the cause of this meandering. One suggested by Claxton, an officer of great experience of Indus inundation canals is reproduced below:

'It is well known that alluvial rivers, bearing large loads of silt, carry them on, not in one sustained effort, but by a series of jumps, or by saltation. The loads have not travelled down continuously from the hills, but are moved along by the processes of sump and ero-ion. Of these two, erosion, the action at banks, distinct from sump action on the bed, is the more important. It gives heavy excess loads at various points, and causes the river to meander. In doing so it presents problems with which inundation canal practice has to deal.

One of the first principles lays down that silt eroded from a bank very soon deposits as a shoal on that side. Many engineers argue that it may be, and is, carried over to the other side. The argument is based on experiments on very narrow streams in which the whole surface slope is affected. This brings about a cross current which has the power of laterally deflecting particles. This is due to the surface slope, and in rivers is confined to the bank. The silt for the remaining width is entirely controlled by the strong forward current, across which nothing may pass. The writer does not appeal to laboratory experiments for his proofs, but has shown by a few examples in other papers that the principle is supported by large river movements, sometimes involving square miles of shoal. These shoals appear and melt away in step with erodions above them, and have the power of deflecting even the main stream. They all obey the one law which the writer has enunciated. He therefore considers it fully established. The theory is illustrated in the figure which is believed to be drawn strictly to principle.

In this diagram there is erosion from A to B on the right side. At A the stream comes into the bank, having deposited its load of silt on that side in the shoal above. The water at A is therefore clear. From A to B erosion is active, and the load of silt is consequently increasing. At B it has grown so great that the river is no longer able to carry it forward and
a shoal begins to form, diverting the stream across to C. From C the process, as at A, is repeated, only this time on the left side. The erosion from A to B is responsible for the shoal B C D E and the erosion from C to D for the next shoal on the left. 4.

Without expressing any opinions on the correctness or otherwise of this theory, it could be said that it does indicate the favourable points for inundation canal heads.

14:2 Obvious the site for the canal head should be that which is least likely to silt. Such favourable suitable sites for points would be just above A, C and E. The canal heads and, heads may with advantage be placed a little higher up in the creek which forms the outfall above one of these points. Creeks are preferred since they are usually more constant than the main stream being subject to mildest attacks. They also allow of the building of groynes or dams and thereby the real outfall may be carried higher up towards the head of the creek itself. Inundation canals invariably work upstream for better command and such canalising of river creeks is very useful. The creek selected should be of reasonable size. If it is too small, it will not give sufficient supply. If it is too big, it will be unsuitable and liable to erosion like the main stream. Besides it is very difficult and expensive to throw a groyne across it.

The best position for an inundation canal head is near the tail end of a creek, as the flow there has less silt and is less liable to changes; also if the creek silts up at its outfall, supplies can still be obtained from the river back water.

Whenver practicable, the main and subsidiary heads for a canal should be selected on different creeks, so that in case of failure of one creek, supplies can still be obtained from the other.

Whether the head is placed on the main stream or on a creek, it should be selected in a straight reach free from or silt upstream. If any chance of erosion is apprehended, a groyne suitably placed below the head will be a useful factor in keeping the canal head clear of silt.

14:3 A canal dependent on a single head can never be sure of supplies throughout the season, and in number of heads in the event of an accident to its head or supply channel, crops grown on it would fail to mature. Each canal is therefore provided with one or more subsidiary heads in
addition to the main head, so that there is always a source of supply to fall back upon.

14:31. Selection of heads is made after the floods are over and the river settles down to winter conditions. No violent changes in the course of the river take place thereafter and the conditions remain much the same till the next flood season.

Working of the existing canal heads and behaviour of the breeding creeks should be studied.

A reconnaissance of the river from some distance above the uppermost head down to the last head on the river should be carried out, and changes in the course of the river, as well as, of all its creeks marked on the previous year’s river survey plan.

Rough cross sections should be taken at the estuaries of important creeks and their approximate discharges noted. Particular notice should be taken of sites where erosion is already active or is likely to start. With this information it is generally possible to select suitable heads for the following year.

14:32. The heads and supply channels are liable to accidents during floods. Erosion may start just upstream of a head and silt it up. Prolonged heading up at the head regulator may silt up the supply channel, or changes in the course of the river may sever it.

14:33 To guard against such accidents, each canal is provided with a main head and one or more subsidiary heads, but supplies should be obtained through one head at a time.

It is not a good practice to have more than one head working during the flood season as with such an arrangement heavy excess is obtained during floods, which is difficult to dispose of and prolonged heading up at the head regulator silt the supply channel.

The main head which is usually the uppermost head, is opened first and used for early and flood supplies. Meanwhile the subsidiary heads are preserved by preventing river spills entering their supply channels and siltting them up. Subsidiary heads should be selected so that they can be preserved during floods.

One of the subsidiary heads is brought into use as soon as the main head or its supply channel fails which will usually be when the river is falling after the floods. The subsidiary head is kept working as long as possible for maturing kharif and sowai crops.
14:4 A channel connecting a "head" (point of offtake from the river) and the head regulator is called a supply channel. This may be a natural creek or an artificially excavated channel.

The problem on an inundation canal is three-fold:
1. Securing early supplies.
2. Disposal of excess received during floods.
3. Maintaining supplies in the canal till late in the season from maturing kharif crops and sowing rabi crops.

Supply channels should, therefore, be designed to meet these three requirements.

A supply channel should be low enough to draw about half the full supply discharge of the canal in low river, i.e., in the middle of April and again in October, and narrow enough to limit the excess in high floods to the minimum possible.

This ideal is achieved by canalising the supply channels and feeding creeks. Canalising means creating a deep and narrow channel out of the usually wide and shallow supply channel. It is carried out by forming berms with the help of earthen spurs or hilla bushing and judicious slit clearance in the form of a connoite. A supply channel should pass through fairly high land where it will be safe from river spills entering it in high floods. Depressions likely to get extra water from the river in floods and lose supplies in low river, should be avoided, but where, this is not possible, banks should be provided and maintained. A deep and narrow supply channel with a reasonably favourable head gives both early and late supplies and reduces the excess to manageable proportions.

Some canals with highly efficient supply channels run through winter also.

14:51 A groyne is an earthen embankment thrown out on the river side on the canal head in order to lead up water. The shank is based on the canal bank or adjacent high land and terminates on an island or extensive shoal in the river.

In designing a groyne, the formation level is fixed with reference to the flood level it will have to withstand. Permanent groynes are designed for the highest water level ever attained at the point. Afflux is calculated carefully and provided for. A free-board of 3 feet is allowed above the level thus arrived at...

The section of the groyne is designed to cover a hydraulic gradient of 1 in 5 to 1 in 7 depending on the soil. Groynes in river bed are mostly made of sand and are subject to wind and...
wave action. Important groynes should be kept 10–12 feet wide at top with side slopes 3:1 on the river side and 2:1 on the other. The hydraulic gradient is covered by making pushkas or flattening the back slope. The groynes are protected against wave action by pitching the slopes on the river side with pushki or by laying fascines. Fascines consist of rolls of pushki of 9–12 inches diameter and 10–12 feet long covered with karanda laid side by side and held with pegs driven into the bank 5 feet apart. For wind action it is sufficient to protect the top or the side slopes with karanda laid about 3 inches thick.

While constructing a groyne, any creek to be crossed should be filled up first. This precaution is necessary as during a heavy freshet, the head bands may be either washed away or outflanked and the creek may begin to flow thus seriously interfering with the work. Failure to take this precaution has in some instances resulted in all work done on high land being lost as the creek continued to flow and the groyne had to be abandoned.

After filling up the depressions, the band should be brought up evenly, spreading the earth to full width of the section previously marked on the ground.

The earthworks should be free from clode and grass roots, etc., and should be thrown in layers, each layer being well consolidated.

Borrow pits should be sited well away from the band on the upstream side if possible—they should in no case be nearer than 50 feet to the work and should not be continuous. At least 20 feet wide strip should be left unexcavated in every chain. This is necessary to prevent formation of a channel parallel to the band.

Before a groyne can be constructed across a flowing creek the creek has to be closed off.

14:32 The most suitable site for closing a creek is right at its effluke. The water thus diverted can easily flow off in the main stream without causing any serious heading up.

For this, materials locally available are used. These are brushwood, pushki, karanda, wooden trestles, ropes, mats and gunny bags.

Closing of creeks involves considerable time, labour and expense and where an alternative source of supply can be arranged, closing of a creek carrying a winter discharge of more than 2,000 cusec should not be attempted. When it
is decided to close a creek, all the materials required, including earth for the bunds must be collected at site and sufficient labour arranged. The closing should be started when the river is at its lowest and completed quickly before the season for freshets.

Where a creek has two or more heads, only one of them is selected for a final closure. The others can be closed with earth bunds without much difficulty, as there will be practically no head across.

The site selected for final closing should be one where the depths are not too great, the bed is comparatively firm and earth for bunds is available close at hand.

Where the depth in the creek to be closed is more than about 5 feet a tree bar is put in first to reduce the discharge. Big branches of trees are tied together, loaded with sand in bags so that they will not float, and dumped side by side and one over the other till they come up above water level and form a bar across the creek. As the branches settle down more are added till sufficient reduction in discharge and depth in the creek is obtained for a closure to be attempted behind the tree bar.

The usual procedure in closing a creek is to start earth bunds from either bank. The bunds are thrown between pichhi rolls about 12' in dia, and 10 to 12 feet long, called "dandans". to prevent wastage of earth in water. The bunds are carried on in this manner up to the central deep portion where two lines of wooden trestles are fixed as sketched below:

Dandans are arranged against the trestles to form "chhaps." Mats and gunny bags sewn together are placed over the "dandans" to staunch the flow through them. The earth bunds are advanced from each side between the "chhaps" till they meet and close the creek.

Where the final head across the closing bund is likely to be more than about 5 feet another chhap is put in above the two closure chhaps to step down the head and facilitate the closure.
The chasps, bunds, mats and bits of broken trestles get buried at site of closure and are a source of weakness; another earth bund should therefore be placed below the closure site.

14:53 During floods the supply channels bring down discharges much in excess of the requirements of the canal. The supplies to the canal are regulated at the head regulator and the excess is escaped through the escape regulator, which is either combined with the head regulator or placed a short distance above it.

The escape channel should have a good slope and the outfall should be at a safe distance so that it will not retrogress back to the escape regulator and endanger its safety.

It is a good plan to utilise the escapage of one canal for supplies to the next one lower down.

This linking should be adopted wherever practicable, as it provides an extra source of supplies to the lower canal and in the case of accidents to its own independent heads supplies from the upper canal can be used by rotation to mature the crops.

14:54 In high floods the escape regulator alone may not be able to cope with the excess discharge. It is therefore usual to have one or more spilling sites on the supply channel.

Sites for such escapage should be selected where the extra supply can be soiled without risk of deep channels developing and taking away such a proportion of the discharge as to jeopardise adequate supplies to the canal. Spilling sites should be selected in reaches where the supply channel passes through high land with a thick layer of comparatively ineradicable clay and a protective covering of grass. The proximity of deep crevasse which give the spill water a big drop and hence a channel may develop rapidly should be avoided.

14:55 Sometimes with a favourably situated head, it is possible to obtain supplies throughout the Arrangement for winter. Winter supplies are very valuable for mooting rabi crops, particularly in areas where there are no wells or the subsoil water is brackish and unfit for irrigation, as in the case in some parts of Dera Ghazi Khan District. Whenever it is possible to arrange winter supplies either by still clearance or by heading up water in a creek, they should be provided.
14.6 For each inundation canal, a report on the working and repair of the heads during the flow season (15th April to 15th October) and proposals for the following year is submitted by the Executive Engineer to the Superintendent Engineer, and by the following year, the Superintendent Engineer to the Chief Engineer on the 16th November. It details the following points:

(a) The effect of floods on the working of the heads.
(b) The damage done to works, if any.
(c) The changes in the course of the river or its creeks and their effect on the various heads.
(d) Proposals for works and important repairs, which it is considered necessary to carry out during the ensuing cold weather to ensure proper supply to the canal in the following year.

The probable cost of the works should be stated so far as this can be estimated without detailed design. A survey plan of the previous year, with important changes in the course of the river during the year sketched on it, is submitted with this report and further information is given, in the form shown as Appendix A to this chapter.

14.71 After submission of the report on the heads described in paragraph 14.6 above, an accurate plan survey of the river is carried out. To save time, skeleton plans are printed showing permanent features like canal head regulators, flood embankment, walls, mosques, tombs, etc., or where there are no such features, survey pillars specially constructed on either bank of the river. Variable details, i.e., course of the main stream creeks, shoals, etc., are filled in by actual survey.

14.72 As soon as proposals for heads are approved by the Chief Engineer, detailed surveys for the works and required are carried out and necessary estimates prepared. All river works should be completed before the river rises. This is necessary for the following reasons:

(a) With the rise of river, spring level in the river bed also rises and silt clearance of supply channels which are usually designed to winter spring level, becomes difficult.
(b) Fish in the river are liable to wash away incomplete groynes and bunds.
(c) The crop cutting season starts and no labour is available for works after the first week of April.
INUNDATION CANAL HEADS

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## APPENDIX A

### MANUAL OF IRRIGATION PRACTICE

**STATEMENT SHOWING WORKING OF IRRIGATION CANAL HEADS DURING YEAR**

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**GAUGE OPENING**

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<th>Date of Opening of Canal</th>
</tr>
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<td>1 2 3 4 5 6</td>
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CHAPTER 15
SILTING TANKS

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CHAPTER 15
SILTING TANKS

DEFINITION AND FUNCTIONS

15.11. A silting tank is an artificial basin constructed alongside an irrigation channel (fig. 1) through which a part or whole of the canal supply is passed at a low velocity, during periods when the silt content of canal water is comparatively high, so that most of the silt charge is deposited inside the tank. Thus a silting tank utilizes the simple process of decantation at low velocities in order to deprive the silt-laden canal water, of most of its silt charge. A low velocity postulates a much flatter slope of the water surface in the silting tank, and a much wider section, than the water surface slope in and the section of the regular channel.

15.12. Silting tanks are constructed and brought into use on the following occasions:

(i) Where it is necessary to fill up deep borrow-pits or otherwise raise the natural surface levels behind the bank of a channel in heavy filling.

(ii) For de-silting of canals, i.e., removing injurious silt charge from irrigation channels.

An incidental use of silting tanks is the reclamation of low-lying and water-logged area situated within the silting tanks, by deposit of silt which raises the natural surface levels of the water-logged area well above the water table, rendering it fit for cultivation.

Fig. (i)

Note: ---Bend or regulator (B) across the canal may or may not be necessary.
15 21.

MANUAL OF IRRIGATION PRACTICE

COMPONENT PARTS OF A SILTING TANK

15.21. As will be seen from fig. (i) a silting tank consists of:

(i) An outer earthen bund A, B, C, which enclosed the basin of the silting tank. This outer bund is carried on high ground, as far as possible, in order to reduce its cost and ensure the safety of the bund against breaches, etc. The canal back from A to C serves as a dividing bank between the canal and the silting tank.

(ii) An inlet, which is a gap in the canal bank near the upstream end of the silting tank, through which silt-laden canal water enters the silting tank. An inlet may be an open cut, a pipe or a barrel or a parca regulator of suitable design.

(iii) An outfall, which is a gap in the canal bank near the downstream end of the silting tank, through which silt-free water from the silting tank flows back into the canal. An outfall may be an open cut, or a high crested weir of a suitable design.

(iv) A bund, regulator or weir at D in fig. (i) just down stream of the inlet. The drop in water surface levels in the canal from inlet to outfall of the silting tank should be sufficient to cover—

(a) Head across the inlet which in the case of a canal or a branch should not be less than 0.50 feet under full supply conditions.

(b) Head across the outfall which in similar conditions should not be less than 0.40 feet.

(c) Water surface slope in the silting tank, which is already mentioned is flat. It is usually of the order of 0.05 per thousand.

This slope should, however, be measured along the outer bund A, B, C of the silting tank (fig. 1), and not direct from A to C.

If the water surface slope in the canal from point A to point C is insufficient to provide this minimum drop, water may have to be headed up in the canal just downstream of the inlet by means of a regulator or weir.

15.22. Inlets are usually of the following types:

Types of Inlets:

(i) A kachha open cut in the canal bank having its flanks suitably protected.

(ii) A barrel or a large pipe placed at bed level. This is of use only in the case of small channels and small silting tanks.

(iii) A needle regulator without any cross regulator D in fig. (i) in the canal, i.e., without control of water surface levels in the canal. A parca inlet has an advantage over a kachha inlet, in as much as the former can be closed immediately in an emergency.

On the upper reaches of the forest, the parca tank take water from the forest into the tank, and discharge it into some drainage channels. The available head is thus increased, and the loss of the joint and capital reduced. This system, however, is only advisable, when surplus discharge can be made available in the canal.
Silting Tanks 15.23.

(iv) A needle regulator combined with a cross regulator in the canal, thus ensuring proper control of water surface levels under all conditions of supply in the canal.

15.23. In designing a pacca inlet, care should be taken to provide a smooth eddy-free “approach” and to keep the crest level of the inlet as low as possible, provided that the length of regulator needles is not so long as to become unwieldy for manipulation. A pacca inlet is sometimes combined with silt vanes in the canal bed for greater silt induction into the silting tank.

15.24. Outfalls of silting tanks are of the following two types:

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<th>Types of outfall</th>
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<tr>
<td>(i) A kachha open cut in the canal bank having its flanks suitably protected.</td>
</tr>
<tr>
<td>(ii) A pacca high crested weir.</td>
</tr>
</tbody>
</table>

A high crest is essential in order to prevent the development of a well-defined and comparatively deep channel inside the silting tank, from inlet to outfall, which is the usual feature (and the base) of silting tanks with kachha open outfalls. Such a well-defined channel carries a major proportion of the discharge let into the silting tank, with the result that most of the silt in suspension is carried forward to the outfall and is passed back into the canal. Actually, in the case of some silting tanks having kachha open cuts as their outfalls, it has been observed that instead of silt depositing in the silting tank, the silt that had already been deposited was scoured out. Therefore, in order to carry out any large scale silting operation successfully, a high crested pacca outfall is necessary.

Provided the water levels above and below a silting tank permit, the high crest of an outfall weir need not be built to the final designed level in the first instance, but may be raised in successive stages from year to year, depending upon the progress of silt deposits in the silting tank. In this way water surface levels in a silting tank are raised slowly to the final designed levels, and thus the outer bund of the silting tank is not strained to the full extent all at once, which is very desirable from the point of view of safety of the outer bund.

The full supply depth on top of the crest of an outfall is usually restricted to 2.0 or 2.5 feet maximum. Greater depth of water over the crest tend to the formation of well-defined channel in the silting tank which must be guarded against, as explained above.

Types of Silting Tanks 15.31. The following are the common types of silting tanks:

(i) Silting tanks worked on the “in and out” system. Such silting tanks are generally small and are mainly used for strengthening banks of channels in filling reaches.
15.31. MANUAL OF IRRIGATION PRACTICE

Inlets and outfalls in the case of such silting tanks are generally kachha. The inlet and outlet openings are placed at an angle of 45° to the centre line of the channel. Square openings are liable to get choked up easily. The openings may be of any suitable width depending upon the discharge to be passed through the silting tank. Such silting tanks would be necessary not be wide, as their operation is limited only to the strengthening of banks.

The position of an inlet in the case of silting tanks worked on the "in and out" system must be moved periodically, because the deposit of silt in such silting tanks reaches a certain maximum level at the inlet end, gradually diminishing towards the outfall end; no further silting up can take place unless the position of the inlet is moved downstream. It is necessary to close an inlet after working it for a period of a few weeks, depending upon the silt charge in the water, and to open up another inlet a few hundred feet downstream, until the silting operations are completed.

For further information on such silting tanks, reference may be made to Punjab Irrigation Branch Paper No. 5, on silting operations.

(ii) Silting tanks into which the whole of the canal discharge is diverted, by placing an earthen cross bund in the canal, just downstream of the inlet. Such silting tanks are necessarily large and are meant to desilt the canal water. The inlets of such silting tanks are generally kachha, but the outfalls should be made pucca for reasons given in paragraph 15.24 (ii) supra.

The main disadvantage of such silting tanks is the recurring annual cost of placing the cross bund in the canal and opening of the inlet in the beginning of the silting season, and of removing the cross bund and closing the inlet at the end of the silting season.

An excellent example of a silting tank of this type is afforded by the Chhalsali Silting Tank, on Main Line Lower of the Western Jumna Canal.

(iii) Large silting tanks provided with regulation arrangements at their inlets, and having pucca outfalls.

The inlets of such silting tanks may be of types (iii) or (iv) of paragraph 15.22 supra. Obviously the best regulation of supplies and hence quantities of silt admitted into a silting tank is secured if its inlet is combined with a cross regulator in the canal itself.

An example of such a modern silting tank with a cross regulator in the canal is afforded by the Indri Silting Tank at the tail of the Main Line Lower of the Western Jumna Canal.
SILTING TANK

15.32. The choice in a particular place of one of the three types described above will depend on the circumstances of each case. An estimate should invariably be made of the discharge required to fill up the tank in a specified time based on the silting intensity at the time of flow. The discharge so estimated will, in a large measure, determine the type of silting tank to be constructed.

CONSTRUCTION OF SILTING TANKS: SPECIFIC FEATURES

15.41. There is no choice of site when silting tanks are constructed for item (i) of paragraph 15.12. For silting tanks for item (ii) *ibid.,* a natural basin or reservoir lying along-side the canal is the best site. In any case the outer bund of the tank as already stated should be located on such high ground as is available.

15.42. Before drawing up an estimate for earthwork in connection with Silting tanks, a careful examination should be made of the area from which earth for the outer bund has to be borrowed in order to ascertain the actual loads of earthwork involved. Generally such areas are already water-logged and deep borrow-pits are not feasible, and if proper care is not exercised in framing the estimate large excesses may have to be faced later on. In fact in some cases it may be advantageous to dig seepage drains in order to lower the water-table of the area to be covered by borrow-pits, so as to be able to place deep borrow-pits, thus reducing the load and cost of earthwork. Borrow-pits should be placed inside a silting tank. For obvious reasons, outside borrow-pits should be avoided.

15.43. All possible care should be exercised in designing and constructing the outer bund of a silting tank, as a breach in it is bound to be disastrous on account of the large volume of water impounded in the silting tank. The inner slope of such bunds is usually made 1 in 2 to 1 in 3 to withstand wave action, and the bund section is designed to provide a cover of at least 2 feet over a hydraulic gradient of 1 in 5 to 1 in 8 depending upon the nature of the soil. The service road should be carried on top of the bund. Earthwork of the outer bund should closely follow the standard specifications for such works.

On opening the silting tank for the first time, water should be let into the tank very gradually, and the inner slope of the bund should be thoroughly puddled from its toe upwards as the water level in tank rises.

15.44. The seepage from big silting tanks is necessarily large and it is sometimes necessary to provide and maintain a seepage drain just outside and along the outer bund of a silting tank to lower the seepage water level, which rises in the vicinity of silting tanks. The working of the silting tanks on the Lower Chenab Canal Main Line above Sagar had to be given up because of the Water logging caused in the lands adjacent to the tanks.
15.45. **If there are any pucca wells within the sitling tanks area, it is necessary to raise the steining masonry of such wells to a level, at least 2 feet above the full supply water level in the tank, in order to avoid wells getting buried underneath the silt deposits. Standing trees in the area may be cut if useful timber is available. Light jungle may be left in.**

15.46. In large sitling tanks it is necessary to provide properly located earthen spurs of suitable design for the protection of the outer bund against wave action, which in high winds can be dangerously severe. Figure (ii) shows the location of four such spurs in the Indri Siling Tank.

![Diagram](image)

Fig (ii) A diagrammatic Sketch of the Indri Siling Tank Western Jumna Canal.

15.47. Generally it should not be necessary to acquire land for sitling tanks. It may be occupied temporarily under written agreements (Razinamas) with the owners of land concerned made through the civil department, on the basis of annual compensation. The owners are in most cases willing to enter into such agreements because their low-lying lands, which are usually water-logged, will be reclaimed by silt deposits.

**MAINTENANCE OF SITLING TANKS : SPECIAL FEATURES**

15.51. Where conditions permit, the water-supply to sitling tanks should be closed in the winter season, and the area thrown open to the owners to cultivate, for the following reasons—

(a) Silt charge in the canal is usually low in the winter.

(b) Water is especially valuable in the rabi season, and the high absorption losses, inseparable from a sitling tank, are thus avoided.

(c) Cultivation of the area produces excellent crops and tends to check the growth of reeds, etc., so preventing deterioration of the soil.
SILTING TANKS

(d) Annual compensation to the cultivators is reduced by half.

(e) A season’s flow in the canal, checks the growth of reeds in the
canal and otherwise maintains the channel in good order, thus
avoiding future heavy expense.

15.52. Great attention has to be concentrated on the maintenance
of the inner slope of the outer bund, which is subject to wave
action. In high winds this wave action can assume dangerous
proportion. In addition to the earthen spurs,—v/le paragraph
15.46 su, r7a, it is necessary to protect the inner slope of the outer bund against
erosion and denudation by wave action. Such protection depends upon
local resources and may consist of rolls of grass or local brushwood and
mats, etc. Such protection has to be constantly replenished, and in the long
run may prove quite expensive. “Pilchis” rolls last much longer, and are,
therefore, to be adopted su protection against wave action, if available at
a reasonable cost. Dry brick pitching laid over a layer of not less than 1"
thick ballast is the best form of protection, but if bricks are not available or
are found to be too expensive a layer of brick-bats 1½" thick should be laid
at those points, at least, which are subject to the severest wave action.

In any case a constant and efficient watch must be kept on the outer
bund to guard against any leakages. Permanent watertight should be located
at suitable intervals along the outer bund.

15.53. Permanent cross-section pillars at suitable intervals (usually
500 feet apart) must be erected along a silting tank before it starts
functioning, in order to observe successive cross-sections of the
silting tank along fixed lines after each silting season, and thus watch the
progress of the silting operations. This method of taking successive
cross-sections for determining the quantities of silt deposited in a silting tank or in
any particular part of it gives fairly accurate results and is to be preferred to
any other methods of arriving at similar data.

15.54. The standard of performance of a silting tank is the average
performance of a silting tank. (These are average 86,400 cubic feet of water) through the silting tank.
This can easily be determined by dividing the total quantity of silt deposited
during the season (arrived at by means of cross-sectional surveys, v/le
paragraph 15.53 su r7a) by the total of daily discharges passed into the silting
tank during the season. This gives a fairly reliable result for purposes
of comparison. As an example, the performance of two silting tanks on the
Western Jumna Canal is given in the appendix to this chapter.
A packet outfall was constructed prior to kharif, 1942 in the Chahlandi Silting Tank.
The effect is apparent from the last column of the appendix.
15.55. A distinction should, however, be drawn between the "efficiency of a tank" and the "performance" of a silting tank. While the efficiency of a silting tank is measured in terms of the percentage of the silt charge entering the silting tank which is intercepted by the silting tank; its performance is measured in terms of the quantity of silt deposited in the silting tank per cubic day, without reference to the silt charge entering or leaving the silting tank.

It is usually necessary to determine only the performance of a silting tank.

Precaution to be Observed

15.61. Indiscriminate use of silting tanks for the purpose of removing excessive silt from a canal system is to be deprecated. It is absolutely necessary to watch carefully for regime changes in channels, undergoing de-silting process, in order to regulate the working of silting tanks in accordance with the regime requirements of such channels. This is best done by a systematic and careful study of the Hydraulic data of the channel concerned. Channel characteristics should be observed regularly as long as silting tanks continue to function.
# APPENDIX

Statements Showing Performance of the Chhalandi and the Hanli Branch Sitting Tanks

<table>
<thead>
<tr>
<th>Year</th>
<th>Total quantity of silts deposited for tempory lapsing</th>
<th>Quantity of all silts deposited in end of the previous year</th>
<th>Quantity of all silts deposited during the sitting season</th>
<th>Quantity of all silts deposited during the sitting season</th>
<th>Total quantity of silts deposited</th>
<th>Volume of water stored during the sitting season in each tank</th>
<th>Remarks as to type of outfall, leak etc., and any interruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2000</td>
<td>562.79</td>
<td>259.28</td>
<td>6.66</td>
<td>235.94</td>
<td>589,313</td>
<td>38.9</td>
</tr>
<tr>
<td>1939</td>
<td>2,000</td>
<td>590.73</td>
<td>571.79</td>
<td>6.66</td>
<td>571.79</td>
<td>714,715</td>
<td>Ditto</td>
</tr>
<tr>
<td>1940</td>
<td>2,000</td>
<td>1,171.12</td>
<td>395.42</td>
<td>6.66</td>
<td>395.42</td>
<td>798,161</td>
<td>Ditto</td>
</tr>
<tr>
<td>1941</td>
<td>2,000</td>
<td>1,567.94</td>
<td>-86.05</td>
<td>6.66</td>
<td>-86.05</td>
<td>Not available</td>
<td>Sever due to a defective outfall</td>
</tr>
<tr>
<td>1942</td>
<td>2,000</td>
<td>1,461.49</td>
<td>360.58</td>
<td>6.66</td>
<td>360.58</td>
<td>495,092</td>
<td>Patco outfall</td>
</tr>
</tbody>
</table>

**Chhalandi Sitting Tank, Area 1.726 Acres**

**Hanli Branch Sitting Tank, Area 4.28 Acres**

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>1940</td>
<td>800</td>
<td>34.37</td>
<td>34.37</td>
<td>45,635</td>
<td>31</td>
<td>Patco outfall, Sitting Tank was opened in June, 1940</td>
<td></td>
</tr>
<tr>
<td>1941</td>
<td>800</td>
<td>34.37</td>
<td>206.89</td>
<td>206.89</td>
<td>257,500</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>1942</td>
<td>800</td>
<td>244.26</td>
<td>105.27</td>
<td>105.27</td>
<td>452,090</td>
<td>74</td>
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CANAL RAILWAYS

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<td>Appendix I</td>
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CHAPTER 16

CANAL RAILWAYS

INTRODUCTION

16.9. The standard railway gauge in India is 5' 6". A railway of this gauge can be carried from the nearest "open" railway line to the site of any work whose magnitude justifies this provision. In the Irrigation Branch of the Public Works Department, it is normal to provide such railway for the construction of canal headworks dams and for the working of departmental quarries such as Uddi Bashi, etc. Canal railways are maintained at the headworks for carriage of materials, even after construction is completed. With the rise in rates of labour, it is now economical to carry the broad-gauge railway transport as far as possible and thereby reduce the use of more expensive means of carriage such as narrow gauge or tramway track, donkeys, carts, etc.

16.01. The standard of construction and maintenance of a canal railway should be suitable to the purpose in view. Obviously it would not be economical to construct and maintain such railway to the standard required for "open line" passenger traffic. On the other hand, too low a standard of materials and workmanship in construction will result in undue inflated maintenance costs and probably also in valuable time lost in avoidable derailments and consequent disorganization of the work.

The general aim is to construct a railway, such that the combination of initial and recurring costs shall be a minimum, consistent with freedom from derailments and other accidents likely to impede construction of the new headworks.

In accordance with the Indian Railways Act, 1890, Canal Railway may only be used for the transport of Government materials. Paying passenger traffic is prohibited and consequently labour or other individuals travelling as passengers do so at their own risk. The standard ordinarily aimed at, is that required by the Senior Government Inspector of Railways for the safe passage of goods traffic at 15 miles an hour. But careful construction and subsequent maintenance can easily raise such railway to the standard required for passenger traffic at 25 miles an hour and this is the standard which the officers in charge of the maintenance of the canal railway should set for themselves.

16.02. Up to date, considerations of initial cost have prevented the ballasting of canal railways in the Punjab. Nevertheless, before the construction of such a railway begins, it is as well to examine the economics of stone ballasting the track. Should local conditions permit of securing ballast at a low initial cost, the ballasting of the track may well be found to be economical in the long run. The principal advantages arising from ballasting the track are:

(a) Lengthened life of sleepers. An increase of 100 per cent in the length of life of a sleeper may certainly be expected although a more exact estimate may not be possible.
16.10 MANUAL OF IRRIGATION PRACTICE

(b) Ballasting the track will render unnecessary the closures of the railway due to heavy rain, which are a feature of earth-packed permanent way. Moreover, the speed-limit on traffic may be raised on a ballasted track.

(c) A general reduction in cost of the maintenance both during the construction of the headworks and subsequently, may be anticipated from the use of ballast. If ballasting is found to be uneconomical, the alternative is an earth-packed and boxed permanent way.

16.03. The rail section to be used is determined by the traffic expected. Ordinarily a rail of 75 lb. per yard is the normal required on canal railways. A heavier section will only be required if peculiar conditions, such as long steep gradients, necessitate the use of an unusually heavy locomotive.

CONSTRUCTION

16.10. The selection of the terminus station on the Northern Railways will generally be easy. It will be the station giving the shortest canal line consistent with constructional costs.

Canal railways are generally short lines, connecting the nearest railway station on the "open" railway line and the works area. For purposes of alignment of the line a trial alignment should be marked on the best available contoured plans preferably - G.T.S. sheets. This alignment should then be set out at site using pegs to mark the intersections of the curves: the actual layout of the curves being omitted at this stage. The alignment should then be carefully inspected by the executive engineer and modifications introduced to meet the requirements of the topographical features of the ground keeping in view the minimum radius of curves and maximum gradients - see paragraph 16.14. The longitudinal section can then be plotted from the contoured survey sheets. At this stage the final general alignment should be approved or modified by the superintending engineer, after which the alignment should be laid out at site with a theodolite, the curves being lightly laid out and very carefully re-inspected by the sub-divisional officer, who will make recommendations to the executive engineer for further modifications in the alignment if necessary. The executive engineer will then re-inspect the alignment and consider the sub-divisional officer's recommendations at site, and make final decisions.

The final longitudinal section can then be prepared by double levelling along the final alignment, and the design of the railway embankment carried out in the divisional office. Double levelling should include taking cross sections at suitable intervals especially where the configuration of the land
demands this, vis-a-vis embankments and cutting. The usual details should also be collected regarding all cross-drainages, roads, canals and watercourses in the course of making the strip survey.

16.11. Branch lines leading to kilns or elsewhere should be aligned in the same considerations as the main line.

In this connection as large a frontage at the kiln site should be presented to the railway as possible for loading purposes. At least one siding will be required at the kiln to facilitate traffic working.

16.12. There will be two main railway stations required, one at the Northern Railway end and the other at the works. Immediately beyond the distant points of the latter, it will generally be found convenient for traffic purposes to locate the first point into the nearest material sidings.

Crossing stations should be sited along the canal railway line at convenient distances. No hard and fast rules can be laid down but some thing of the order of 7 miles apart may be found suitable. A crossing station will be required near the off-take of any branch line for signalling and other traffic control purposes.

At each crossing station there should be a loop line capable of stabilising the longest canal train which can be handled including the locomotive and brake van. The length between fouling points is controlled by the shortest passing loop siding on the Northern Railway showing the point between the quarry and the canal terminus.

At the terminus there should be at least three lines to commence with, viz., one main line, one stubbing siding and one weigh bridge siding; all connected by points and crossings at each end to the canal main line outside the Northern Railway boundary. At the railway station in the works area there should also be at least three lines, viz., one main line, one stubbing siding and one passing siding, all in the form of loops. Both at the terminus and the works railway station the initial alignment should permit of one additional loop and two sidings at a subsequent date.

The length of stubbing siding and additional loops should not be less than 1,700 feet. This is worked out by assuming that the canal trains generally consist of 47 trucks, plus brake van and an engine. The length of S.V.C. trucks, buffer to buffer, is 30 feet and an H.G. engine is 60 feet long. The canal train would thus be 1,500 feet long and the additional 200 feet are allowed for the distance between the water column and the starting signal (if any) and between the latter and the fouling board.
16.13. A canal railway must be equipped with a weigh-bridge of its
own, in order to check stone consignments from the quarry and
other materials such as coal and oil in bulk. The weigh-bridge
should be situated at the terminus station, and provision should
be made for back-shunting trucks into the stabling siding to clear the main
line towards the works when necessary.

16.131. A turn table capable of dealing with the heaviest locomotives
likely to be used, is advisable at the terminus station. At the
work station a reversing triangle will be found most convenient
and along this triangle can be situated the cement stores; the unloading of
cement generally blocks the line for a short period only.

16.132. Watering points should generally be available both at the
terminus and at the works station. Standard water columns
should be erected with a gravity feed from high level tanks. The
quality of water must be such as will not prim in the locomotive boilers.

Curves and gradients are therefore, usually only required on bridge approaches,
Crossing existing waterways or to get the railway line on to the
top of an embankment. There are technical reasons in connection with the
construction and operation of a canal railway on account of which the
minimum radius of curves is greater than that specified on the Northern
Railway.

Curves of shorter radii than the minimum radius specified (vide
appendix I) must be avoided at all costs. Besides being unsafe, sharp curves
increase wear and tear on the flanges of the wheels of the rolling stock, and
unduly strain the track itself. The tractive effort for the locomotive is also
increased with a corresponding reduction in speed.

Check rails should be provided at curves of radius 715' (8° curves)
or less, and at level crossings. The minimum clearance of check rails for
a curve should be 1½ inches. At level crossings the minimum clearance
should be increased to 2 inches, and the maximum may be 2½ inches.

All sidings and loops should be sited or level reaches of the lines.

16.15. In the case of a headworks, the centre line of the weir or barrage
should and generally will be known, before the alignment of the
sidings within the headworks area is taken in hand. Something
must also be known at this time of the probable width of the excavation of the
barrage downstream of the centre line. The feeder line to the concrete mixers
at the barrage, the pitching stone sidings and the stone yard should be aligned
along the whole length of the barrage downstream and in the beginning 300
feet from the top of the barrage excavation line. During construction, this
line can be slewed upstream or downstream as occasion demands. The main line from the headworks railway station should run direct to the nearest flank of the barrage.

Taking off the main line should be arrangements of sidings for various kinds of the main materials to be accumulated in reserve and separate sidings should be allotted to each kind of material, e.g., stone ballast, fine stone aggregate, pitching stone, building stone. Backs will generally be transported direct from kims to the site of work to avoid excessive breakages due to frequent handling.

Other sidings will be indicated by the requirements of the works, e.g., sidings into the workshops and stores to the powerhouse and to the precasting area, etc. Lines are also usually required on the ring road, and on both the gable banks. This all connotes a very careful planning of buildings and stacking grounds within the headworks area concurrently with the layout of the sidings bearing constantly in view the minimum radius of curves. Too much emphasis cannot be placed on this desideratum for smooth traffic working.

The layout of sidings within the works areas should not be unduly cramped, and some latitude should be left for future modifications in siting of buildings and additional siding accommodation.

16.16. The earthwork in railway embankments should be carried out in the best traditions of the Irrigation Branch in accordance with the specifications laid down in Chapter 38. A well-constructed embankment in the beginning will save endless cost in maintenance and will greatly improve train running. Where possible the embankment should be constructed before a monsoon season and allowed to settle during the rains before linking the track.

Borrow-pits should not exceed 3 feet in depth and should not be closer to the toe of the embankment than 10 feet.

The embankment as initially constructed should allow 10 per cent for settlement in height.

For minimum formation widths in embankment and cutting see appendix I. Cutting through sand tibias should be avoided where possible, blown sand being a source of constant trouble on the line.

16.17. Abutments and piers of bridges on canal railways should be built in first class brickwork or coursed rubble masonry on foundations to suit the character of the site. In the design, the equivalent supercharge induced by the approach of the exile loads of the
heaviest locomotive likely to be used, should be taken into account and the bridge department of the Northern Railway should be consulted, where loading diagrams will be obtainable to suit the locomotives likely to be used.

Bridge timbers instead of ordinary sleepers should be used over the girders. See appendix I—and should be fastened to the latter by standard hook bolts. Standard bearing plates should be used under the rails and check rails should also be introduced.

Culverts or siphons carrying watercourses and other small channels below the railway line should preferably be constructed with Hume Pipes, with a minimum earth cushion on top of 2 feet below the formation level. Other forms of masonry culverts will suggest themselves to meet special circumstances. Metal barrel, e.g., Armco culverts should be avoided except under temporary lines.

PERMANENT WAY

16.21. The sleeper spacing is fixed in accordance with the axle loads anticipated, see Appendix I. The kind of sleepers to be used will depend on circumstances, such as the importance of the line, availability and cost.

When sleepers are used without bearing plates the adzing should be done as per sketch below. The slope of 1 in 20 must be accurately cut, the rail seat planed smooth and carefully checked. The rails should be laid 1/8 inch slack to gauge.

![Fig 1](image)

16.22. Linking of the track is a highly specialized job and should only be undertaken by and under the supervision of staff trained in the work on the Northern Railway. Even for the maintenance of the line a P.W.I. or a sub P.W.I. will be required, so the services of a suitable retired railway official of that status should be secured from the beginning of the construction. At the same time the Sub-Divisional Officer in charge must familiarize himself with the subject in general by consulting standard books on the subject. Only a general outline of the work is indicated in this handbook.
The linking operations should begin from the terminus end of the line where materials are received. During construction and for maintenance later on, broad gauge material trolleys will be required, about two for every 7 miles length of the main line. Sleepers and rails should be laid out on these trolleys for about the first mile, but as soon as sleepers have been properly spaced on the formation and the rails linked, it will be more economical to shut further supplies of sleepers, rails and fastenings, using a light locomotive and end-opening trucks. A "traveling" locomotive will prove most useful for this work. As soon as a length of track is linked, the first packing will be taken in hand to enable the material to be shunted over the track at about 5 miles per hour, with reasonable safety.

The initial sleepers placing, linking and packing may be done by a contractor, and depending on the length of the line, progress at the rate of 1/2 mile to 1 mile per day can be anticipated. All work after that is to be carried out departmentally by P.W. gangs.

16.23. After the linking comes the packing which is a very specialised job, and which is to be undertaken by the P.W. gangs. Several backings will be necessary before the line can be first opened to slow traffic. On the quality of packing depends the whole future working of the line. A railway line has to be gradually "run in" with constant packing and reboxing to eliminate "switch backing" of the track.

Lastly comes the boxing of the permanent way. The width of boxing on earthy tracks should be 12 feet with 7 inches of earth packing below the bottom of sleepers. The sleeper level is thus 1 foot above the formation level. Figure 2 below.

16.24. Except between points and crossings the ends of all curves sharper than 1° should be properly eased by transition curves. This should be done by means of a freemoline. A suitable length (in feet) for the transition spiral is given by the formula

\[ 6x \] (Maximum permissible speed in miles per hour).

16.25. All curves must be super-elevated on the outer rail and should be calculated from the formula:

\[ \text{Super-elevation} = \frac{GV^2}{125R} \text{ inches.} \]
16.26. The gauge on curves on broad gauge track shall be as follows:

<table>
<thead>
<tr>
<th>Curvature of track</th>
<th>Gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 3° = Under 1,910' radius</td>
<td>5'—6'</td>
</tr>
<tr>
<td>3° —</td>
<td>1,910' Do</td>
</tr>
<tr>
<td>4° —</td>
<td>1,432' Do</td>
</tr>
<tr>
<td>6° —</td>
<td>935' Do</td>
</tr>
<tr>
<td>8° —</td>
<td>716' Do</td>
</tr>
<tr>
<td>10° —</td>
<td>573' Do</td>
</tr>
</tbody>
</table>

16.27. The standard type of points and crossings to be used is 1 in 8\(\frac{1}{2}\).

Foulong boards consisting of an old piece of sleeper painted white shall be placed between the rails where two tracks converge to 14 feet 2\(\frac{1}{4}\) inches and 14 feet 4\(\frac{1}{4}\) inches centre to centre, in the case of 1 in 12 and 1 in 8\(\frac{1}{2}\) turn out respectively.

Suitably constructed dead ends must be provided at the end of all open sidings.

16.28. Hand-operated home signal posts should be erected at each station, and where branch lines meet the main line. Signals are not required in the headworks area unless special circumstances demand.

All stations on the main line should be connected by a through telegraph line.
Buildings

16.31. The minimum requirements of buildings on a canal railway include:

(a) At the terminus and at headworks.—Accommodation for one station master and one signalman with separate room for each on the platform.

(b) At crossing stations.—Accommodation for a station master with an office room on the platform.

(c) At the terminus.—Accommodation for a P.W.I., and gangmen and weigh-bridge house should also be provided.

(d) Along the line.—Accommodation for P.W. gangmen.

Quarters for gangmen should also be situated at crossing stations while special quarters are required for gangs in the headworks area where, due to the length of the sidings extra gangmen are required.

A locomotive shed is required at headworks fitted with suitable inspection-pits. An ash-pit near the engine-shed is also required.

16.32. Platforms are generally only required at the terminus and the works stations and need not be of greater length than that required to accommodate two trucks and one brake van. It is economical to build these structures—whatever form of construction is used in the buildings—of brickwork in cement mortar with a concrete coping (see Appendix I).

Maintenance

16.41. All work on the permanent way must be done departmentally after the initial packing. This work should be carried out by trained permanent way gangs under the supervision of a competent P.W.I. or Sub-P.W.I. depending on the length and importance of the line.

The strength of the P.W. gangs will depend upon the age of the line, the traffic involved, whether the track is ballasted or not and to some extent on the total length of the line. During the first year packing and boxing operations are heavier than those required later on, as the line becomes "run in." Again, a definite schedule of gangmen per mile cannot be specified—since a minimum strength of gangmen is required to handle rails and other heavy jobs.
The following list of establishment will form a guide to good maintenance on a canal railway where the line has been well-constructed initially, and in its third year of working and where the main line, excluding sidings and loops in 22 miles long:—

1 P. W. I. or Sub-P. W. I.
1 timekeeper.
9 mates.
9 keymen.
50 gangmen.
1 Carpenter.
1 Carpenter's coolie.
1 Blacksmith.
1 Hammer man.
2 Earthwork mates
20 Earthwork coolies
4 Chowkidars.

In addition to the above another gang of 20 gangmen will be required at headworks for siding accommodation on the scale envisaged in this chapter.

16.42. Regarding the general maintenance of the permanent way the following points should receive continual attention:

- The clearance of check rails at crossing, and the gauge at points and crossings must be constantly checked.
- All rail gauges, spirit-levels and level boards must be checked before issue to the work.
- It is important to see that the gang use their levels, battens, height boards and sight boards correctly.
- It is important to see that all gangmen understand the correct use of the beater.
- When lifting or packing a joint that is low, the two sleepers on either side of the joint must be packed at the same time.
- The running road at either end of bridges and culverts of all descriptions requires constant and careful packing to prevent slacks forming.
- Lifts of more than 2" shall not be done at a time on a running road, and in no circumstances shall any heavy lifts be attempted during the rains.
- The clearance for expansion of rails at joints must be carefully maintained, and joints should be kept square except where staggered on curves.
Canal Railways

16.43

(i) The easing off of the super elevation at each end of a curve must be carefully checked to ensure smooth running into and off curves.

(ii) Care must be taken that on the straight, the rails are truly level across, and on curves the proper super-elevation is both given and maintained.

(iii) Where there are two or more tracks running parallel, the farm between the two tracks must be dug out clearly to the formation level. This is necessary for drainage and separation of tracks, specially in yards.

(iv) The formation bank and the side drains in cutting must be properly maintained.

(v) All level crossings should be overhauled one a year.

(vi) Except where creep is excessive, i.e., more than six inches, adjustment of the creep should form a part of the annual work of overhauling on each section. It should, however, form a separate operation, which should precede overhauling of the track in any particular length. Special arrangements were necessary to adjust excessive creep, must be made well ahead of the time of overhauling, so as not to interfere with the progress of overhauling of track.

16.43. The following programme is suggested as a guide and may preferably be adhered to, except when interrupted for special reasons, e.g., repairs contingent on derailments October to May—

(i) Monday to Thursday and Monday to Friday, i.e., 4 and 5 days, respectively in alternate weeks should be spent on overhauling systematically once per year, the whole of the track between stations, all lines in station yards, including running lines and all sidings and locomotive yards.

Gang sections must be overhauled in continuous lengths. If it is absolutely essential to interrupt the work of overhauling during the days set apart for overhauling, the time so lost must be made up in the remaining days of the week.

All boxing must be opened out at least once and preferably twice, on the earth packed line, the spees examined and serated.

Each fish plate should be removed, cleaned, oiled and reversed once. Fish bolts and nuts should be cleaned and oiled at the same time. Black oil should be used.
16.44  MANUAL OF IRRIGATION PRACTICE

The track must be properly packed under each rail seat for a length extending from 16 inches outside the rail to 20 inches inside the rail. Packing marks should be cut in the sleepers.

The work is to be done continuously from one end of a gang length to the other. Any arrears at the end of May are to have precedence in the following October.

(ii) Normally half of each Friday and the whole of each Saturday is to be used for packing up slacks or for any other work of an urgent nature, such as attending to bridge approaches, cuts, points and crossings, etc. If local conditions permit, some part of Fridays and Saturdays may be used for overhauling, provided there is no detriment to the work specified for those days.

June.—During this month attention must be given to the cleaning of all waterways; for bridges, culverts and pipes, to the cleaning out of side drains and catch-water drains for cuttings and to reconditioning of any portion of the Line which may require it. If time permits, extra attention should be given to track on bridges and to bridge approaches.

July to September.—These months are to be spent on patrolling the line by the gangs during rainy weather or floods, cleaning drains and waterways as required, packing up of low joints and slacks as they occur, and on other such essential work.

16.44. Sleepers can now be creosoted in the Punjab and their life is thereby increased. The following statement shows the probable life of different kinds of sleepers in a ballasted track. The life of a sleeper in an earth packed track cannot be estimated owing to the rapid deterioration which may take place due to lack of proper drainage and due to presence of white ants:

<table>
<thead>
<tr>
<th>Type of Sleeper</th>
<th>Life in Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deodar-creosoted</td>
<td>20</td>
</tr>
<tr>
<td>Chir-creosoted</td>
<td>17</td>
</tr>
<tr>
<td>Fir-creosoted</td>
<td>11</td>
</tr>
</tbody>
</table>

While the probable replacement of sleepers in an earthen track cannot be estimated as stated above, yet it may easily attain the figure of 20 sleepers per mile by the third year and may keep on rapidly increasing. A record of sleeper replacements should be maintained.

16.45. Regarding purchase of sleepers for maintenance purposes:—

All sleepers required for Irrigation Branch railways must be first class creosoted timber sleepers and must be obtained through the sleeper pool, Northern Railway, by annual tenders placed through Chief Engineer, Irrigation Branch’s Office.
If an indent is placed with the Sleeper Control Officer in January, he can make arrangements in April next for the purchase of sleepers, which will then be crosseted. So the supply will be made actually in the financial year after the one in which the sleepers are purchased and crosseted.

On the 15th December each year the superintending engineers will, therefore, submit—

(1) the preliminary indent for the sleepers required in the financial year next after the ensuing financial year, and

(2) the final indent for the sleepers required in the ensuing financial year.

The life of a crosseted or sleeper is 17 years under light canal railway traffic.

Sleepers required for other purposes may be obtained from the open market.

**Running of Canal Railways**

16.51. Certain specialised staff is required, e.g., station masters, guards, checker of traffic, shunting jammers, shunters, pointmen, wheelmen. All these are specialised jobs and should be recruited from ex-railway men. An endeavour should not be made to train inexperienced men, since this department has neither the superior staff nor the knowledge to train these men properly. Other petty establishment will also be required. The train examiner is posted by the Northern Railway.

### 16.52. Rules to safeguard against accidents on canal railways

#### Precautions

1. **Supervision of shunting of ballast, stone or other material trains.** All shunting of vehicles must be done under the personal supervision of the guard, or if there is no guard available the subordinate-in-charge or any person deputed by him in writing on each occasion such as the shunting jamaadar, pointman or any other responsible person who will be termed the shunting supervisor. Before commencing shunting, the shunting supervisor must obtain the instructions of the station master on duty, or where there is no station master, a person appointed to perform the duties of a station master by the sub-divisional officer for a particular station. The shunting supervisor is also responsible for taking every precaution to safeguard coolies working (if any), during shunting and he is also responsible—

   - (i) that the correct vehicle is attached or detached;
   - (ii) for ascertaining that part of the train which is being shunted and giving the necessary signal; and
   - (iii) for the correct setting of all points over which shunting is done.
In addition to the above, at a key siding station, where shunting has to be performed, the shunting supervisor will—

(i) on arrival stop his train clear of the foundling mark and before detaching the engine, put the brake-vaal hand-breaks hard on, and if necessary, sprag the wheels of the vehicles;
(ii) see that the indicator and points are reset to their normal position after shunting is completed and before he leaves the station;
(iii) take the station master’s siding key to the station master of the next block station and take his signature in the guard’s journal.

When vehicles have to be shunted, the person conducting the shunting must warn workers by blowing a whistle at least twice and by audibly announcing the fact that the vehicles are to be shunted. The movement is not to commence till the track is cleared of the workers.

(2) Responsibility for warning staff and for the performance of careful shunting (in and out of goods and other sidings where loading or unloading is in progress).—The shunting supervisor will be held responsible for warning all persons engaged in loading or unloading vehicles or other operations on or near the line, before he commences shunting on to or with these vehicles. No hand shunting or loose shunting connected with those vehicles which are being dealt with, or which will foul the lines on which such work is going on, may be done until permission has been obtained from the station master or his substitute.

(3) End flaps of low-sidet trucks when shunting.—Special care is required in coupling and uncoupling trucks which have their end flaps or doors down. Such trucks, when empty or not loaded with loads which require the flaps to be down, must have the flaps fastened up. Shunting must not be performed until this is done. If the trucks are so loaded as to necessitate the flaps being down, shunting cooies must not be allowed to get between two trucks until the buffers are pressed together, and must be warned not to raise their heads between the end flaps. Shunting cooies must be warned of this danger before they are allowed to work.

(4) Hand shunting of vehicles.—When it is necessary to hand shunt any vehicles the shunting supervisor must supervise the work. Cooies and others must not be allowed to hand shunt the vehicles by pushing them at the buffer. They must either push vehicles from between the buffers or at the side of vehicles, outside the rails. Contractors’ and traders’ cooies must not be allowed to move vehicles at stations except under the orders and personal supervision of the shunting supervisor.

(5) Railway servants and others taking shelter under vehicles.—No one should be allowed to sit or lie under vehicles.
(6) *Shunting staff not to stand on tie-rods, axle-boxes, buffers of vehicles or of engines.*—The shunting supervisor must not allow anyone to ride on tie-rods, axle-boxes buffers of vehicles or engines.

(7) *Precaution when coupling or uncoupling vehicles.*—(a) When vehicles are coupled or uncoupled during shunting operation (other than hump shunting) the vehicles are not to be moved until the coupling coolie has got clear of the vehicles.

(b) No one must get between a vehicle and the front of an engine fitted with a cow-catcher for the purpose of coupling up), until the engine has come to a stand.

(8) *Couplings hanging during shunting operations.*—Couplings must not be allowed to hang during shunting operations. These must be hooked on to the bracket provided for the purpose.

(9) *Passing between buffers.*—If it is necessary to pass between two vehicles with their buffers within two yards of each other, the staff must go under the buffers and not between.

(10) *Working of stone trains at night.*—No stone train is allowed to load or unload at night except in cases of emergency and under special orders of the subordinate-in-charge.

(11) *Precautions to be taken by guards of stone trains.*—Guards of ballast trains must remain in charge of their trains so long as coolies are in the trucks or any shunting is to be done. They must be specially careful that all the coolies are seated on the floor of the trucks while shunting is being carried on. The guard is responsible that no coolies take rest or shelter beneath wagons or close alongside the truck, and must insist on the driver sounding his whistle before moving the engine. Before a stone train is moved, the driver must give two clear whistles at an interval of half a minute as a warning to the coolies that the train is about to move. Before this, the guard must have walked along the whole length of the train from his van to the engine to satisfy himself that there are no people sheltering beneath the vehicles. This applies to all cases where the train has been more than an hour standing.

(12) *Guards of stone trains responsible for detaching unfit vehicles from stone trains.*—The guard-in-charge is responsible for seeing that vehicles, which have not correct doors, fittings and are dangerous for the carriage of coolies, do not run on the trains, and that they are duly cut off for repairs. As an added precaution of overseer in charge should inspect all vehicles in use at least once a month and see that their defects are removed.
(13) Regulation speed of shunting operations.—The regulation speed of shunting operations (other than hump shunting) is 8 miles an hour, which must not be exceeded. Staff conducting shunting operations must exercise caution and exhibit signals for the shunter or driver to reduce speed when pushing or approaching vehicles.

(14) Responsibility of guard or shunting supervisor for shunting of complete trains in the station yard.—Whenever a complete train of any description is to be shunted from one line to another, or placed in, or taken out from a siding, such as in the process of crossing or giving precedence to another train, the guard or shunting supervisor in charge of the train will supervise the shunt and will be responsible—

(a) that points and crossings are correctly set for the shunt;
(b) for exhibiting the necessary signals to the driver performing the shunting; and
(c) for seeing, on completion of the shunt, that the crossings are clear.

(15) Securing of vehicles in sidings.—Vehicles standing on sidings must be coupled together, and have their brakes well pressed down and fastened, the vehicles at each end being also sprocketed.

(16) Motor trolley and locomotives should in no case be run in opposite directions on the same line.—If it is necessary to run the trolley at the same time as the engine in the same direction the trolley should in all cases follow the train.

(17) A push trolley nearing a locomotive from the opposite directions should be removed from the line at least 2,000 feet ahead of the locomotive.

At night time a push trolley preceding a locomotive should show a red light to the loco driver, so long as it is on the track and when it has been removed the light should be turned green to show the loco driver that the line is clear.

(18) No unauthorised push or motor trolleys should be allowed to make use of the track without a proper permit.

(19) During night running locomotives, push trolleys and motor trolleys should have “clear” front lights and “red” tail lights.

Running accounts

16.53. Accounts pertaining to the running of a casual railway must be kept in a clear and accurate manner so as to reflect the real cost of transportation of materials in the various “works” estimates. The system is briefly described below:—

Estimate No. 1.—It is an annual suspense estimate for the supply of power. The operation side will provide for the maintenance and running of
(a) the various types of heavy locomotives in use, and (b) the maintenance and running of the light locomotives used for odd jobs such as handling of a few trucks where it would be uneconomical to run a heavy locomotive. A Sentinel locomotive is a very useful type of light locomotive for use under this head. The outturn side of the estimate will provide for—

(a) the required number of steam hours of heavy locomotive at a worked out rate per hour;

(b) the required number of steam hours of light locomotive at a worked out rate per hour.

It will be necessary for the Sub-Divisional Officer in charge of Traffic to make an estimate of the total number of steam hours for which (a) heavy locomotives, and (b) light locomotives will be required to run, before the Sub-Divisional Officer, in charge of Power, can frame this estimate.

Estimate No. 2.—This suspense estimate will be for the maintenance of rolling stock. On the operation side there will be provision for the maintenance of all the rolling stock likely to be used during the year, the charges will differentiate between—

(a) rolling stock operated on the main line, i.e., between the terminus and the headworks stations,

(b) internal traffic rolling stock, i.e., trucks used only on the canal railway, principally in the headworks area, i.e., trucks not good enough to run on the Northern Railway line.

The outturn side of this estimate will provide for the hire charge of—

(a) the number of ordinary trucks,

(b) the number of trucks required for internal traffic.

An advance estimate of the total number of trucks to be used during the year will be necessary.

Estimate No. 3.—The final estimate, which will also be a suspense estimate, will be for—

‘Traffic Working on the Railway for the year 19’.

In this estimate the operation side will include the out-turn of estimates Numbers 1 and 2 together with the probable cost of establishment required for traffic working, see paragraph 16.51 and other items in connection with the full working of the line, i.e., provision for maintenance of the weighbridge (including one test by Northern Railway test wagon), and the turn table, as also the cost of lighting the sidings at headworks—cost of lighting oil for shunting staff and train guards, flags, etc.
Provision will also be made for vehicle replacements on account of trucks when handed over to the Northern Railways at the terminus, these minor parts replacements are supplied by the Northern Railway before the train examiner permits the stone trucks to go back on to the open line.

The outturn will provide for three items, viz:—

N. No. ——— trucks, miles @ A rupees/truck/mile
(main line running)
N. No. ——— trucks for internal @ B rupees/truck
traffic.
12 months—dak allowance and @ C rupees/month.
petty goods.

These outturn rates will thus accurately reflect the total cost of running the canal railway in the various “works” estimate to which they will be debited monthly, on the basis of the numbers of truck miles actually run over the main line, the number of internal traffic truck loads run and the months during which dak and petty goods were carried. As in all suspense estimates the actual total number of truck miles or total number of internal traffic trucks will not be exactly according to estimate—but the usual pro-rata adjustment will be made against the various works estimates in the March Supplementary Accounts. A specimen abstract of this estimate will be found at Appendix II.
APPENDIX I

SCHEDULE OF DIMENSIONS

I. Spacing of Tracks—
  Minimum distance centre to centre of tracks: ........ 14'–6"

  On curves, the following extra clearance should be given:

<table>
<thead>
<tr>
<th>Degree of curvature</th>
<th>Extra clearance in inches between adjacent tracks when there is no structure between tracks.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1°</td>
<td>4</td>
</tr>
<tr>
<td>1½°</td>
<td>6</td>
</tr>
<tr>
<td>2°</td>
<td>7</td>
</tr>
<tr>
<td>3°</td>
<td>8</td>
</tr>
<tr>
<td>4°</td>
<td>10</td>
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<tr>
<td>5°</td>
<td>11</td>
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<td>6°</td>
<td>12</td>
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<td>7°</td>
<td>13</td>
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<tr>
<td>8°</td>
<td>14</td>
</tr>
<tr>
<td>9°</td>
<td>16</td>
</tr>
<tr>
<td>10°</td>
<td>17</td>
</tr>
</tbody>
</table>

II. Minimum horizontal distances:
  Minimum horizontal distance from centre of track to any structure from rail level to 10' above rail level: ........ 5'–6"
  Minimum horizontal distance from centre of track to any structure except a platform, from 1 foot above rail level to 14'–6" above rail level: ........ 7'–0"
  Minimum horizontal distance of any telegraph post measured from the centre of and at right angles to the nearest track: ........ The height of the post + 7'–0"

Where the line is in cutting, a telegraph post erected outside the cutting must be a distance from the edge of the cutting not less than the total height of the post.
III. Minimum height
Minimum height above rail level of the lowest portion of any conductor crossing a railway, other than telegraph, telephone, and other such low tension wires, under conditions of maximum sag shall be:

- Up to 440 Volts:
  - Outside station limits
  - Inside station limits
    - Unearthened Neutral
    - Earthened Neutral
  - Minimum height above rail level to the lowest wire of any portion of a guard or guard cradle under conditions of maximum sag

IV. Maximum degree of curvature
- 10° (Radius 573')
- 5° (Radius 1,146')
- Recommended for sidings and reversing triangles (short curves only) 7° (Radius 819')

V. Gradients
- Maximum gradient
- Recommended

There should be no change in gradient within 100 ft of any points or crossings.

Maximum gradient in station yards unless special safety devices are adopted

Recommended level
(For this purpose a station yard may be taken to extend to a distance of 150 feet beyond outer-most points at either end of this station).

VI. Formation Widths
- In Embankment
- In Cutting (Excluding side drains)

VII. Sleepers
- Minimum length
- Minimum breadth
- Minimum depth
<table>
<thead>
<tr>
<th>VIII. Minimum number of sleepers per rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to and including 17 ton axle loads</td>
</tr>
<tr>
<td>Up to and including 18.5 ton axle loads</td>
</tr>
<tr>
<td>Up to and including 22.5 ton axle loads</td>
</tr>
</tbody>
</table>

Where "n" is the length of the rail in yards.

Note—(a) On bridges, where main sleepers rest directly on longitudinal girders, the sleepers are to be spaced so as to allow not more than 1 foot 6 inches between the edges of adjacent sleepers and are to be not less than 6 inches deep exclusive of any notching which may be required to allow for cover plates, number 6.

(b) The length of these sleepers laid on longitudinal girders may be reduced to not less than 1 foot shorter than the distance outside to outside of the planks.

IX. Ballast

| Width of ballast at level of foot of rails | 11'-0" |
| Depth of ballast below sleepers            | 8'-0" |

X. Points and Crossing

| Standard points to be used | 1 in 8½ |
| Diamond crossings, not flatter than       | 1 in 10 |

XI. Platforms

| Height of coping above rail level          | 2'-0" |
| Maximum and minimum distance from centre of track to face of platform coping | 5'-6" |

XII. Ash Pits

| Average depth | 2'-6" |
| Clear length at bottom | 65' |

XIII. Sidings and loop lines

(i) Minimum clear length of sidings on main lines of the Northern Railway equals 2,200 feet.

Note—This allows for H.G. engines carrying about 32 trucks or wagons.

(ii) Minimum distance centre to centre between converging tracks where fouling boards should be placed, varies with the types of track layouts. But it is safe to place the fouling board where the minimum distance centre to centre of track is 14'-6".

XIV. Dimensions of S.V.C. trucks.

<table>
<thead>
<tr>
<th>Description</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of truck proper</td>
<td>26'-10&quot;</td>
</tr>
<tr>
<td>Length of truck buffer to buffer</td>
<td>30'-0&quot;</td>
</tr>
<tr>
<td>Width of truck</td>
<td>9'-4&quot;</td>
</tr>
</tbody>
</table>
MANUAL OF IRRIGATION PRACTICE

(iv) Height of truck floor above rails .. 4'—4'
(v) Height of sides above floor .. 2'—3'
(vi) Height of end flaps .. 1'—2'
(vii) Size of doors on either side .. 8'×2'—6'
(viii) Tare weight .. 11 tons 12 Cwt.
(ix) Carrying capacity .. 20½ tons
(x) Cubic capacity for stone .. 450 cft.

These trucks are all low sided, and have one hinged door on either side. Both end flaps are hinged and drop over buffers. All the trucks have vacuum and hand brakes.

XV. Dimensions of Northern Railway Trucks.

The dimensions of trucks and wagons in use on the Northern Railway are very variable, but the average length over buffers may be taken as 25'—5" and the floor level of the truck as 4' above the rail level.

XVI. Dimensions and carrying capacity of the goods locomotives in use on the Northern Railways.

(i) The lengths of buffer to buffer of the various types of goods locomotives in use on the Northern Railways are as below:

"N" class .. 70'—6'
"XA" class .. 62'—0'
"H.G." class .. 60'—4'
"M.G." class .. 59'—2'
"S.G." class .. 53'—10" (maximum)
"M" class .. 51'—8'
"PT" class .. 43'—8'

(ii) The following table gives some idea of the average gross load which can be hauled by different engines:

<table>
<thead>
<tr>
<th>Grade group</th>
<th>N</th>
<th>ROG</th>
<th>ROG</th>
<th>ROG</th>
<th>Tons</th>
<th>Tons</th>
<th>Tons</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in 360 or flatter</td>
<td>..</td>
<td>3,100</td>
<td>3,225</td>
<td>3,565</td>
<td>4,995</td>
<td>1,250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in 100 or flatter</td>
<td>..</td>
<td>Not used</td>
<td>400</td>
<td>400</td>
<td>425</td>
<td>400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in 50 or flatter</td>
<td>..</td>
<td>Ditto</td>
<td>Not used</td>
<td>340</td>
<td>385</td>
<td>320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of quantity</td>
<td>Amount of expense</td>
<td>Rate</td>
<td>Amount</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>----------------------------</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rs.</td>
<td>A. P.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 months</td>
<td>Establishment</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>679</td>
<td>0</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>0</td>
<td>Month</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7,469</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 month</td>
<td>Do</td>
<td>1,131</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,121</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,100 Nos.</td>
<td>Vehicle replacements</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 months</td>
<td>Lighting oil</td>
<td>8</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>96</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 months</td>
<td>Maintenance turn table</td>
<td>50</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>L.S.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 months</td>
<td>Maintenance weigh bridge</td>
<td>350</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>350</td>
<td>L.S.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160 Nos.</td>
<td>Hire of trucks</td>
<td>15</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5,400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,445 steam hours</td>
<td>Heavy locomotive hours</td>
<td>6</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>9,934</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3,000 steam hours</td>
<td>Light locomotive hours</td>
<td>3</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7,875</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>12 months</td>
<td>Sheds, etc.</td>
<td>61</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>61</td>
<td>L.S.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 months</td>
<td>Lighting siding and cost of balls</td>
<td>50</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>600</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>34,056</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUTTURN</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>22,827 Nos.</td>
<td>Track miles</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22,827</td>
<td></td>
</tr>
<tr>
<td>3,587 Nos.</td>
<td>Intercity traffic trucks</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10,029</td>
<td></td>
</tr>
<tr>
<td>12 months</td>
<td>Dak allowances and earnings petty goods</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,200</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>34,056</td>
</tr>
</tbody>
</table>
SCHEDULE OF DIMENSION

XVII. Miscellaneous

Maximum clearance of check rail opposite nose of crossing 12"

Maximum clearance of check rail opposite nose of crossing and at heel of switch rail 11"

Minimum height above rail level for discharge orifice of water tanks or water cranes 12'—0"
CHAPTER NO. 13

LEVELLING

"Levelling" is the method of determining the relative heights of points on the earth surface. It deals with measurements in a vertical plane.

The equipments for leveling consist of a level, levelling staff, a chain or tape for measuring horizontal distances and a Field Book for recording the readings.

The level consists of a telescope with a diaphragm carrying horizontal and vertical cross wires, a long spirit level attachment and arrangements for revolving the telescope in azimuth about its vertical axis and for swinging its line of collimation slightly in a vertical plane about its transverse axis. The telescope can be so adjusted that a line of sight, or line of collimation of the telescope is directed to a graduated staff (levelling staff) held vertically at the point where a height measurement is required. There are various types of levels commonly used viz. Dumpy level, Y level, the Cooke Reversible level, the Clinometer level and the Tilting level.

Leveling staff is used to determine the vertical distances of points (b) below the horizontal line of sight. The leveling staff is simply of 2 types viz. Self-Reading Staff and Target Staff. The most commonly used levelling staff is the one with three telescopic lengths. Since it can be read directly by the person conducting the level operations, it is called a Self-Reading Staff. The staff commonly used is 14' long with a bottom length of 5 ft. and the two telescopic lengths of 4.5 ft. each. The levelling staff is made of well seasoned, hagony wood adequately protected with brass mountings. A levelling staff is graduated into feet (tents and hundredths). The figures indicating feet are printed in red on the left hand side. The odd tenths of a foot are marked by black figures on the right hand side. Each figure is exactly one tenth of a foot so that the bottom of the figure indicates the even tenth.

The staff appears up side down when viewed through the telescope so that readings are taken from above down-wards.

Adjustment of the Level. The adjustments of a level are of two kinds— (1) Temporary Adjustments and (2) Permanent Adjustments.

TEMPORARY ADJUSTMENTS

The temporary adjustments are setting up, levelling and focussing and are performed at each set-up of the instrument. They are imperative before taking the readings. The temporary adjustments are carried out while setting up the level, planting the tripod and focussing eye-piece and object glass to eliminate Parallax.
Before taking out the instrument from the box, the position of various components of the instruments have to be observed carefully so that the instrument can be replaced in its proper position without any difficulty. For setting up the level the clamp screw of the instrument is fixed on the Tripod by holding it in the right hand and by turning round only the lower part of the instruments with left hand. The instrument is screwed firmly.

After the instrument has been placed at a convenient height with Tripod legs separated well apart and the Tri-brach Spring as level as can be judged by the eye, the foot screws are brought in the Centre of their run. By fixing only 2 legs firmly on the ground and by moving the third leg to the left or right the main bubble is brought approximately in the Centre. Then the third leg is moved in or out until the bubble is approximately in the Centre. Lot of time is saved if nearly all the leveling is done by means of Tripod legs.

The telescope is placed parallel to a pair of foot screws and the bubble is brought to the centre by turning these screws equally either both inward or both outwards. The telescope is then turned through 90 degree so that it lies over the third foot screw and the bubble is brought in centre by turning this screw. The process is repeated till bubble remains in the centre of its run in both positions at right angles to each other. The Eye Piece is moved in and out until the cross hairs are distinctly seen. The telescope is directed towards the staff and on looking through the Eye Piece, the image of the staff is brought between the vertical hairs. The focusing screw is adjusted until the parallax is eliminated. The level is thus set and focussed for use in the field.

PERMANENT ADJUSTMENTS

It is desirable that the permanent adjustments of the instrument should be as perfect as possible and should be made, if necessary, in Headquarters before leaving for field work. The essential adjustments are—

1. To make the line of collimation, that is, the line joining the central intersection of the cross wires with optical centre of the Object Glass, coincide with the geometrical axis of the telescope, or at right angles to the vertical axis and (ii) to make the axis of the bubble tube parallel to the line of collimation.

However, if care is taken of such matters as the equality of length of fore and back-sights, any error due to imperfect permanent adjustment is eliminated.

These are points of reference and are of various types according to the nature of permanency required. There are generally 4 kinds of Bench Marks:

(a) G. T. S. (Great Trigono Metrical Survey).
(b) Permanent.

(c) Arbitrary, and

(d) Temporary.

1. **G.T.S. Bench Marks**—These are the bench marks established with very high precision all over the country by Survey of India Department. Full descriptions of Survey of India Bench Marks are given in the Levelling Pamphlet of the area. The pamphlet is available from the Director Geodetic Branch, Survey of India, Dehradun. The position of G.T.S. Bench Marks is also marked on the G. T. S. Survey Sheets.

2. **Permanent Bench Marks**—These are established between the G.T.S. Bench Marks on clearly defined and permanent points by various agencies carrying out the construction works etc. in the field. Their positions are marked on a flat surface by a rectangle or in the form of broad arrow and horizontal groove.

3. **Arbitrary Bench Marks**—They are the reference points whose elevations are arbitrarily assumed. They are used in small levelling operations.

4. **Temporary Bench Marks**—They are the reference points established at the end of day's work so that when the work is resumed, it is continued with reference to this Bench Mark.

When difference of level between two points is required, the levelling instrument is set up at a convenient spot and adjusted at a position from which both the points can be seen. The spot should be so selected that it is approximately mid way between the two points and the distance of the spot from the points to be sighted is such that the staff can be read distinctly (within 3\(^\circ\)).

The staff-holder is then sent to one of the points with the graduated staff, which he holds vertically, the lower end resting on the point whose level is required. For holding the staff in a vertical position, the staff-men stands behind the staff, holds together with the heel of the staff between the toes and holds it between the palms of his hands at the height of his face.

The staff-reading is taken in the following order:

(j) Having set up the levelling instrument carefully the telescope is directed towards the staff held vertically;
The st. ff is brought between the two vertical hairs and reading taken at the interception of the hair ensuring all the time that the b.bble is central;

The st. ff is then set to the second point and the process repeated.

Where the levels of many points are required several may be read from one position of the level. The last reading taken from any position is called a 'Back Sight'; the last reading from any position is a 'Fore Sight' and all others are called 'Intermediates'.

It is usual to assume some arbitrarily horizontal plain or level surface lying below all the points. This is called 'Datum'.

The level of each point is then read by giving its height above this datum. This height is called 'Reduced Level' of the point.

The reduced level of the collimation plane of the level in any position is called the 'Height of the instrument'.

The difference of levels from point to point is called a 'rise or fall' according to whether the second point is higher or lower than the first.

There are two systems of working out the reduced levels of points:

1. The subtraction of levels:
2. The addition of levels:

In this system the elevation of the plane of collimation (height of instrument) for every set up of the instrument is determined and then the reduced levels of various points with reference to this line of collimation are determined. The elevation of plane of collimation for the first set up of the level is determined by adding the back-sight to the reduced level of the bench mark. The reduced level of the intermediate points and the first change points are obtained by subtracting the st. ff reading of this point from the height of the instrument. When the instrument is shifted to the second position a new plane of collimation is set up. The levels of the two planes of collimation are correlated by means of the back-sight and fore-sight taken on the change point. The elevation of this plane is obtained by adding the new back-sight taken on the change point from the second position of the level to the reduced level of the first change point. The reduced level of the successive points and the second change point are found by subtracting their st. ff reading from the elevation of this plane of collimation. The operation is repeated until all the reduced levels are worked out. On completing the reduction of the levels, accuracy of the arithmetical calculations is checked. The difference between the sum of back-sight and sum of the fore-sight should be equal to the difference between the first and last reduced level.
LEVELING

The Rise and Fall system.—It consists in determining the difference of levels between consecutive points by comparing each point after the first with that immediately preceding it. The difference between their staff reading indicates a rise or a fall according as the staff reading at the point is smaller or greater than at the preceding point. The reduced level of each point is then found by adding the rise or subtracting the fall from reduced level of the preceding point. Arithmetical check is necessary in this system also. The difference between sum of the back-sight and sum of fore-sight is equal to the difference between sum of the rises and that of the falls and is equal to the difference between the first and the last reduced level.

Comparison of the two systems.—The height of instrument method is less tedious, more rapid and involves less calculations. However, in this system mistakes made in reduction of levels of the intermediate points remain undetected. In the rise and fall system, however, there is a complete check on each of the intermediate reductions. While the first system is generally used in profile levelling and in setting out levels on construction work, the second one is preferred for differential levelling, check levelling and other important works.

The following precautions may be taken in entering the staff reading in a field book:

(i) The readings should be entered in the respective columns and in order of their observation;
(ii) The first entry on the page is always of back-sight and the last one always a fore-sight;
(iii) In carrying forward the reading from one page to the next, if the last entry happens to be of intermediate sight, it is entered in both intermediate sights, and fore-sight columns and in the back-sight and intermediate sights columns as a first entry on the next page. The entries in the remaining columns against it should also be repeated on the next page;
(iv) The fore and back sights of the change point should be written in the same horizontal line;
(v) The R. L. of the plane of collimation should be written in the same original line opposite the back-sight;
(vi) Bench marks, change points and other important points should be described in remarks column preferably with sketches.

1. Differential levelling.—It is the operation of levelling to determine the elevation of points some distance apart or to establish bench marks;
2. **Check Levelling** — It is the operation of running levels for the purpose of checking a series of levels, which have been previously fixed. At the end of each day's work, a line of levels is run, returning to the starting point of that day with a view to checking the work done on that day.

3. **Profile Levelling** — It is the operation in which the object is to determine the elevation of points at known distances apart along a given line, and thus to obtain the accurate outline of the surface of the ground. It is also called the Longitudinal Levelling or Sectioning.

4. **Cross-Sectioning** — It is the operation of levelling to determine the surface undulations or the outline of the ground transverse to the given line and on either side of it.

5. **Reciprocal Levelling** — It is the method of levelling in which the difference in elevation between two points is accurately determined by 2 sets of observations when it is not possible to set up the level midway between the two points.

6. **Barometric Levelling** — It is the method of levelling in which the altitudes of points are determined by means of Barometre, which measures atmospheric pressure.

7. **Hypsometry** — It is the method of levelling in which the heights of mountains are found by observing the temperature at which water boils.

8. **Trigonometrical Levelling** — It is the process of levelling in which the elevations of points are computed from the vertical angles and horizontal distances measured in the field.

The permissible closing error in levelling may be expressed

\[ E = C \sqrt{M} \]

Where \( E \) = the error in feet, \( M \) = the distance in miles, and \( C \) = the constant.

The value of the constant \( C \) depends upon the quality of the instrument, the observer's care and skill, the character of the country and the atmospheric conditions. However, the generally accepted values of \( C \) are as under:

1. **Rough Levelling**  \[ E = \pm 0.4 \sqrt{M} \]
2. **Ordinary Levelling**  \[ E = \pm 0.1 \sqrt{M} \]
3. **Accurate Levelling**  \[ E = \pm 0.05 \sqrt{M} \]
4. **Precise Levelling**  \[ E = \pm 0.02 \sqrt{M} \]

The standard fixed by the International Geodetic Association for levelling of high precision is \( E = \pm 0.004 \sqrt{M} \).
CHAPTER 19

BENCH-MARKS

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CHAPTER 19

BENCH-MARKS

INTRODUCTION

19-0 Bench-marks are the basis of all work into which the determination of height enters. They provide a standard datum on which all level surveys should be based.

All level surveys are now referred to bench marks fixed by the Trigonometrical Survey of India. The values of these bench-marks will be found in books published by the Survey of India and entitled "Leveling of Precision in India: Heights of Bench-marks". The heights of the bench-marks given in these books are the finally corrected heights deduced from the final adjustment of the whole net-work of levelling lines in India. They are referred to mean-sea-level.

DEFINITION, LOCATION AND DESCRIPTION OF BENCH-MARKS

19-1 A bench mark may be defined as a mark, generally located on a permanent structure, whose height above a fixed datum is known.

As bench-marks are intended for future reference they should, if possible, be located on permanent structure such as
BENCHMARKS

masonry buildings, bridges, etc., and fixed in a position where they will be secure from injury, easily accessible and readily identifiable from their description.

A brief description, which will serve to locate and identify each benchmark, should be recorded in the level book and also in some permanent record such as a 'register of benchmarks'.

BENCHMARKS USED BY THE SURVEY OF INDIA

191 The benchmarks used by the Survey of India are ordinarily of four classes: Standard Embedded (2 kinds), Rock-cut and Inscribed.

Standard Benchmarks—Standard benchmarks are of various designs. They are only erected in important towns where arrangements for their preservation can be made and where it is desirable that conspicuous marks should be provided. Each standard benchmark is described in detail in the book, published by the Survey of India, to which it belongs.

Embedded Benchmark—Type A.—The type A benchmark (see diagram in Appendix I at end of the Chapter) consists of a galvanized iron pipe 6 inches in diameter and 3 feet long standing on a slab of concrete 1 foot square and 2 inches thick. The larger end of the pipe is provided with four flanges which rest on the slab of concrete. The upper surface of the slab is about 4 feet 9 inches below ground level so that, when fixed in position, the top of the pipe is about 1 foot 9 inches below the surface of the ground. The pipe is supported by well rammed earth up to 8 inches from the top. A solid cast-iron cap is screwed and riveted to the upper end of the pipe and bears the inscription shown in the margin. A strongly built brick vault, resting on concrete foundations, covers and protects the benchmark. Vertically above the pipe there is a 6 inches square aperture in the crown of the vault and over this aperture there is a hollow masonry pillar carrying a mark stone bearing the inscription shown in the margin.

- G. T. SURVEY

Benchmark

- UPHILL MARK

The whole structure is below the surface of the ground except the upper-mark stone which projects a few inches above it.

Embedded Benchmark—Type B.—The type B benchmark (see diagram in Appendix I at end of the Chapter) consists of a dressed stone 18" x 12" x 12" set on a bed of concrete
3 feet square and 2 feet thick and surrounded by brickwork G. T. S. M.

set in cement. The upper surface of the stone, which is 18" x 12", is flush with that of the brickwork and is about 2 feet below ground level. The upper surface of the stone is inscribed as shown in the margin. The central mark is a 3 inch square, a quarter of an inch deep.

Note—In the 1960 edition of "Levelling of precision in India—Heights of Bench-marks" embedded bench-marks are described as interred bench-marks.

Rock-cut bench-mark—Type C.—A rock-cut bench mark (see diagram in Appendix I at the end of the Chapter) consists of the inscription shown in the margin deeply engraved on solid ground rock. The diameter of the circle is from 1½ to 2 inches and the letters are of about the same height. The inscription is protected by a hollow masonry pillar 2 feet square and 1 foot high, on the top of which is fixed a stone bearing the inscription G. T. Survey O.

Upper-mark

Inscribed Bench-marks—These usually consist of one of the inscription given below according to the amount of space available,

G. T. S. O. or B O M or O B. M.

The bench-mark is cut on the rock ‘in situ’, the flooring of verandahs the coping of bridges or culverts, mile stones, stone steps of houses, etc. They are not protected.

In the case of a standard bench-mark the published height is that of the top of the monolith. In the case of bench-marks inscribed with □ or O the height is that of the surface within the square or circle. When, instead of a square or circle, there is some other mark or inscription the height refers to the portion of the stone where the inscription is cut.

Publications by the Survey of India Containing Heights of Bench-Marks

193. The description and height of all bench-marks fixed by the Trigonometrical Survey of India will be found in books
BENCHMARKS

published by the Survey of India and entitled "Levelling of Precision in India—Heights of bench-marks".

Each book contains a description and the height of all bench-marks in an area of 4° in latitude by 4° in longitude. Each of these areas is given a sheet number and is divided up into 16 parts lettered from A to P, each part being 1° square.

The bench-marks are numbered according to the degree sheet in which they fall, the numbering in each sheet being quite independent of that in the surrounding sheet. To indicate a particular bench-mark, therefore, it is only necessary to give its number and the degree sheet in which it falls, e.g., bench-mark No. 5 in degree sheet 44 A is written E. M. 5/44A.

The degree sheets containing bench-marks in which the Punjab Irrigation Branch is interested are numbers 38, 39, 43, 44, 52 and 53, the most important sheet being No. 44.

The map at the end of the chapter (Appendix II) shows the lines of levelling in sheet No. 44.

LEVEL DATUM OF EARLY CANAL PROJECTS.

19.3 Irrigation engineers must bear in mind, that prior to the publications of the books referred to in paragraph 19.3, the construction of the early canals was based either on the old heights of the G. T. S. bench-marks, which were determined during the G. T. S. levelling operations of 1862, or on some arbitrary datum.

Levelling operations carried out in the Ferozepore division of the Sindh Canal during 1918-19 showed that the heights of the G. T. S. bench-marks in that division, as given in degree sheet No. 44 referred to in paragraph 19.3, were 0.2 to 0.3 feet lower than those determined in 1882 on which the construction of the canal was based.

Before levelling operations are started in any area the engineer-in-charge should ascertain on what datum the heights of existing canal bench-mark are based.

CANAL BENCHMARKS

19.5 As canals in the Punjab are designed to work with very flat water slopes, the average being about one foot in a mile, bench-marks, whose height above a definite datum has been accurately determined, should be fixed at frequent intervals along every irrigating channel. At least one bench-mark should be fixed on every bridge, fall, regulator and other important masonry work.
The most suitable type is the ‘inscribed bench mark’ which can conveniently be cut into the parapet, wing wall or other suitable place on a masonry work. At least one and preferably two bench-marks should be fixed on each work.

C. B. M.

A suitable inscription is

\[ G = \text{The central circle} \]

which should be at least 1\(\frac{3}{4}\) inches diameter, is the bench-mark and the number below it, is the serial number of the bench-mark as recorded in the bench-mark register.

An interred (embedded) bench-mark (Type A) should be constructed in every canal inspection house compound. This type of bench-mark must be protected from the action of salts in the soil. For protection it is suggested that the concrete foundations of the brick vault and pipes should be constructed on clean dry coarse sand (tilt is not suitable), whose depth should be at least 1 foot. The filling round the pipe and the outer face of the vault should be sand.

As an additional protection the outside face of the vault and pillar carrying the mark-stone should be sprayed with hard bitumen.

The reduced value of the canal bench-marks should be based on G, T.S. datum and obtained by double levelling in a closed circuit. In special circumstances competent authority may order precision levelling being carried out. Special level books must be used for such levelling and they must be carefully recorded. After the completion of the circuit, the results should be abstracted as per sample at Appendix III. This forms a very useful record and should be carefully preserved.

In the Lower Chanab East Circle, where the work of fixing bench-marks has been recently completed, it was found that best results were obtained if the work was centralised in the circle office. The Superintending Engineer arranged not only for the levelling operations, but also for preparing the registers and issuing Addenda and Corrigenda when necessary.

**Bench-Mark Registers.**

A suitable register must be prepared and maintained in which the description, location and height of each bench-mark is recorded. A separate register should be prepared for each 'canal division' and a copy of it should exist in the Circle, Divisional and
BENCH-MARKS

Sub-divisional Library. Each sectional overseer should be supplied with a register containing details of the bench-marks in his section.

A suitable form of register will contain the columns noted below:

(a) Reduced distance of structure on which bench-marks inscribed.
(b) Description of bench-mark.
(c) Serial number of bench-mark.
(d) Height of bench-mark.

When a structure, on which a bench-mark exists, is altered and the bench-mark is dismantled, a new bench-mark should, if possible, be inscribed on the new structure and its description and height recorded. Such changes should be recorded in the bench-mark register by issuing addenda and corrigenda slips.

Suitable instructions for the maintenance of bench-mark registers should be given in the register.

Typical instructions will be found in the appendix IV at the end of this chapter.

MATTERS OF IMPORTANCE.

197 Irrigation engineers should give the following important matters their attention:

(a) The reduced distance of the structure on which a bench-mark is inscribed and a detailed description of the bench-mark should be recorded in the level book.

(b) When a structure is constructed or remodelled the description and height of the bench-mark to be used for execution of the work should be recorded on the drawing of the structure. This should be called the 'referring bench-mark'.

When the structure has been completed the description and height of any bench-marks inscribed on it should be recorded on the completion plan.
## APPENDIX III
### LOWER GUGENA DIVISION
#### ORDINARY DOUBLET LEVELLING

**Circuit No. 17.**

Starting from U.S. pavement Bridge Head Minor No. 2, Tarharni distributed at C.B. M. No. 317 and going R. L. = 562.438 (a) along it to the tail and then finishing at U.S. pavement Bridge R. D. 75,009 Tarharni Disty.

C.B. M. No. 1408

<table>
<thead>
<tr>
<th>Reduced Distance</th>
<th>Description of Benchmark</th>
<th>Reduced Level OBSERVED</th>
<th>Reduced Level CONNECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>As obtained by B. Halim Singh</td>
<td>As obtained by B. Bhaskar Anand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>As obtained by B. Halim Singh</td>
<td>As obtained by B. Bhaskar Anand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>As obtained by B. Hanum Singh</td>
<td>As obtained by B. Bhaskar Anand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Accepted Benchmark Levels</td>
<td></td>
</tr>
</tbody>
</table>

**Minor No. 3 Tarharni Distributor**

<table>
<thead>
<tr>
<th>Head Mr. No. 2</th>
<th>U.S. P.T. Bridge</th>
<th>317</th>
<th>562.438</th>
</tr>
</thead>
<tbody>
<tr>
<td>16000</td>
<td>D.R. S. Wing U.S. P.T. Bridge</td>
<td>1408</td>
<td>559.024</td>
</tr>
<tr>
<td>16000</td>
<td>U.S. L. Wing Flame</td>
<td>1401</td>
<td>554.538</td>
</tr>
<tr>
<td>20700</td>
<td>U.S. P.T. Bridge</td>
<td>1402</td>
<td>551.024</td>
</tr>
<tr>
<td>35500</td>
<td>U.S. L. Wing Tail Cluster</td>
<td>1403</td>
<td>548.024</td>
</tr>
<tr>
<td>35500</td>
<td>D.R. S. Wing Tail Cluster</td>
<td>1404</td>
<td>545.024</td>
</tr>
</tbody>
</table>
APPENDIX IV

INSTRUCTIONS FOR MAINTENANCE OF A BENCH-MARK REGISTER

1. This register will be maintained in the Circle, Divisional and Sub-Divisional offices. Each sectional overseer should be supplied with a copy of the portion of the register containing bench-marks in his section.

2. The individuals, noted below, will be responsible for the maintenance of the registers in their possession:
   - Circle office register
   - Circle Head Draftsman
   - Divisional office register
   - Divisional Head Draftsman
   - Sub-divisional office register
   - Sub-Divisional Officer
   - Section register
   - Section Overseer

3. When the individual, who is responsible for the maintenance of a register, is transferred he should record a certificate in the form given below on the fly-leaf of the register:

   "Certified that this register has been carefully maintained by me during my incumbency of the........ The last addenda and corrigenda posted by me is No........ dated............."

4. Sectional overseers will submit, on the first day of each month, a return in which details of any bench-mark damaged, replaced or altered should be reported. New bench-marks should also be included in this return. The return should be submitted to original to the Superintendent Engineer through the Sub-divisional and Divisional Officer.

   If no changes have taken place during the month a "nil" report should be submitted.

5. Alterations in the register will be made by Addenda and Corrigenda slips, which will be issued by the Superintendent Engineer. Addenda and Corrigenda slips will be pasted on the blank page opposite the page to which they refer.

   An account of the Addenda and Corrigenda slips issued will be maintained on the last page of the register by the individual responsible for the maintenance of the register.
## CHAPTER 21
WELL MEASUREMENTS
OBSERVATION AND RECORD

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</thead>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selection of wells</td>
<td></td>
<td></td>
<td>21.2</td>
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<tr>
<td>Method of observation</td>
<td></td>
<td></td>
<td>21.3</td>
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<td>Method of Record</td>
<td></td>
<td></td>
<td>21.4</td>
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<tr>
<td>Miscellaneous instructions</td>
<td></td>
<td></td>
<td>21.5</td>
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<tr>
<td>Appendix</td>
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<td></td>
<td></td>
</tr>
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</table>
CHAPTER 21
WELL MEASUREMENTS—OBSERVATIONS AND RECORD

THE OBJECT OF WELL MEASUREMENTS

21.1. When irrigation is started in a tract, the channels, the irrigation field ditches, together with road and railway embankments tend to block the natural drainage of the countryside, enabling rain accumulations to seep into the soil to a greater extent than before. Additionally, that portion of the seepage, from the canals, distributaries and water courses, which is not re-evaporated from the surface, sinks to the subsoil water-table. Consequently the spring-level rises in some parts, in the course of years, the low-lying areas become water logged. It is important, therefore, to watch the gradual rise of the spring-level. This is done by regularly observing the water levels of a large number of selected wells all over the area of every canal system.

SELECTION OF WELLS

21.21. A detailed list of the wells under observation in each circle is well list and given in the Circle list of wells and the position of each is shown on the well Plan of the canal. A copy of this plan is supplied to each division, and should be carefully kept and used solely for purposes of reference in questions connected with the spring-levels. Tracings showing the position of the wells in each sub-division, are supplied from time to time for the use of sub-divisional officers.

21.22. The wells are ranged along or near lines of cross sections traversing the entire canal tract. Each well is distinguished by a Roman numeral indicating the line of cross section to which it belongs and below the Roman numeral by a number (in Arabic numerals) showing its serial number in the line of cross section. A cast iron plate, called the well plate, is permanently fixed in the masonry of each well bearing on it in raised figures both the cross section and serial number of the well. These plates are of a standard pattern and can be obtained from the Superintendent, Irrigation Works, Nangal Township.

1.23. Every well plate has a projection from which all measurements of the depth of water surface in the well are made. This is called the measuring point. After the plates have been fixed, the reduced levels of the measurement points are ascertained by levelling from standard bench-marks. The lines of levels should be run by two independent levelers, and divisional officers should satisfy themselves that all the reduced levels of the measurement points have been carefully verified before finally accepting and reporting them. For the purpose of well measurements, the levels of the measuring points need be reported up to one place of decimal only.
21.24. In order that the depth of water surface in the well as measured from the measuring point on the well plate should give directly the depth of subsoil water level below the average ground level in the vicinity of the well, it is necessary that the measuring point is fixed at the level of the average natural surface in the vicinity. When fixing well plates, it should be seen that this condition is satisfied as far as possible. In no case should the R.L. of the measuring point differ from the average natural surface level round the well by \( \pm 1.0' \) or more.

In the case of existing well plates which are fixed so that the measuring point is not within \( \pm 1.0' \) but is within \( \pm 3.0' \) of the average natural surface level a suitable correction should be used. This correction is equal to the difference between the R.L. of measuring point and the average R.L. of natural surface. When the R.L. of natural surface is higher than the R.L. of measuring point the correction is positive.

If in any existing well the R.L. of a measuring point differs from the R.L. of natural surface by \( \pm 3.0' \) or more, the measuring points should be refixed. If for any reason this cannot be done, the matter should be referred to the Superintending Engineer, Drainage Circle, for further instructions.

21.25. Opposite all provincial and circle well lines terminating on rivers, sites should be fixed for making observations of water surface level in the river simultaneously with the well measurements on the lines. Such sites should be distinguished by the Roman numeral of the well line opposite which the river site is situated and below the Roman numeral capital letters A, B, C, etc., should be used depending on the number of creeks which may flow, in various seasons. These river sites should be marked on the well Plan of the canal.

THE METHOD OF OBSERVATION

21.31. The depth of the surface of water in each well below the measurement point is measured twice a year, during the first week in June and the first week in October, by the Overseer in whose section the well is situated, or to whom the duty may be assigned by the divisional or sub-divisional officer. The measurements should be made to one place of decimal only. In the case of village drinking wells the measurements should be made either at daybreak or in the afternoon, that is, in each case, before the women of the village draw their morning or evening supplies of water. In the case of wells used for irrigation the observer should endeavour, as far as possible, to take the measurement when the well is not being worked, and at as long an interval as possible after the last working. If the well is not working at the time of measurement but has been worked during the previous 24 hours the interval which has elapsed since it was last worked should be noted. If the well be working or has only ceased working for
21.32. **WELL MEASUREMENTS—OBSERVATIONS AND RECORD**

A few hours the actual depth below measurement point should be recorded, but the observer should endeavour to ascertain by local enquiry what reduction in this depth would occur if the well were not worked and should separately propose for acceptance this modified depth.

21.32. The overseer should submit his report of well measurements in the form appended (stereo. I.B. No. 315) to the sub-divisional officer before the 15th June and 15 October. The sub-divisional officer should arrange to check a reasonable number of measurements either before or after the receipt of the overseer’s report. The sub-divisional officer’s check should include all wells whose water levels have been reported to differ by 2 feet or more in June or October measurements compared with those of the corresponding month of the previous year. He will then fill in column 11 of the form so as to show the reduced level of water surface in each well which he recommends for acceptance, and he should indicate the wells, the measurements of which he has personally checked by underlining with red ink their reduced level as shown in the last column. The assumed reduced spring-levels in wells which have been recently working should be shown in the last column in red ink figures. The sub-divisional officer should then keep a copy of the measurements in a register (stereo I.B. No. 316) and forward the overseer’s report in original to the executive engineer after entering on the back of it any remarks which he may desire to offer and detailing explanation in case of all those water levels that differ from the previous year’s observations by two feet or more. These reports are due in the divisional office on 1st July and 1st November and would be returned to the sub-divisional officer by the divisional office after completing their register, as laid down in paragraph 21.41, below.

21.33. In submitting detailed reasons for fluctuations of two feet or more with the corresponding observations of the previous year, the sub-divisional officer should particularly report if any of the following causes was in operation:

(a) Working of the well for which an incorrect allowance has been made.
(b) Failure of rain, scanty or excessive rainfall in the locality.
(c) If the well is old and not in use it may have got plugged.
(d) Proximity of ponds, channels or flowing river creeks in which conditions of water level of supply may have been different to those in the previous year.
(e) If the well has low Parapets, surface water might have entered into it.
(f) The well may have been in continuous use for a long period during drought prior to observations.
(g) The well may have been filled with canal water a few days before the observations. In such cases the period which has elapsed should be ascertained.

(h) River spill over the area in which the well is situated.

(i) Abnormal draw-off by mechanical pumping.

(j) Proximity of rice fields where rice was not cultivated in the previous year.

**THE METHOD OF RECORD**

21.41. A register should be maintained in the divisional office in the prescribed form (stereo I.B. No. 316). For those wells for which a correction is necessary, vide paragraph 21.24, the correction should be entered in red ink beside the R.L. of measuring point. The register should be posted from columns 9 and 11 of the reports received from the sub-divisional officers in stereo, I.B. No. 315. The entry from column 9 should be modified by applying the correction where necessary so as to bring the depth in relation to the natural surface. The modified depth so obtained should be entered as the numerator and the entry from column 11 indicating the spring level as the denominator of the fraction. The entries should be to one decimal place only. Care must be taken to show in each case the underlining which indicate the measurements which have been checked by the sub-divisional officer and to make the entries in red ink for the wells which were being worked at or near the time of observation. If the divisional officer accepts the sub-divisional officer's explanation and disagrees with the explanation offered in the previous years, he should record a definite statement to that effect.

21.42. The divisional register when completed should be forwarded to the superintending engineer at the latest by the 15th July and 15th November each year. For wells in which a fluctuation of two feet or more is found with the corresponding observation of the previous year a separate statement should be submitted along with the register of measurements to the superintending engineer in the form below:

Statement explaining rise or fall of 2' and more than 2' between well measurements of June/October.

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Circle Serial</th>
<th>Provincial Serial</th>
<th>R.L. at M.P.</th>
<th>Spring Level Rise/Fall</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>June</td>
<td>October</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

In case of double wells fill in both columns.
21.43. A register in a similar form should be maintained by the Superintending Engineer but such as to include the wells on each section line in all divisions. The reduced levels of water surface in all wells for the preceding June and October may be posted in the circle register from the divisional registers. The underwritings indicating the checks by the sub-divisional officers should be shown in this register also, while the spring levels of wells which were being worked at or near the time of observation will be entered in red ink, as in the divisional register. The circle register should be completed as quickly as possible.

21.44. The superintending engineer will scrutinize the divisional registers and at once draw the attention of executive engineers to any apparent discrepancies, or to any insufficiency in the checks made by the sub-divisional officers. He should also take steps to ensure prompt attention being given to any wells included in the Circle List of wells that may have been omitted from measurement. Where feasible such wells should be restored for measurement by fitting them with a 6-inch diameter porous concrete pipe; otherwise the abandoned well should be replaced by some other well suitably situated in its vicinity.

There should be no unnecessary delay in selecting a new well in place of an abandoned one. Four months should be ample to make any such changes and a new well should be ready in time for the next observation in June or October as the case may be.

All wells whose levels are affected by ponds and johars in their vicinity should be substituted by others suitably situated. When suitable wells are not available it may be necessary to sink observation pipes.

21.45. The circle register, along with the statement giving reasons for fluctuations of 2 feet or more in the spring levels, will then be forwarded by the superintending engineer to the superintending Engineer, Drainage Circle, at the latest by the 1st August and 5th December, respectively, each year. Particulars of newly selected wells should be reported by the local superintending engineers to the Superintending
Manual of Irrigation Practice

21.5—

Engineer, Drainage Circle, in the following form along with an index plan showing the positions of the new and old wells in relation to other wells in the vicinity:

.............................. Division

.............................. Circle

Particulars of the newly selected wells

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Date No.</th>
<th>Circle</th>
<th>Prov.</th>
<th>Well No.</th>
<th>Name of village</th>
<th>Name of Officer</th>
<th>Purpose for which intended</th>
<th>Diameter</th>
<th>R.L. of M.P.</th>
<th>R.L. of Average level of water</th>
<th>Distance from old well</th>
<th>Distance from end of well</th>
<th>Situation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<td>10</td>
<td>11</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Miscellaneous Instructions

21.5. Wells too near a supply or irrigating channel should not be lightly changed since in doing so the continuity of record is broken. If any such wells are proposed to be changed the case should be referred to the Superintending Engineer, Drainage Circle, stating whether substitute wells can be found or not. The substitute wells should not be closer than 1,000 feet from main canals and branches and 500 feet in the case of distributaries.

No observation pipe should be sunk within a radius of 500 feet from an existing well.

Galvanized iron pipes are of little use in alkaline soils as electrolytic action takes place and hastens corrosion. Black pipes coated with Khanki mixture should always be used.

Some wells are filled with canal water to improve the quality of water. It should be seen that no well under observation is so treated within two months of the date of the next well measurement.
## WELL MEASUREMENTS OBSERVATIONS AND RECORD

### APPENDIX

Report of Well Measurements

<table>
<thead>
<tr>
<th>Cross-section No.</th>
<th>Serial No.</th>
<th>Date of Observation</th>
<th>Height of observation</th>
<th>Earliest working depth as observed</th>
<th>Earliest working depth as observed since last working commenced</th>
<th>Depth of Strata below Measuring Point in Feet</th>
<th>Remarks by Over'Connor</th>
<th>Remarks by Sub-Divisional Officer</th>
<th>Remarks by Sub-Divisional Officer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<td></td>
</tr>
</tbody>
</table>


CHAPTER 22

RAINFALL—OBSERVATION AND RECORD

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General
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Registration of rainfall
Rainfall statistics
List of rain gauges by canals showing Indian Standard Time, corresponding to 08:00 Local Mean Time
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Specimen form Stereo J. B. No. 461
Form B
Form C
Form D

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CHAPTER 22

RAINFALL—OBSERVATION AND RECORD

GENERAL

22:10 Rainfall is defined as a shower of condensed atmospheric moisture falling visibly in separate drops. The extent of rainfall varies considerably over the surface of the earth and conditions of life—human, animal and plant in any area are greatly dependent on it.

In the Punjab, the incidence of rain throughout, and in the catchment areas of its rivers differs so markedly that some areas are desert and barren except where irrigation is practised, and others flourish on the ample rainfall received.

22:11 Rainfall is one part of a cycle of natural events which may be summarised as:

Rainfall cycle in nature.

(a) The diffusion of water vapour in the atmosphere by evaporation from water surfaces due to the heat of the sun, and by transpiration from plant life.

(b) The rising of this comparatively light moisture to the higher layers of the atmosphere, where reduced pressure and temperature cause condensation and cloud formation.

(c) Precipitation of rain due to supersaturation occasioned by further lowering of temperature and pressure in the upper layers of the atmosphere.

These changes are also associated with general movements of the atmosphere (wind) from one part of the earth to another, by reason of the varying pressures of the atmosphere at different points. These movements, in the neighbourhood
of hill and mountain formations, frequently occasion the necessary atmospheric changes of pressure and temperature to cause rain. It is for this reason that rainfall is frequent and heavy in favourably situated mountainous regions.

22:12 While the lives of all are indirectly influenced by the rainfall of the areas in which they live, utility of rainfall data, engineers, generally, are very directly concerned with rainfall. The irrigation engineer, in particular, must devote careful study to rainfall conditions, not only in the area where the irrigation of crops is to be practised, but also in the catchment areas of rivers. In the one case it will be possible to decide the amount and period of the supply of irrigation water required for crops, and in the other rainfall data will help to forecast seasons of good river supplies.

For estimation of floods in rivers and in drainage crossings, figures of rainfall intensities, or rainfall in one hour, are of great importance.

In the Punjab, where the subsoil water-table is rising in many irrigated tracts, rainfall data assists in the explanation and prediction of water-table level variations.

Rainfall reports are also of great assistance in the distribution of water over a canal system when water is short; for a good shower in one area may allow the requirements of others to be met. Timely knowledge of rainfall in the catchment is wasted by those responsible for the safety of canal headworks, so as to be prepared for the floods, and it is customary to provide this information as a matter of routine.

Additionally, considered rainfall data allows of better estimates of cropped areas and of financial returns to be expected from the various canals.

Rainfall data to be of any use, must be reliable and the figures representative of the area.

22:13 For this purpose the rain gauges must not only be efficiently built and correctly read, but also they should be evenly spaced throughout the area so that the data may be averaged correctly without recourse to weighting for special area. The records of a particular gauge relate, of course, to that site only and thus the larger the number of gauges the more accurate will be the results obtained from averaging the several values recorded. It is thus necessary to take into consideration the
map showing the sites of gauges, before accepting average figures. In this way the probable accuracy of the computation may be determined.

22.14 Rainfall in the Punjab plains may generally be looked upon as a blessing, in view of the beneficial results, on agriculture, which attend timely rains. But the engineers have also to consider the figures of expected run-off.

The relation between rainfall and run-off from a catchment is a subject of great complexity and uncertainty and it will suffice if it is stated that no better guide can be taken in estimating the run-off from an area, than to analyse the data available for a similar catchment. The area of the catchment and the rainfall data will of course be factors of importance, but there are many others to which careful consideration must be given. Amongst these, the type of surface, the shape, slope and general direction of the catchment may be remembered when considering the similarity of catchments and the run-off likely to be experienced.

In steep catchments where tree cover and plant life may be sparse, by reason of natural causes or even from excessive grazing, the run-off is very rapid. The resulting discharge may do great damage by forming ravines, and in the removal of soil from the catchments and from the margins of torrents. Such rapid flow-off also causes heavier discharges during short periods, in the torrents and rivers, than would be the case if trees and plants were present in the catchments to delay matters. Damage is also sometimes caused by the deposit of eroded sandy material on cultivated fields along the torrents lower down. If the available rain can be temporarily absorbed and the run-off spread out, the water will be available for irrigation and other uses over a longer period. Thus tree cover and plant growth may be looked upon as a form of delay action reservoir, holding up the rain in the spongy top soil and allowing a slower rate of run-off, which can be used with greater advantage. The conservation of forests and of plant life, in the catchments of the rivers and the torrents, therefore, is a policy to be favoured. It may perhaps be mentioned that in so far as snow fall is concerned, the effect of tree cover may be rather different. Trees tend to protect the snow from the melting effects of sunshine, till the temperature of the atmosphere makes it all melt quickly. In this way, river discharges due mainly to
RAINFALL—OBSERVATION AND RECORD

melting snow under tree cover, tend to be high and of shorter duration than would be the case where tree cover is absent.

ERECTING SYMON'S RAIN GAUGE

22:20 The rain gauge used in the Irrigation Branch, Public Works Department, is the five inch Symon's rain gauge, the same as used by the Meteorological Department. Their location in the canal irrigated areas of the Punjab is listed in Appendix I.

22:21 The erection of rain gauges must be carried out with care and precision and the selection of the sites be decided on the following recognized principles:

(1) It is accepted that a rain gauge located in an open unprojected space registers less than the actual rainfall; for wind eddies, near the gauge, cause rain drops to miss the gauge opening. Thus a certain amount of protection from the wind is desirable. Accordingly gauge sites should be selected so that the nearest standing object is rather more distant than twice the height of the object, but not tree, however, should exist within 30 yards of the gauge.

(2) A rain gauge should not be constructed on the sides or top of a hill, nor should it be located on a building, except in very special circumstances.

(3) Before work is carried out the site selected should be approved by the Executive Engineer of the division.

22:22 The Symon's rain gauge consists of 3 parts:—

Description of Symon's rain gauge.

(a) the base, which is built into a masonry or concrete foundation;
(b) the body, in which is housed the glass bottle for collecting the rainwater;
(c) the funnel, which collects the rainfall. A measuring glass (together with a spare one) is kept with the gauge reader.

The foundation for the gauge is formed by a masonry or concrete cube, of side 2 feet, sunk into the ground so that its top surface is truly level, and two inches above the general local ground level. The base of the gauge is built firmly into
this block so that the top of the finished gauge may be exactly one foot above the natural surface. It is necessary that the mouth of funnel of the gauge when completed is truly horizontal. In no circumstances should the body of the gauge be fixed to the base; it should fit the base accurately and be easily removable.

To protect the gauge from damage, it should be surrounded by an open fence, the height of which, above the mouth of the gauge should be not more than half the distance between the fence and the gauge.

### 22.23 Every rain gauge station is supplied with a spare measuring glass which is to be brought into use if the first is broken and a new measuring glass should be indentified for immediately, from the Sub-Divisional Officer concerned. The Sub-Divisional Officer keeps a small stock of these measuring glasses and the Executive Engineer a rather larger supply.

All rain gauges and measuring glasses are supplied by the Executive Engineer, Stores Division, who is responsible for the accuracy of the equipment. Indents for rain gauge equipment and spare parts may be placed on that officer.

If the glass receiver bottle of a gauge is broken another bottle may be obtained locally, of any shape, provided it fits into the gauge and is capable of holding about 5' of rain.

### 22.24 It is essential that rain gauge sites should be inspected from time to time, by both the Sub-Divisional Officer and the Executive Engineer, so that any defects can be remedied.

The inspecting officers should determine whether—

(a) the instrument is suitably placed and in good order;
(b) the observer is able to make rainfall measurements correctly and to enter them properly in his register;
(c) the rainfall registers are properly and neatly kept up and are in good condition;
(d) the observations are being made daily at the time specified for the station.  
In dealing with (a) above, it is to be noted whether—
(e) there are trees growing or buildings existing or anticipated, within 90' of the gauge, which are likely to affect the degree of exposure;
(f) the gauge is properly fixed according to instructions.
RAINFALL—OBSERVATION AND RECORD

(iii) the rim of the funnel when pressed home is level, and obvious displacement of the gauge has not taken place since erection,
(iv) the rim of the funnel is circular and free from distortion or damage,
(v) the joints of the funnel are intact and without leaks.

REGISTRATION OF RAINFALL

22:30 Rainfall measured by pouring water which has collected in the glass bottle into the measuring glass; which as provided in the Irrigation Branch Public Works Department can contain 1" of rainfall and is graduated in divisions representing one hundredth of an inch. The figures engraved on the glass at every tenth division facilitate the measurement. Should there be more water in the bottle than the measuring glass can hold, the latter is filled carefully to its top mark, is emptied and again used to measure the remaining water from the bottle. The total rainfall to be recorded is the sum of such measurements. The receiving bottle usually can hold three or four inches of rainfall but if the showers are heavy it may be necessary to measure the water collected more than once in a day—the sum total of all measurements during the preceding 24 hours being entered as the rainfall for that day.

22:32 To enable measurements of the intensity of rainfall to be made conveniently, two receiving bottles are provided. The intensity of rainfall is obtained by measuring the water collected during a 20 minutes period. The necessary changing over of the receiver bottles should be done quickly so that all the rain during the 24 hours is collected. Care must be taken to add water measured during the 20 minutes intensity observations to that collected during the rest of the 24 hours period, in obtaining the rainfall of the day. Intensity of rainfall observations over a 20 minute period may be recorded only by officials of a grade equal to or higher than that of a canel signaler.

The intensity of rainfall per hour is computed and recorded by the Overseer or the Sub-Divisional Officer from the data recorded for the 20 minutes observations, whenever he inspects a rain gauge, or at the end of the month when the Senior I. B. No. 460 or 461 is received in the sub-divisional office.

22:32 Rain gauges are read every morning regularly at 98:00 hours Local Mean Time—whether rain is thought to have fallen or not. The Indian Standard times of the various stations
22.33—MANUAL OF IRRIGATION PRACTICE

Corresponding to 0800 Local Mean Time are given in Appendix I.

22.36 The gauge reader’s initial record of rainfall data is entered in the Stereo I. B. forms Nos. 460 and 461, as per copies attached, Appendices II and III. Copies may be obtained from the Superintending Engineer, Southern Drainage Circle, found in the form of registers.

RAINFALL STATISTICS

22.40 The following are the basic principles in connection with the tabulation of statistics of rainfall in the Irrigation Branch—

(i) The unit of area is the civil district.
(ii) The reported rainfall for each civil district is to be based on the observations at Stations within the canal irrigated tract.
(iii) The final compilation of all rainfall statistics is undertaken by the Superintending Engineer, as it frequently happens that two canal divisions of a circle record rainfall in the same district.
(iv) A day on which not less than 0.1" of rain falls is considered a “rainy” day.

22.41 In the record and compilation of rainfall statistics five forms, viz., Stereo I. B. Nos. 460, 461 and forms B, C and D are used. Specimens are attached as Appendices II, III, IV, V and VI. A typical example for the Gujarawala District has been worked out in detail on forms B, C and D, which make their use quite clear. Brief notes explaining the various columns have also been given.

Forms I. B. Stereo Nos. 460 and 461 are used by the rainfall observers in alternate months. The initial record of a rain gauge station, filled in by the observer either in form No. 460 or No. 461, according to the month to which it relates, will be transmitted by the sub divisional office to the divisional office where a duplicate copy will be made in an identical register maintained in that office. The original record of the rain gauge will be returned to the rain gauge station through the Sub-divisional Officer concerned. The Executive Engineer will transmit his copy to the circle office for preparation of forms B, C and D in that office after which the Superintending Engineer will return the same to the divisional office.
RAINFALL OBSERVATION AND RECORD - 22.42

On receipt of the above information from the divisional office, the Superintending Engineer posts the gauge readings into form B (Appendix IV) which is similar to that published weekly in the Gazette (India), Government of India, Revenue and Agriculture Circular No. 5, dated 29th August, 1880. It shows days of the month in vertical columns and rain gauge stations, grouped by districts, on the horizontal lines. This form conveniently shows all the gauges in the circle on one sheet of a book and is the initial circle register from which forms C (Appendix V) and D (Appendix VI) can be compiled. It is also useful for ascertaining details of rainfall, such as the maximum fall in 24 hours, number of rainy days in a month, etc.

The monthly date of rainfall as recorded in form B are posted into another circle register in form C. In this, each district or group of gauges is allotted twelve pages, one for each calendar month of the year. The monthly totals for each gauge in the group are entered on the line for the year. The page assigned to the month concerned. For each gauge site, two columns are provided. In the left hand column the total rainfall of the month, is entered in black ink, while on the right is shown in red ink, the aggregate of the totals up to date. The aggregate figures divided by the number of years involved give the average rainfall of the month for the gauge station, to date. It is not necessary to work this out in all cases, and the averages can be shown, when necessary, by pencil figures over the aggregate. The column to the right, headed “Total rainfall at all stations”, gives, for each year, the total rainfall of the gauges comprising the group. The mean district rainfall, for the next column is found by dividing the figures of the preceding column by the number of gauges recorded. In the penultimate column the aggregates of the “mean district rainfall” are entered, whence are derived “Average mean district rainfall” for the last column.

By “mean” rainfall is meant the intermediate value of all the gauges in a group during a given month, and by “average” the intermediate value of the readings of a gauge, or group of gauges, for the month over a series of years.

Form D is printed in the volume “Statistics of Irrigation Water Distribution, etc.”

It shows the monthly rainfall for each gauge, and mean monthly readings and average for previous years, for each district for the year under review. It also compares the totals of the period for each gauge with those of the corresponding
period of the previous year, and with the averages of all the previous years on the record. For the purposes of form D, three periods are adopted viz:--

<table>
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<th>Period</th>
<th>Season</th>
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<tr>
<td>1st April to 30th September</td>
<td>(Kharif)</td>
</tr>
<tr>
<td>1st October to 31st December</td>
<td>(Early Rabi)</td>
</tr>
<tr>
<td>1st January to 31st March</td>
<td>(Late Rabi)</td>
</tr>
</tbody>
</table>

22-42 The rainfall statements at present rendered by Irrigation Branch Officers are as follows:

Rainfall statement rendered by L. B. Officers.

(1) In the weekly weather reports the rainfall on each day of the week is reported for important rain gauge stations in a canal division.

(2) In the monthly "statement of Irrigation Operations" the actual rainfall of the month is compared with the average of past years for each civil district.

(3) In form No. I of the half-yearly statement of Irrigation Operations the actual rainfall of the months in each civil district and the half-yearly totals are compared with the monthly actuals and totals of the corresponding half of the previous year.

(4) In the Arboricultural Report the actual and average rainfall for the year are shown for each civil district.

(5) In the statement showing included in the statistics of irrigation, water distribution, etc., the actual monthly rainfall at each canal station, for the year under review is shown. In periods kharif, early rabi, late rabi and the total fall at each station in each period is compared with the total of the previous year and the average of previous years.

(6) In the statistical statement I-A of the Administration Report the average rainfall for a number of years (including the year under report) is shown for each canal.

(7) In the statistical statement IV-E of the Administration Report the actual total rainfall of the year in each civil district is compared with that of the previous year.
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<th>Serial No.</th>
<th>Name of Railway Station</th>
<th>Name of Civil District in which situated</th>
<th>Lat. (Geodetic)</th>
<th>Correc. to L.S.T.</th>
<th>L.S.T. corre. to U.S.T.</th>
<th>Remarks</th>
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**UPPER CHENAB CANAL CIRCLE**

**LOWER CHENAB CANAL EAST CIRCLES**

1. **Pusca Dalla** | Sheikhupura | 73° 30 | 0° 36 |
2. **Ajianwala**  | Ditto        | 73° 45 | 0° 35 |
3. **Chabarkana** | Ditto        | 73° 45 | 0° 35 |
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**LOWER CHENAB JUNNA CANAL EAST CIRCLE**

**FEROZEPURE CANALS CIRCLE**

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**FEROZEPORE CANAL CIRCLE** — cond. H. M. H. M.

**DEBAJAT CIRCLE**

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**GUJRANWALA DISTRICT.**

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**NOTE:-**

1. Rain gauge station reported in The Punjab Gazette are in italics.
2. Civil rain gauge stations are star-marked.
## APPENDIX II

### RAINFALL RECORDED AT GUJRANWALA-RAINGAUGE STATION.

Gujranwala Sub-Division, Gujranwala Division, Upper Chenab Canal.

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[Observer: ]
### APPENDIX III

**RAINFALL RECORDED AT GUJRANWALA RAINGAGE STATION.**

Gujranwala Sub-Division, Gujranwala Division, Upper Chenab Canal.

| Year | 1942 |

| Month | February | April |

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**Total:** 2.33

Observer: [Signature]
### Stereo I, B. No. 460

**RAINFALL RECORDED AT HarfoI RAINGAUGE STATION.**

Harpoki Sub-Division, Gujranwala Division, Upper Chenab Canal.

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CHAPTER 24

Accidents to and on canal works

CONTENTS

Introduction .................................................. 24.0
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Accidents on Canal railways ................................... 24.3
Accidents in Workshops ....................................... 24.4
Accidents in Power Houses and on Transmission Lines ....... 24.5
Accidents on other Canal Works ................................ 24.6
Accidents in connection with the storage and use of explosives 24.7
Compensation for injury to personnel .......................... 24.8
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CHAPTER 24

ACCIDENTS TO AND ON CANAL WORKS

Introduction

240 The importance of taking every reasonable precaution to prevent accidents, not only to the personnel employed on canal works but also to the works themselves, is perhaps not sufficiently realized by officers and the staff employed on these works.

In this chapter are given a few examples of accidents of common occurrence to and on canal works and suggestions for prevention of such accidents.

Although an accident to a canal work may not cause loss of life or injury to personnel it may cause serious damage to and, in extreme cases, the complete failure of a large area of irrigated crops. Such damage to or failure of crops brings in its train hardship to the cultivators and, in most cases, the loss of a large area of food and other valuable crops.

In the paragraph referring to compensation for injury to personnel are given some extracts from the "Workmen's Compensation Act of 1923". A perusal of this paragraph
ACCIDENTS TO AND-ON CANAL WORKS

will indicate the extent to which Government may be involved in the payment of compensation to personnel employed on a canal.

241 The orders contained in paras: 1:84 and 2.101 of the Public Works Department Code should be followed.

ACCIDENTS ON CANAL HEADWORKS

2420 A serious accident to a canal headworks may necessitate the closure of or the reduction of the supply in a canal at a time when the demand for water for irrigation is very keen. so every possible precaution must be taken to prevent accidents.

Accidents that do occur can generally be attributed to one of the following causes:

(a) failure to comply with the rules and regulations framed for the control and maintenance of the headworks.
(b) defective gates, shutters and regulating machinery.
(c) unauthorised use and defective maintenance of aerial ropeways.
(d) use of unseaworthy boats and employment of inefficient boatmen.
(e) failure to maintain embankments in good order and to patrol them during floods.

SUGGESTION FOR THE PREVENTION OF ACCIDENTS ON CANAL HEADWORKS

2421 These rules are carefully prepared, and if they are rigorously followed, accidents will be few. Any accident which is found to be due to non-compliance with any of the rules and regulations, will be blamed as due to gross negligence of the person concerned. Copies of these rules, both in English and vernacular, should be available on the headworks at all times and a copy should be in the possession of the executive engineer, sub divisional officer, overseer, head jamadar and all Naib jamadars. The main points requiring attention are recorded below.
24·211—

MANUAL OF IRRIGATION PRACTICE

24·21 The sub-divisional officer is responsible for selecting suitable men and he should see that training and discipline are healthy, able-bodied and strong swimmers. The sub-divisional officer should also arrange for proper training of the staff, and he should frequently satisfy himself that each man understands his duties. He should take care that proper discipline is maintained at all times and the staff actually live in the quarters provided for them.

24·212 The regular observation of soundings and probings is most important as they show any subsidence in concrete block and loose stone protection and enable the officer in charge to put in additional protection before an accident occurs.

24·213 Marks should be made on pier and abutments to indicate a line below which the ‘standing wave’ should not be allowed to form. If the wave forms below this line a deep scour hole may occur into which the loose stone protection and concrete blocks may subside.

The position of the ‘standing wave’ can generally be regulated by adjusting the opening of the gates.

24·214 Observations in pressure pipes indicate the upward pressure on the floor of a structure. Such observations are important as they enable action to be taken to strengthen the floor before it blows up.

Pressure pipes are liable to become choked with sand or silt which must be removed before observations are made.

24·215 The most important rule to be observed, if accidents occur during the passage of a flood, is that which lays down that either the executive engineer or the sub-divisional officer shall be present on the headworks during the passage of a flood.

Other suggestions for the prevention of accidents during the passage of a flood are:—

(a) reduce cross flow in the vicinity of the works to a minimum. Pay special attention to the flow round noses of spurs and groynes.

(b) distribute the flood discharge over the width of the weir in such a way as to reduce severe action in the vicinity of the works to a minimum.
ACCIDENTS TO AND ON CANAL WORKS

(c) comply strictly with the rules regarding closing the canal during the flood and re-opening after the flood has passed.

24-22 Local rules should be framed for the working, maintenance and inspection of machinery on headworks.

To prevent accidents special attention should be paid to the moving parts of machinery and regular inspections by competent mechanics should be carried out.

24-23 Local rules should be framed for the working and maintenance of aerial ropeways.

Working and maintenance of aerial ropeways.

To reduce accidents to a minimum the following precautions should be taken:—

(e) Ordinarily only one cradle should use the ropeway at one time. If two cradles must be used there should be a barrier on one of the piers at about the centre of the weir and this barrier should be kept locked to prevent the cradles crossing.

(f) When not in use cradles should be chained and locked to the terminal standards.

(g) Only strong and physically fit belters, who have been trained in working the cradle, should man it.

(b) Belters working the cradle must wear shorts and shirts the ends of which must be tucked inside the shorts. No loose clothing should be worn.

(c) The cradle should be allowed to run free on the down grade. On no account should the belters be allowed to increase the speed on the down grade by pulling at the rope.

(f) The cradle should not be used when a strong wind is blowing.

(g) The ropeway and cradles should be inspected by competent mechanics at regular intervals and prompt steps taken to remedy any defects.

24-24 Local rules should be framed for the use and maintenance of boats. The rules should, inter alia, contain instructions regarding:—
24-25 LOCAL RULES SHOULD BE FRAMED FOR CONTROLLING THE
RATING AND PASSAGE OF RAFTS AND COUNTRY BOATS ACROSS A
COUNTRY BOATS, HEADWORKS.
The rules should, inter alia, contain instructions regarding:

(a) selection of sites for mooring on arrival at a headworks.
(b) navigation of rafts and country boats across a headworks.
(c) entry of country boats and rafts into a canal.
(d) record of country boats and rafts using a headworks.

24-30 ACCIDENTS ON CANAL RAILWAYS

Accidents on canal railways can generally be attributed to one of the causes noted below:

(a) Derailments resulting from bad maintenance of the permanent way.
(b) Collisions between trains and trolleys.
(c) Use of unserviceable locomotives and rolling stock.
(d) Loose shunting of vehicles.
(e) Hand shunting by pushing at the buffers of vehicles.
(f) Permitting persons to shelter under stationary vehicles.
(g) Failure to lock points and crossings.
(h) Excessive speed.
SUGGESTION FOR THE PREVENTION OF ACCIDENTS ON CANAL RAILWAYS

24:31 Rules for the prevention of accidents on canal railways will be found in chapter 16, paragraph 16.32.

Attention should also be paid to the instructions for maintenance which will be found in paragraphs 16.41 to 16.43 of the same chapter.

ACCIDENTS IN WORKSHOPS

24.40 If reasonable precautions are taken very few accidents should occur in a well managed workshop. Accidents, which do occur, can generally be attributed to ignorance or neglect of the rules framed for the safety of the workmen employed in a workshop.

Standing orders for the safety of workmen should be framed by the officer in charge of each workshop. A copy of the rules, both in English and Vernacular should be posted at the entrance to the workshop and at other suitable places and steps taken to ensure that all employees are made to understand them immediately on recruitment.

The suggestions noted below will assist officers in charge of workshops to frame suitable local rules:

(a) The following parts of transmission machinery shall be securely fenced if in motion and within reach:

(f) All shafts, couplings, collars, clutches, toothed wheels, pulley driving straps, chains and ropes, except such as are, in the opinion of the Inspector, by construction or position equally safe to every person employed as they would be if securely fenced or guarded.

(ii) All projecting set screws, keys, nuts or bolts on revolving parts except such as are countersunk or otherwise made equally safe.

(iii) The underside of all heavy overhead main driving bolts or ropes if there is say probability of persons having to pass under them.

(b) The following parts of machine tools shall be securely fenced:

(f) The back gears and change wheels of lathes, the back gears and level gearing of drilling machines, and the gearwheels of planing, shaping, slitting and milling machines which are within reach.
(c) All emery wheels and tool grinding machines shall be fitted with strong iron hood guards and shall also have a plate glass shield so fitted as to prevent flying particles from entering into the operator's eyes.

(4) All hoist gates shall be self-locking and only capable of being opened when the cage is opposite the floor.

(5) All band saws shall be fitted with expanded metal cage guards enclosing the upper half of the machine. The saw under the table shall also be completely guarded.

(6) Every opening in the ground or in a floor, which by reason of its depth, situation, construction or contents could cause personal injury, shall be so fenced as to prevent such injury.

(7) All important pulleys shall be provided with belt hangers or perches.

(8) Suitable striking gear shall be provided and used to move driving straps on all fast and loose pulleys.

(9) Service platforms and gangways shall be provided for overhead shafting and, where required by the inspector, shall be securely fenced with guard rails and toe boards.

(10) No transmission machinery in motion shall be cleaned with cotton waste, rags or similar material held in the hand. No woman or child shall clean or oil any part of a machinery whilst that part is in motion.

(11) Every shafting ladder shall be fitted with either hooks or some effective non-skid device.

(12) No person, engaged in oiling or adjusting belts or in any work whatsoever within reach of unfenced transmission machinery, shall be allowed to work whilst wearing loosely fitted clothes such as dhoties, shirts, shirts with long sleeves, etc., etc.
ACCIDENTS TO AND ON CANAL WORKS

24:42

24:41 The instructions contained in paragraph 24:50 also apply to workshops in which electric power is used.

Special attention should be given to the instructions in paragraph 24:51 for restoration of persons suffering from electric shock.

24:42 (1) Every workshop shall be provided either with —

(a) an ample supply of water maintained at a sufficient pressure to reach all parts of the workshop together with the necessary hose pipes and hydrants for making effective use of the water, during the time the workshop is in operation, or

(b) both buckets and chemical fire extinguishers on the following scale:

(i) There shall be at least six buckets in every workshop and, if the floor space exceeds 6,000 square feet, an additional bucket for every 1,000 square feet in excess of the first 6,000 square feet.

Buckets shall be painted red and kept permanently on stands. They shall be kept filled with water or sand at the discretion of the officer in charge of the workshop.

(ii) One extinguisher of at least two gallon capacity of soda acid or compressed carbon dioxide type for a floor space of 6,000 square feet and an additional extinguisher for every additional floor space of 6,000 square feet or part thereof.

(2) All apparatus for extinguishing fires shall be kept in good order and shall be periodically examined and tested.
24-43 — MANUAL OF IRRIGATION PRACTICE

24-43 A few suggestions regarding storage of inflammable liquids, such as oil and petrol will perhaps be helpful.

(a) Inflammable liquids, such as oil and petrol should be stored in specially constructed godowns. Godowns in which inflammable liquids are stored, should be located at least 500 feet from residential or industrial buildings. The godowns should be well ventilated.

(b) Receptacles containing inflammable liquids should be stacked in such a way as to permit free passage of air between the receptacles.

(c) No naked lights should be allowed inside the godown and smoking inside or in the vicinity of the godown should be prohibited.

(d) Materials, other than inflammable liquids, should not be stored in godowns specially provided for the storage of inflammable liquids.

24-44 In every workshop there shall be maintained, in a readily accessible place, first aid appliances consisting of an adequate supply of sterilized dressings, sterilized cotton, wool, and a tincture of benzoin for cases of burns, etc. The appliances shall be kept in good order and they shall be placed under the charge of a responsible person who understands how to use them and who shall be readily available during working hours.

The words "First Aid" shall be clearly painted on the box, cupboard or other receptacle containing these appliances.

ACCIDENTS IN POWER HOUSES AND ON TRANSMISSION LINES

24-50 Standing orders should be framed by the officer in charge of each power house for the safety of workmen on transmission lines. A copy of the rules, in both English and Vernacular, should be posted at suitable places in all power houses and sub-stations. Copies should also be supplied to all members of the Supervisory Staff and steps taken to ensure that all workers are made to understand them immediately on recruitment.
The suggestions noted below will assist officer in charge of power houses to frame suitable rules:

(a) All workmen, employed on or near any circuit or machine that may be alive, should wear rubber gloves and use insulated tools such as pliers, screw-drivers, etc.

(b) No workman should ascend a ladder which is in any way unsafe or which is not held by at least one man at the lower extremity. When poles have to be climbed a lineman's safety belt should be used.

(c) No workman should work in or near electrical lines, which are or may be alive, until he is in possession of a safety check which bears the number of the line on which work is to be done and which corresponds in number to the number of the key which operates the lock with which the switch controlling the line in question has been locked in the “off” position. The safety check will be retained by the workman until his work on the line has been completed and he and his men have withdrawn from the site of the work and until the work performed has been tested and checked by some responsible person.

(d) No coils of wire, loose wires, strings or the like should be left hanging from a pole, or pylons after completing work on it.

(e) Workmen should not wear loose clothing such as dhotis, shirts with long sleeves, etc.

(f) In the event of fire at or near any motor, switch, electrical line or gear an endeavour should be made to switch off the current and then put out the fire with sand. Under no circumstances should water be used to suppress a fire in any electrical apparatus.

All fire buckets should be kept filled with sand and sand dumps should be established at suitable places.

(g) All electrical apparatus should be earthed and frequent checks should be made to ensure that the earths are effective and have not become disconnected.
24:51 - MANUAL OF IRRIGATION PRACTICE

(a) In order to eliminate the risk of shock, when operating a switch board, operators should stand on rubber mats.

(b) "Danger boards" should be placed in a prominent position on any switch that has been locked in the "open" position. These "danger boards" will read "DANGER, men working on line".

24:51 - Electricians and others employed in power houses and on transmission lines should be taught how to restore a person suffering from electric shock. They should memorize the following:

(a) Removal from contact—If the person is still in contact with the apparatus that has given him the shock, break the electric circuit at once if there is an interrupter close at hand. If there is no interrupter lose no time and proceed to remove the body from contact with the live conductor. Do not touch the man's body with bare hands. If rubber gloves are not at hand, pull him off the live conductor by his coat, if his clothes are not wet, or fold your coat or some dry article, such as a newspaper, into two or three thicknesses, using this as a pad, take hold of the body and pull it away from the circuit; or a broom handle may be used to raise the body or to detach the wires from it. A good plan is to stand on a dry board, or on a thick newspaper, or a bundle of sacking.

(b) Preliminary Steps—Extinguish any sparks, if the patient's clothes are smouldering, ascertain if he is breathing, and send for a doctor. If apparently not breathing, proceed as follows:

(c) To recover patient—If there are any burns avoid, if possible, so placing the patient as to bring pressure on them. It is far preferable to operate as in Diagrams 1 and 2 with the face downward. If badly burnt in front turn to the alternative method shown below. Stimulants should not be administered, unless recommended by a medical man.
1. First Motion.—Observe diagram 1 "Expiration" Kneel over the patient, rest the hands flat in the small of his back, let your thumbs nearly touch, spread your fingers on each side over his lower ribs, as in the first diagram.

2. Now lean firmly but gently forward over the patient, exerting a steady pressure downward, still following the first diagram.
3. Second Motion—Observe diagram 2 "Inspiration". Rock yourself gently backwards, but do not remove your hands. Merely keep them in position for the next "Expiration" pressure.

4. Continue these two movements.

5. The double movements should be gone through about fifteen times per minute. The object is to keep expanding and contracting the patient's lungs, so as to imitate slow breathing. If the operator himself breathes slowly, letting the air out as he presses forward, and drawing it in as he rocks backward, he will naturally arrive at the proper rate, and will understand the reason of the movements. In cases of severe shock, respiration is seldom established under one hour while three hours may be necessary to restore normal breathing.

ALTERNATIVE METHOD

(This method should only be used with the permission of a doctor or gazetted officer.)

1. Should it be expedient to place the patient on his back, first loosen the clothes around the chest and stomach. Then place a rolled-up coat, or other improvised pillow beneath the shoulders, so that the head falls backwards. The tongue should then be drawn forward.

(A)
2. **First Motion.**—The operator must kneel in the position shown by figure A, grasp the patient just below the elbows, and draw his arms over his head until horizontal retaining them there for about two seconds.

3. **Second Motion.**—Next bring the patient’s arm down on each side of his chest and pressing inwards upon it leaning upon his arm so as to compress his chest as in figure B.

4. Remain thus for two seconds and then keep repeating the two motions at the same rate.

5. **Note.**—The lung inflating effect in figure A is much assisted if the arms be swung outwards as they are lifted.

6. If more than one person be present, the patient’s tongue should also be drawn out during each outward or lung-inflating stroke (figure A), and released during each inward or lung-deflating stroke (figure B).

7. **General.**—Be careful to avoid violent operation, as injury to the internal organs may result from excessive and sudden pressure.

8. **Upon Recovery.**—Burns, if serious, should be treated with a proper oil dressing. Avoid exposing patient to cold. Administer no restoratives until the doctor comes. Cold water may be drunk, and smelling salts applied in moderation.
ACCIDENTS ON OTHER CANAL WORKS

24-60 Accidents to and on other canal works can generally be attributed to one of the causes noted below:

(a) breaches caused by defective maintenance or bad regulation,

(b) scour in the vicinity of masonry works resulting in damage to and, in some cases, the collapse of the whole work.

(c) Damage to the foundations of structures caused by the movement of sand or silt under the foundations resulting from pumping during the execution of alterations or repairs.

(d) Accidents to syphons and culverts under a canal caused by cracks in the masonry or obstructions in the barrel or outfall channel.

(e) Accidents resulting in danger to or loss of life of workmen due to:

(i) defective scaffolding, centering or falsework.

(ii) undercutting the sides of deep excavations and permitting the sides of such excavations to be dug to too steep a slope.

(iii) failure to take suitable precautions when sinking masonry wells.

(iv) failure to erect warning notices and construct suitable diversions when executing work within the boundaries of a public road.

SUGGESTIONS FOR THE PREVENTION OF ACCIDENTS ON OTHER CANAL WORKS

24-61 Breaches are caused by defective maintenance, bad regulation and sometimes, by silt movement. Suggestions for ensuring good regulation and reduction of silt movements to a minimum will be found in chapter 11.

Paragraph 8-6 of chapter 8 deals with the maintenance of canals. Breaches can be reduced to a minimum by efficient maintenance so the instructions in this paragraph should be studied and followed.
ACCIDENTS TO AND ON CANAL WORKS —24-62

To prevent breaches in channels whose banks consist of soil impregnated with salts steps should be taken to form a wide silt berm as soon as possible after the canal is opened for the first time. When this berm has formed a silt push should be constructed on the berm to prevent leakages at the point where the top of the berm joins the bank.

Rat holes are a frequent source of leakages and breaches. The only remedy is filling up the holes. Patrol belchers should walk along the berm instead of on the top of the bank, dig out the holes to a depth of about one foot, and then refill them.

24-62 The Government take a very serious view of cutting of canal banks of the Government channels. Cats, because apart from considerable loss in revenue to the Government on account of dislocation of irrigation, such an act causes heavy damage and is generally detrimental to the interests of the irrigator on the channel effected. Constant vigilance on the part of the canal staff and vigorous action by the Police, the Civil and the Canal authorities are essential, in addition to such punitive measures as are permissible under the law, to check such offences effectively.

Extent of such offences depends on the state of demand. Failure of rains may accentuate their frequency. Under such conditions the police patrols should be reenforced to strengthen the canal patrols, specially in the dangerous reaches in the vicinity of notorious villages. In the case of habitually offending villages, Government should be approached to impose punitive police posts.

A lot of success can be achieved in putting down such offences if the Civil, the Police and the Canal Officers cooperate thoroughly. Government has issued suitable special instructions from time to time, for the guidance of all concerned, and these instructions should be studied and rigorously carried out.

24-63 Deep scour holes generally only occur below a fall or control point. These scour holes Scour endangering structure are frequently due to defective regulation, which causes wave or eddy action. Subdivisional officer and overseers should from time to time show the regulating staff how to reduce such action to a minimum.
If a scour hole develops to such an extent as to endanger the structure temporary measures must be taken to protect it until the canal can be closed.

24:64 In order to prevent silt or sand being sucked out Accidents due to from below the foundations of a structure pumping, the officer in charge of the work should fix a level below which water in the foundation pit should not be lowered by pumping during the execution of alterations or repairs.

24:65 Serious accidents have occurred due to the outfall channel of syphons and culverts becoming blocked by silt or detritus or by sand being syphons and culverts drawn out from below the foundations by the action of springs.

Syphons and culverts should be divided into three categories, viz.,—
(a) those in which serious cracks have developed or dangerous springs exist.
(b) those in which there are small cracks and springs.
(c) those which are intact and free from springs.

Ordinarily category (a) should be examined every month, category (b) once a year, and category (c) every second year.

Superintending Engineers should frame local orders for the examination of syphons and culverts.

A log book should be kept for each syphon and culvert in which a record of all inspections should be made. Prompt action should be taken to remedy defects found during inspections.

24:66 Scaffolding and false work should be constructed of sound material whose dimensions are adequate. Scaffolding, centering and false work should be tested after erection. Centerings and false work should be strong enough to support not only the dead load but also any live load that may be imposed.

As far as possible workmen should not be allowed to go under a centering when work is in progress.
24:67 Undercutting the sides of deep excavations and digging the sides to a very steep slope should not ordinarily be permitted. If the side slopes must be excavated to a slope steeper than say 1 to 1 or if slips are liable to occur the sides should be shored up with timber.

Excavated soil should not be placed so near the edge of the pit as to cause a surcharge on the side slopes.

24:68 Only labour, who are accustomed to do well sinking, should be employed on this class of work. Suitable staging should be erected on the well to prevent workmen falling into or outside the well.

All tools and plant such as tripods, hooks, dredgers, ropes, etc., should be inspected periodically to ensure that they are serviceable.

24:69 When work is to be carried out within the boundaries of a public road the road should be closed by barriers, which should be lighted at night.

During daylight a man with red and green flags must stand about 25 feet in front of each barrier to direct traffic.

Night watchmen must be provided to keep lights burning.

Whenever feasible suitable diversions should be provided and these should, if possible, be located beyond the road berms. If a diversion cannot be provided traffic must be allowed to use the berms, which should be kept free of all obstructions.

24:610 As huts for labour are generally constructed of highly inflammable material such as sarkanda grass precautions against fire must be taken.

A few suggestions are given below:

(c) There should be a space of at least 50 feet between huts. No individual hut should occupy more than 200 feet.

(b) Bamboo with iron hooks, should be kept at suitable places in the camp so that, in case of fire, a burning hut can be quickly pulled down. Heaps of dry sand should also be available at suitable places in the camp.
endeavours should be made to persuade the labour not to smoke or cook their food inside the huts.

ACCIDENTS IN CONNECTION WITH THE STORAGE AND USE OF EXPLOSIVES

2470 Space will not permit detailing all the precautions to be taken when storing, handling and using explosive so only the more important precautions to be taken are given in the paragraphs below.

When explosives are to be used on a large scale the gazetted officer in charge of the work should study the Explosives Rules contained in Notification No. M.1217 (1), dated 30th November 1940, published by the Department of Labour of the Government of India.

Before any explosives, detonators or fuses are purchased, the district magistrate should be consulted in order to ascertain whether a license is required.

2471 Below are given the more important precautions to be taken when storing explosives:

(a) Explosives should be stored in a substantial building constructed of brick, stone or concrete, separated from any dwelling house, highway, public thoroughfare or public place by a distance of at least 150 feet and closed so as to prevent unauthorised persons from having access thereto.

(b) Detonators, fuses and percussion caps shall be kept at safe distance from explosives, preferably in a separate building.

(c) No person entering a room or building, where explosives are stored, shall have in his possession any matches, fuses or other appliances for producing ignition or explosion of any article made of iron or steel, nor shall he wear boots or shoes containing iron or steel, unless covered with rubber, leather or felt overshoes.

(d) No person shall smoke, and no fires or lights shall be allowed in the proximity of a place where explosives are stored.
2472 The following precautions shall be taken when handling and using explosives:

(a) Packages containing explosives shall not be thrown, dropped, rolled or pulled along the ground, but shall be passed from hand to hand and carefully deposited.

(b) Packages containing explosives shall not be exposed to the sun or allowed to come into contact with water or moisture.

(c) Persons using, possessing or in charge of explosives shall take suitable precautions to prevent theft and unauthorised use of them.

(d) Detonators and fuses shall be kept in separate containers and no account shall be kept in the same container as explosives. They shall not be kept on the person of any individual employed on a work.

(e) For making the hole in an explosive cartridge to take the detonator only hard wood shall be used. On no account shall any metal implement be used.

(f) Only wooden tampers shall be used for tamping explosive charges.

(g) Before an explosive charge is fired all persons employed on the work shall be cleared away to a safe distance.

(h) After firing an explosive charge sufficient time must be allowed to elapse before men are allowed to return to work within the danger zone otherwise asphyxiation from carbon monoxide fumes may occur.

(i) When explosive charges are connected in a circuit and detonated by a twist expoder the work of setting the charge, connecting the circuit and firing the charge should be supervised by a gazetted officer or some responsible person appointed by him.

(j) Some explosives are very dangerous in frosty weather. If work cannot be suspended such
The Workmen's Compensation Act (Act VIII of 1923) provides for the payment of compensation by the employer, when personal injury is caused to a workman by accident arising out of and in the course of his employment.

In the following paragraphs extracts from the Act and comments thereon are given so that irrigation engineers and overseers may realise the importance of taking suitable steps to prevent accidents, which may cause personal injury to workmen. They must realize that Government may, in some cases, be called on to pay heavy compensation.

2481 Reference need be made to only two definitions in the Act. They are the definitions of a 'workman' and an 'adult'.

A 'workman' is defined as any person other than a person whose employment is of a casual nature and who is employed otherwise than for the purpose of the employer's trade or business who is employed on monthly wages not exceeding three hundred rupees, and in any such capacity as is specified in Schedule II of the Act.

The portion of Schedule II, which concerns the Irrigation Branch, lays down that the following persons are 'workmen' within the meaning of section 2 (1) (a) and subject to the provisions of that section, that is to say, any one who is employed, otherwise than in a clerical capacity, in the construction, working, repair or demolition of any aerial ropeway, canal, pipe-line or sewer (see paragraph (1) (a) of Schedule II).

An 'adult' is defined as a person who is not under the age of 15 years.

2482 Section 3 (1) of the Act, which is reproduced below, lays down when an employer is liable to pay compensation. Special attention is drawn to sub-sections (a) and (b) of this section.
Section 3 (1) runs as follows:—

"If personal injury is caused to a workman by accident arising out of and in the course of his employment, his employer shall be liable to pay compensation in accordance with the provisions in chapter II of the Act:—

Provided that the employer shall be so liable:—

(a) in respect of any injury which does not result in the total or partial disablement of the workman for a period exceeding seven days;

(b) in respect of any injury, not resulting in death, caused by an accident which is directly attributable to:—

(i) the workman having been at the time thereof under the influence of drink or drugs, or

(ii) the wilful disobedience of the workman to an order expressly given, or to a rule expressly framed for the purpose of securing the safety of workman, or

(iii) the wilful removal or disregard by the workman of any safety guard or any other device which be known to have been provided for the purpose of securing the safety of workman."

24-83 Section 4 and schedule IV of the Act lay down the amount of compensation that shall be paid, subject to the provisions of the Act, where:

A. Death result from the injury.
B. Permanent total disablement results from the injury.
C. Permanent partial disablement results from the injury.
D. Temporary disablement, whether total or partial result from the injury.

Space will not permit the reproduction of the whole of section 4 and schedule IV but a few examples, taken from
schedule IV, are given in the statement below, which will show the amount of compensation that may be payable.

<table>
<thead>
<tr>
<th>Monthly wage of the worker (Rs)</th>
<th>Amount of Compensation (Rs) for Death of adult</th>
<th>Permanent total disablement of adult (Rs)</th>
<th>Half monthly payment as compensation for temporary disablement of adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than 21 but not more than 35</td>
<td>500</td>
<td>1,200</td>
<td>80</td>
</tr>
<tr>
<td>21</td>
<td>720</td>
<td>1,680</td>
<td>10</td>
</tr>
<tr>
<td>35</td>
<td>1,200</td>
<td>2,520</td>
<td>15</td>
</tr>
<tr>
<td>50</td>
<td>2,400</td>
<td>3,696</td>
<td>20</td>
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<tr>
<td>70</td>
<td>2,100</td>
<td>3,696</td>
<td>25</td>
</tr>
<tr>
<td>90</td>
<td>3,600</td>
<td>4,200</td>
<td>30</td>
</tr>
<tr>
<td>100</td>
<td>5,000</td>
<td>4,200</td>
<td>30</td>
</tr>
</tbody>
</table>

Where permanent partial disablement results from the injury, a percentage of the compensation which would have been payable in the case of permanent total disablement as being the percentage of the loss of earning capacity caused by the injury may be paid.

A few examples, taken from schedule I of the Act, are given in the statement below:

<table>
<thead>
<tr>
<th>Percentage of loss of earning capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of right arm above or at the elbow</td>
</tr>
<tr>
<td>Loss of leg at or above the knee</td>
</tr>
<tr>
<td>Permanent total loss of hearing</td>
</tr>
<tr>
<td>Loss of one eye</td>
</tr>
<tr>
<td>Loss of index finger</td>
</tr>
</tbody>
</table>
The Act also provides for the appointment of Commissioners to settle claims, and lays down rules for the submission of claims, reports of fatal accidents, medical examination etc.

Procedure to be followed in the event of an accident causing injury to Government employees (workers).

In order to safeguard the interests of Government and its employees, it is of the utmost importance that the proper procedure should be followed in the event of an accident involving Government employees and particularly those which result in injuries to workmen which are likely to result in a claim for compensation under the Workmen’s Compensation Act.

The following instructions which are intended as a guide to officers and subordinates should be carefully noted and complied with as and when the need arises.

In the event of an accident, the injured person reporting the accident, and subsequently sent to the nearest dispensary for further treatment if considered necessary.

In the event of death or where the injury is of such a nature that the workman will be unable to return to work within 48 hours, the following report should be submitted:

(i) to the District Magistrate or to the Sub-divisional Magistrate if the District Magistrate so directs.
(ii) to the Chief Inspector of Factories on Form ‘F’ as laid down in the Punjab Factory Rules 1936.

Both the above reports should issue within four hours of the occurrence.

(iii) to the Commissioner appointed under the Workmen’s Compensation (Amendment) Act 1933 by registered post within 12 hours of the occurrence.
(iv) to the Superintending Engineer concerned through the normal channel within 24 hours of the occurrence.
(v) in the event of death, to the officer in charge of the police station for the area in which the accident took place.
The submission of above reports should be regarded as the initial action to be taken and it should be supplemented later where necessary by a report on an enquiry held in accordance with the instructions given below. These initial reports should give, in addition to the name or names of workmen injured and the extent of injuries sustained, brief details as to how the accident occurred, and whether the injured person or persons were engaged on their legitimate duties at the time of the occurrence.

24:853 In the case of an accident resulting in death or serious injury which is likely to result in a claim for compensation under the Act, an official enquiry should be held within 24 hours of the occurrence by an officer not below the rank of a sub-divisional officer or in cases where this is impossible by the senior official on the spot.

The object of such an enquiry which should preferably be held on the site of the accident, should be to ascertain the reason for the accident and in particular, to bring out facts to show whether the accident was due to negligence on the part of the injured person or persons. I. e., whether the person or persons were under the influence of drink or drugs or had wilfully disobeyed any rule framed for the safety of the workmen or had disregarded or removed any guard or safety device which had been provided for the safety of workmen.

To this end, the statements of all witnesses should be brought on record—a sketch of the site of the accident will also be found useful in many cases.

A report on the enquiry should normally be submitted to the Chief Engineer through the usual channels within 48 hours of the occurrence together with recommendations by the Executive Engineer and the Superintending Engineer concerned as to whether a claim for compensation, if preferred should be accepted. The Chief Engineer after examining the report and recommendations thereon will record his orders as to the acceptance or rejection of a claim if preferred and return the report to the divisional office where it should be safely recorded until required for dealing with a claim as detailed in para 24:81 below.

A certificate on the proper form should also be obtained from the Civil Surgeon of the District concerned certifying the extent of the injuries sustained by the individual(s) and this report should then be recorded in
the divisional office for reference purposes if and when a claim is preferred. The Civil Surgeon’s certificate should state clearly whether the disablement is permanent or temporary and in the former case the loss in earning capacity involved.

24.854 It may sometimes happen that a workman who reports an injury sustains minor injuries which are regarded as unimportant in the first instance is subsequently prevented, by those injuries from returning to work within 48 hours. In such case, a report should be sent to the authorities mentioned in para 24.86 supra within 24 hours of the expiry of the above period. In all other cases, a report of the accident need only be sent to the divisional officer for record purposes.

24.855 Where the period of total or partial disablement does not exceed 7 days, the injured workmen should be paid wages for the period for which he was declared unfit for duty by the Civil Surgeon, provided he attended a civil dispensary if instructed to do so.

Where temporary or partial disablement results from the injury, a half monthly payment of the sum shown in schedule IV of the Workmen’s Compensation Act is payable on the 16th day after the expiry of a waiting period of 7 days from the date of disablement and thereafter half monthly during the full period of disablement or during a period of 5 years whichever period is shorter.

If the injured person is a minor, the amount of the half monthly payment should be equal to one half of his monthly wages subject to a maximum of Rs. 30.

24.856 If the workmen had been in continuous service for not less than 12 months immediately preceding the accident, his monthly wages should be reckoned as one-twelfth of his total wages for that period.

Where the period of continuous service is less than one month, the monthly wages of the workman shall be assumed to be the same as an average monthly amount being earned by a workman employed on the same work and on the same wages by the same employer, or if there is no workman so employed by a workman employed on similar work in the same locality.
In all other cases, the monthly wages shall be 30 times the total wages earned for the last continuous period of service immediately preceding the accident divided by the number of days comprising such period.

24.957 On receipt of a claim for compensation for injuries sustained, the enquiry report should be consulted to ascertain whether the accident was due to negligence or misconduct on the part of the injured person or was an accident in the true sense of the word. In the latter case, the amount of compensation should be worked out on the basis of the Civil Surgeon's report and Schedule I or IV (whichever is applicable) of the Workmen's Compensation Act. Schedule I details the list of injuries deemed to result in permanent partial disablement together with the appropriate percentage of loss of earning capacity. Schedule IV details the amount of compensation payable in the event of death or permanent total disablement of adults.

In the case of minors, the following amounts have been fixed as a compensation payable in the event of death or permanent total disablement:

- In the case of death: Rs. 200.
- In the case of permanent total disablement: Rs. 1,200.

In cases where more injuries than one are caused by the same accident, each of which is held to cause permanent partial disablement, the amount of compensation payable should be aggregated but should not in any case exceed the amount which would have been payable if permanent total disablement had resulted from the injury.

When the amount of compensation deemed to be payable has been calculated, the Divisional Officer should forward the claim together with the original report of the enquiry and the Civil Surgeon's certificate to the Chief Engineer through the proper channel for sanction.

Claim for compensation received in respect of accidents which the Chief Engineer has ruled were due to a fault or faults on the part of the injured person or persons and are therefore not to be considered should be returned to the applicant by the Executive Engineer under registered cover duly rejected. Appeals if any against such rejections will then have to be dealt with by the Commissioner appointed under the Act.
Similarly, should the injured person in any case dispute the amount of compensation awarded to him, the matter shall be referred by the Executive Engineer to the Commissioner appointed under the Act for his ruling. Should the effect of this ruling be to enhance the amount of compensation already sanctioned, the case should be referred back to the Chief Engineer for revised sanction.

24-88 The actual payment of the compensation money to the injured persons must be made by the Commissioner appointed under the Act. Payment of compensation by the employer, his representative or any other interested party is forbidden.

COMPENSAZON FOR DAMAGE TO PROPERTY

24-89 Space will not permit reference to all the causes which may give rise to claims for compensation for damage to property so the more common causes, with which the Irrigation Branch may have to deal, are given below:

(a) Damage resulting from a cut in the canal bank.
(b) Damage resulting from a breach in the canal bank.
(c) Damage done to land entered upon when an accident happens or is apprehended to a canal.
(d) Damage done to land and crops by removal of earth for repairs to banks.

Specific instructions exist for dealing with the four cases mentioned above and comments on these instructions will be made later. If a claim for compensation for damage to property from any other cause is received, the case should ordinarily be referred to higher authority for legal advice.

24-87 In the case of a proved cut in a canal bank, the Government is not liable to pay any compensation for damage to property, but the onus of proving that a cut was made lies on the Irrigation Branch.

In view of this it is therefore incumbent to all divisional officers, subdivisional officers, zillads and others who have to deal with cases of cuts, to take great care in writing reports and passing orders on such cases. The record of such cases should contain clear evidence to prove that a cut was made.
A breach may be caused by:

(i) Negligence.

(ii) Vicarage or an act of God.

(iii) Other causes.

(a) If the plaintiff can prove that the breach was caused by negligence of any employee of the Irrigation Branch, compensation for damage to property will probably be payable. It is, therefore, incumbent on all persons responsible for the management and maintenance of a canal to take all reasonable precautions to prevent a breach. The onus of proving negligence lies on the plaintiff and when he has discharged it, the Irrigation Branch, if it denies negligence must produce proof in rebuttal. The record of all breach cases should contain such evidence as may be available to show that the breach was not due to negligence. A correct record of the facts will assist greatly in defeating any attempt by the plaintiff to prove negligence where there was in fact no negligence.

(b) If the breach was caused by vicarage or an act of God, compensation will not be payable, but the onus of proving this will be on the Irrigation Branch.

(c) If the breach is due to other causes compensation can be claimed under section 8(i) of the Canal Act (Act VIII) of 1873. The conveyance of water through a canal is an act performed in the exercise of statutory authority conferred by section 6 of the Act. The provision in section 8(i) of a specific remedy for damage caused by such exercise of powers will exclude other remedies. Section 8(i) provides that compensation may be awarded in respect of any other substantial damage not falling under clauses (a) to (d) of section 8 caused by the exercise of the powers conferred by the Act, which is capable of being ascertained and estimated at the time of awarding such compensation. Claims for compensation, under this provision, must be dealt with by the Collector under section 10 of the Act. The Civil Courts will have no jurisdiction.

No claim for compensation for damage shall be made after the expiration of one year from the day on which the damage occurred, unless the Collector is satisfied that the claimant had sufficient cause for not making the claim within such period.—side Section 9 of the Act.
(d) In the majority of cases claims are preferred to the Canal Officer, who, after investigating the case, offers the claimant suitable compensation after an estimate to cover the cost has been sanctioned by competent authority. If the offer is not accepted, the claimant can take the case to the Collector, provided it is not time barred.

(e) Too much stress cannot be laid on the importance of efficient handling of all breach cases, as Courts view with suspicion any delay in inspection, assessment of damage, and delays in recording statements. In all cases the record should contain a statement of damage resulting from the breach. If a Canal Officer cannot assess the damage he should call in an officer of the Civil Department to assist him.

24-89 Section 15 of the Canal Act lays down the procedure to be adopted in tendering Compensation for damage done to land entered upon for the purpose of repairing or preventing an accident. According to this section the Canal Officer shall tender compensation to the proprietors or occupiers of the land. If the tender is not accepted the Canal Officer shall refer the matter to the Collector who shall award compensation as though the Provincial Government had directed the occupation of the land under section 45 of the Land Acquisition Act of 1870.

24-90 Paragraph 411 of the Manual of Orders issued by the Punjab Government for the guidance of Compensation for officers of the Irrigation Branch (third edition) lays down the procedure to be followed in assessing and tendering compensation for damage to land and crops caused by removing earth for repairs to banks. Compensation must be offered in the following cases:

(a) Destruction of standing crops.
(b) Removal of earth from ploughed or sown land.
(c) Prevention of cultivation when demanded by the cultivators. In order to reduce expenditure on payment of compensation to a minimum repairs should, except in emergent cases, be executed at times when no damage will be done to crops—no interruption caused to cultivation—and no loss caused to the cultivators.
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CHAPTER 25.

Electrical installations in Punjab P. W. D., Irrigation Branch.

INTRODUCTION.

25-1 The subject "Electrical Installations" is very vast. In the past few years, Irrigation Branch has undertaken the works of very great magnitude involving erection of power houses upto 5000 K. W. capacity and erection of high tension lines and Sub-stations upto 33000 volts. It is not possible to describe the details of erection and maintenance in one chapter.

The types of electrical installations normally required for Irrigation Works are described below. This does not cover more advanced practices adopted during the past few years as these are essentially of specialized nature—

(1) Generation of electric energy.
(2) Low Tension and High Tension Lines.
(3) Sub-stations.
(4) Electrification of buildings (Residential and Non-residential).
(5) Installation and maintenance of electric motors.
(6) Safety Rules.
25.2—25.3 MANUAL OF IRRIGATION PRACTICE

GENERATION OF ELECTRIC SUPPLY.

25.2. (1) Usually the construction jobs in the Irrigation Branch are taken in hand in the countryside and for the construction purposes electric energy is needed. According to the load conditions the power plant is installed.

The prime movers generally used in the Irrigation Branch are:

(1) Diesel Engines.

(2) Steam turbines.

The proper selection of the prime mover is dependent upon the local conditions. Every type of prime mover has economic limits of its use. Of course, steam turbines are undoubtedly better than Diesel Engines in operation, but the Diesel Engine has its own advantages. Generally, up to 500—800 K. W. Diesel Engines are used and Steam Turbines are used, above this limit. At remote places, where it is not economical to install stationary plant or stretch Low Tension or High Tension lines due to the time factor Portable Diesel or Gasoline plants are used.

LOW TENSION AND HIGH TENSION LINES.

25.3. (2) After the power is generated it is transmitted to load centre at 400 volts, 11 K. V., 33 K. V. and at above voltages according to the distance required to be covered with horizontal and delta vertical formation of the conductors on poles and rails, etc., with horizontal formation of conductors more economy in length of poles can be effected.

The following factors are considered while designing the power distribution lines—

(1) Height of conductor above the ground level.

(2) Spacing of conductors.

(3) Type of poles.

(4) Type of insulators.
ELECTRICAL INSTALLATIONS

(5) Power to be carried by the line.

(6) Mechanical load.

These factors are determined by the general character of the route, the length of the span, working voltage and the provisions stated in the Indian Electricity Rules—

(1) *Height of conductor above ground level.*—It is the usual practice to keep the lowest conductor at a height not lower than that stated below—

(a) *For 400 volts line*—

(i) 15 feet, when the line is running in open country.

(ii) 18 feet, when the line is passing through overhead.

(iii) 19 feet, when the line is crossing roads or streets, etc.

(b) *For 11000 volts 11 K. V. line*—

(i) 17 feet, when the line is running in open country.

(ii) 19 feet, when the line is passing through inhabited area.

(iii) 20 feet, when the power line is crossing through roads or streets.

(c) *For 33 K. V. line and above.*—The clearance above ground is not kept less than 17 feet plus 1 foot for every 33000 volts or part thereof by which the voltage of the line exceeds 33 K. V. The minimum clearance along or across any street is not kept less than 20 feet.

(2) *Spacing of the conductors.*—

(a) *400 volts and 11 K. V. line*—

(i) for horizontal formation—2 feet between conductors.
(8) For delta formation: (As shown)

33 K.V. line—
(i) Horizontal formation
4'-6" between conductors.
(ii) For delta formation.
(As shown)

(3) Poles. The length of the poles required for a particular location is determined by the vertical spacing of the conductors, the sag, the clearance required above ground and the depth of the pole underground (which is usually 1/5th of the length of the pole). The length of the poles used for 400 volts lines is 30' and pole used for 11 K.V. line is 36'. But with the horizontal formation of the conductors, the length of the poles can be further reduced by 2', thus 28' long pole for 400 volts lines and 34' long pole for 11 K.V. lines can be used safely. Tubular steel poles are used commonly as these are more rigid in construction and give good appearance. In places where termite decreases the life of wooden poles, the steel poles are used. These enable the use of longer spans than the wooden poles, and are both used for transmission and distribution lines. All steel poles are painted every 3rd or 4th year to have unlimited life. Sometimes steel rails are also used as poles when tubular steel poles or wooden poles are not available.

The following standard sizes of tubular poles are generally used:

<table>
<thead>
<tr>
<th>Approximate weight for 4&quot; x 4&quot; x 80' (long) for L.T. Lines</th>
<th>Safe working load with safety factor 3</th>
<th>Breaking load</th>
</tr>
</thead>
<tbody>
<tr>
<td>497 lbs.</td>
<td>507 lbs.</td>
<td>981 lbs.</td>
</tr>
<tr>
<td>502 lbs.</td>
<td>516 lbs.</td>
<td>1046 lbs.</td>
</tr>
</tbody>
</table>
At times wood poles are preferred because of their low cost. Wood poles are very elastic and best suited for short spans. Wood poles possess the advantage of increasing the insulation strength of a line against lightening. They reduce the risk of flash over between conductors and carrying structures in case of high voltage lines. The life of untreated poles varies between 5 and 10 years, depending upon the type of soil in which they are erected. These poles should be treated with a good preservative which is usually creosote. The creosoted poles have 15 to 20 years' life.

The reinforced concrete poles are also used when steel poles or wood poles are not available. These poles are costlier than wood poles. These are very difficult to erect and carry, but require less maintenance and supervision.

4. Insulators.—The insulators used for the lines are usually made of porcelain and glazed or of glass. These are of pin or strain type. These are usually of following mechanical strength—

<table>
<thead>
<tr>
<th>Pin</th>
<th>Suspension and Tension</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 lbs</td>
<td>1500 lbs</td>
</tr>
<tr>
<td>800 lbs</td>
<td>3000 lbs</td>
</tr>
<tr>
<td></td>
<td>4000 lbs</td>
</tr>
<tr>
<td></td>
<td>6000 lbs</td>
</tr>
</tbody>
</table>

5. Line conductors.—The distribution/transmission lines are usually designed with 10% voltage drop. The most commonly used conductors for overhead transmission line is copper as it can be easily spliced and it conducts electric energy very readily ranking next to silver. But A.C.S.K. conductors ranging from 0.035 sq. inch to 1 sq. inch equivalent copper conductors are also used for the transmission of power. Hard drawn copper is used on account of its greater strength than the medium hard drawn and annealed copper.
It is not advisable to use line conductors having less than the following sectional areas:

- 8 SWG copper (0.02 sq. inch) for spans upto 150 ft.
- 0.025 sq. inch stranded copper for spans upto 220 ft.
- 0.03 sq. inch stranded copper for spans over 220 ft.

Solid copper wires should only be used upto 2/0 SWG. If the conductor size works out to be too large then circuit should be divided into two parallel circuits. It is not advisable to use copper conductors of cross sectional area bigger than 2 sq. inch. The table showing constants of Hard drawn copper conductors is given below:

<table>
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<th>Table XI.—Constants of Hard drawn Copper Conductors</th>
</tr>
</thead>
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<tr>
<td>Size of conductor, SWG or No. and diameter of wire comprising conductor</td>
</tr>
<tr>
<td>Inch</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>7/20x</td>
</tr>
<tr>
<td>7/10x</td>
</tr>
<tr>
<td>7/0</td>
</tr>
<tr>
<td>7/10A</td>
</tr>
<tr>
<td>9/0</td>
</tr>
<tr>
<td>7/166x</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>7/108x</td>
</tr>
</tbody>
</table>
## ELECTRICAL INSTALLATIONS

<table>
<thead>
<tr>
<th>Size of conductor, SWG or No. and diameter of wire comprising conductor</th>
<th>Overall diameter of conductor</th>
<th>Nominal area of conductor</th>
<th>Weight of conductor per mile</th>
<th>Ultimate tensile strength</th>
<th>Current rating for temperature rise of</th>
<th>Resistance per mile at 60° F. Ohms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inch</td>
<td>Sq. inch</td>
<td>lbs.</td>
<td>lbs.</td>
<td>amp.</td>
<td>amp.</td>
<td></td>
</tr>
<tr>
<td>3/8</td>
<td>0.072</td>
<td>0.100</td>
<td>2.025</td>
<td>5.767</td>
<td>184</td>
<td>248</td>
</tr>
<tr>
<td>7/12</td>
<td>0.388</td>
<td>0.150</td>
<td>2.105</td>
<td>5.872</td>
<td>186</td>
<td>253</td>
</tr>
<tr>
<td>2/0</td>
<td>0.422</td>
<td>0.206</td>
<td>1.925</td>
<td>5.876</td>
<td>187</td>
<td>253</td>
</tr>
<tr>
<td>1/0</td>
<td>0.224</td>
<td>0.082</td>
<td>1.070</td>
<td>4.886</td>
<td>150</td>
<td>202</td>
</tr>
<tr>
<td>3/16'</td>
<td>0.285</td>
<td>0.075</td>
<td>1.585</td>
<td>4.280</td>
<td>140</td>
<td>200</td>
</tr>
<tr>
<td>1</td>
<td>0.109</td>
<td>0.071</td>
<td>1.479</td>
<td>5.025</td>
<td>123</td>
<td>200</td>
</tr>
<tr>
<td>3/16</td>
<td>0.347</td>
<td>0.060</td>
<td>1.070</td>
<td>5.780</td>
<td>125</td>
<td>170</td>
</tr>
<tr>
<td>2</td>
<td>0.708</td>
<td>0.080</td>
<td>1.218</td>
<td>2.381</td>
<td>111</td>
<td>187</td>
</tr>
<tr>
<td>2/17</td>
<td>0.347</td>
<td>0.060</td>
<td>1.060</td>
<td>2.914</td>
<td>110</td>
<td>187</td>
</tr>
<tr>
<td>3</td>
<td>0.232</td>
<td>0.050</td>
<td>1.215</td>
<td>2.575</td>
<td>103</td>
<td>187</td>
</tr>
<tr>
<td>4</td>
<td>0.237</td>
<td>0.047</td>
<td>0.800</td>
<td>2.480</td>
<td>91</td>
<td>124</td>
</tr>
<tr>
<td>3/14</td>
<td>0.282</td>
<td>0.040</td>
<td>0.640</td>
<td>3.077</td>
<td>79</td>
<td>117</td>
</tr>
<tr>
<td>5</td>
<td>0.212</td>
<td>0.035</td>
<td>0.710</td>
<td>2.277</td>
<td>70</td>
<td>110</td>
</tr>
<tr>
<td>3/16'</td>
<td>0.246</td>
<td>0.029</td>
<td>0.640</td>
<td>3.077</td>
<td>70</td>
<td>110</td>
</tr>
<tr>
<td>1/0</td>
<td>0.102</td>
<td>0.029</td>
<td>1.374</td>
<td>68</td>
<td>82</td>
<td>1.4910</td>
</tr>
<tr>
<td>3/16</td>
<td>0.224</td>
<td>0.015</td>
<td>1.032</td>
<td>1.215</td>
<td>65</td>
<td>88</td>
</tr>
<tr>
<td>1/0</td>
<td>0.176</td>
<td>0.025</td>
<td>1.178</td>
<td>61</td>
<td>83</td>
<td>1.2760</td>
</tr>
<tr>
<td>3</td>
<td>0.162</td>
<td>0.020</td>
<td>1.227</td>
<td>62</td>
<td>70</td>
<td>1.2760</td>
</tr>
</tbody>
</table>

### 25.5 Preventing measures
The disturbances like over-voltages, short circuits and ground faults take place in overhead lines. It is necessary to prevent the occurrence of such disturbances, or to limit the possibilities of damage to equipment. The principal employed is to disconnect as soon as possible the faulty section of line.
as possible the defective sections of the network before the abnormal conditions have had time to create any considerable damage.

The switching over voltages can be eliminated or reduced by use of modern switches with high speed of break. Lightning over-voltages are so great in value that any amount of insulation that is economically feasible would fail to eliminate flashovers. Increase in the insulation of the line only transfers the flashovers to the terminal equipment where they would cause greater damage than the line. Overhead ground wires are provided to protect the line to some extent from lightning and lightning arrestors should be good and reliable otherwise these shall add to the troubles.

25.6. Sectionalizing switches and fuses.—The overhead lines are exposed to the hazards of wind, lightning storms etc. In order that the resulting interruptions to service may be confined to as small a part of system, fused switches are installed at strategic points and fused in accordance with co-ordination plan on the calculated short circuit available at various points on the system. This ensures that the fuse nearest to the trouble operates properly. Usually 70 to 80% of the interruptions are due to temporary fault conditions. The use of repeater type switches is preferred as these have the ability of clearing temporary faults and automatically restoring the service. Overhead lines of 11 K.V. and above at sub-stations are equipped with circuit breakers having overload and earth leakage relays. 11 K.V. lines are provided with air-break switches at intervals of about 10 miles. The distribution transformers are protected by fuses both on primary and secondary sides.

25.7. Patrolling of Overhead lines.—Every line must be patrolled twice a week and the patrolman must note the following points while patrolling and report to the Sub-Divisional Officer:

1. Cracked poles or wood pecker holes in the pole.
2. Broken or rotted cross arms.
3. Broken or cracked insulators.

(8)
(4) Sag condition of line conductors and earth wire.
(5) Broken strands in conductors.
(6) Leaning poles.
(7) Loose or broken stay wires.
(8) Missing or loose nuts on insulators and poles.
(9) Condition of guard wires.
(10) All trees or branches of trees which are liable to touch the line or fall on the line.
(11) Dead birds hanging on the line.
(12) Any bird nests, etc., on the poles.
(13) Condition of earthen embankment round the poles.

Sub-stations.

25.8. A sub-station is always placed in the centre of gravity of the load. The site of the transformer is calculated from load available in the vicinity. The site is selected by keeping in view the availability of space, transport facilities, public safety and accessibility, etc.

25.9. Types of sub-stations.—There are two types of substations:

(a) Indoor type sub-stations.
(b) Outdoor type sub-stations.

Choice of Sub-stations.

25.10. (1) Indoor type sub-stations.—These sub-stations are most costly and built where there is a big load and large number of L. T. feeders are taken out for distribution. These are specially built at those places where there is lot of traffic and open structure is liable to be damaged with the movement of heavy machinery, just like mobile cranes, etc., or where there is danger to life. Underground Power cables are used for transmitting the power.

25.11. (2) Outdoor type Sub-stations.—These are further divided into:

(a) Pole mounting sub-stations.
(b) Floor mounting sub-stations.
Pole mounting Sub-stations

1. Single pole mounting sub-stations are erected where there is only lighting load or small power load. Single phase transformer for lighting load and 3 phase transformer for power load up to 25 KVA capacity are generally installed. Drop-out type switches with fuses are generally used on the primary side and 500 volts switch fuses are used on the secondary side. Lightning arrestors are provided to hilly areas as lightning is quite common in such areas in the Punjab State.

2. Two pole mounting sub-stations.—Transformers upto 200 KVA capacity are mounted on two pole structures, with spacing of poles from 6 to 8 feet apart. Lightning arrestors and a gang operated switch with fuses or drop-out switch are provided on the primary side and 600 volts air-break switches are provided on the secondary side. For this type of sub-stations substantial hand rail should be built around the platform and is required to be connected to earth.

Floor mounting substations.—These substations are erected where transformers of more than 200 KVA capacity are to be installed. Floor mounted substations have their own advantages although these are more costly to install for the reason that proper foundations are required for the transformers. These substations are more easily serviced, and inspection is very easy. It is easier to replace a floor mounted transformer when a transformer is damaged or is to be replaced by a transformer of higher capacity due to increase of some unforeseen load. This type of sub-station is required to be efficiently protected by fencing not less than eight feet in height or other means so as to prevent access to the electric supply lines and apparatus therein by an unauthorized person. While installing the transformers in substations it should be seen that the neutral of transformers is earthed by not less than two separate and distinct connections with earths having its own electrodes at the substations.

All the metal parts (not including as conductors) like body of transformers, poles, frame of isolating switches, operating
handles, metallic casing of air break switches etc., should be connected to earth by not less than two separate and distinct connections with earths.

25-13 Earths.—Copper plates of 2 x 2 x \( \frac{1}{2} \) size M. S. Plates or cast iron plates of 2 x 2 x \( \frac{1}{2} \) sizes are generally used as earth plates buried in ground. The depth to which these are required to be buried depends upon the soil. In order to get good earth i.e., of low resistance to ground common salt, saw dust and charcoal are used and placed in direct contact with electrodes.

Copper rods can also be used instead of copper or cast iron plates.

Usually 2 ohms resistance to ground is required in substations.

25-14 Protection of Sub-stations :-

(a) H. T. all circuit breakers are provided on the primary side in indoor type substations.

(b) Drop-out type fuses are provided on the primary side in all the three phases in outdoor type substations upto 200 KVA, capacity and gang operated air break switches with horn gap fuses or liquid fuses are provided in substations with capacity more than 200 KVA.

(c) Individual lightning arrestors are provided on the H. T. side of all the substations.

(d) The protection on the L. T. side of a transformer is very essential as the fuses in the H. T. side of the transformer upto 40 KVA are not very dependable. The transformers usually burn due to sustained overloading. The fuses on L. T. side of the transformer are accurately graded for the full load of the transformer and are provided as near the transformer as possible. It is advisable to provide all circuit breakers (operated, in case of fault, by over current and earth fault relays) or air circuit breakers on L. T. side of transformers with capacity over 200 KVA.
25.15. Inspection of Transformers before commissioning—

(a) The bushings and terminals are examined for any sign of damage.

(b) All the bolts, nuts and screws on the lid bushings, clamps, valves and plugs, etc., are tightened.

(c) The seal from the silicagel breaker is removed and breather is screwed into the transformer.

(d) The insulation resistance of windings, etc., is measured with a megger. The transformer is dried if the value of the insulation resistance is not satisfactory.

(e) The oil in the transformer should be up to the proper level. Otherwise it should be topped up with good (having following qualities) and tested oil. The primary requirements of this oil are:

(i) High dielectric strength.

(ii) Freedom from inorganic acid, alkali and corrosive sulphur to prevent injury to insulation or conductors.

(iii) Low viscosity to provide good heat transfer.

(iv) Good resistance to emulsion so that the oil should throw down any moisture entering the apparatus instead of holding it in suspension.

(v) Freedom from sludging under normal operating conditions.

(vi) Oil should be tested for its dielectric strength and freedom from moisture. It should stand 60 K. V. dielectric strength.

25.16. History Sheet—History sheet is maintained in the form of a register in which the date of purchase of
the transformer, value, test certificates, reference, all inspection data, including results of oil, sample tests, earth resistance and repairs done to the transformer are entered in the chronological order.

Sub-station Register.—The brief history of the sub-station is entered in this register with different equipments installed in it with changes and repairs, etc. A periodic record of load on the sub-station is also kept in this register. A clamping ammeter is used for checking the load periodically.

25:17. Routine Maintenance —

(a) After a few days of operation on load, the transformers and other equipment are checked for oil leaks from gasket joints at all openings (main base cover, main cover, bushings, etc.) which are not noticeable when the oil is cold. The temperature of the transformer on load is checked.

(b) A visual inspection of sub-station is also done every month without de-energizing the sub-station. Necessary care for personal safety is taken and the supervisor inspecting the sub-station keeps himself at a safe distance from the energized parts. During this inspection only leaks, etc., are checked. The sub-station earths are also entered.

(c) A detailed check-up of the sub-station is done once in six months by completely shutting off the sub-station—

1. All connections of bus-bars, etc., are checked to find out that these are not becoming hot due to any loose connection or otherwise.

2. Bushings and insulators are checked for cracks.

3. Oil leakages are checked. Transformer winding insulation is checked.
(4) The oil level is checked and made up by good quality oil.

(5) Lightning arrestors are checked for earth connections.

(6) The earths are watered and ground resistances are checked.

(7) The breathers are cleaned and silicagel changed.

(8) In case of oil circuit breakers with automatic tripping arrangement, oil is reconditioned. Main contacts are checked, cleaned and set right. Operating mechanism is checked and oiled. Quite often trouble is fore-stalled by tightening a wire of switch, replacing spring cotter pins, when thorough inspections are made. Before inspecting the mechanism be sure that the breaker control voltage is off.

(9) All the fuses are checked and contacts tightened if required.

(10) The operating mechanism of insulators checked and oiled, main contacts checked and adjusted if required.

(11) The samples of oil are drawn every year to check up the dielectric strength of the oil. The principal causes of deterioration of insulating oil in service are water and oxidation. In case any moisture in oil is observed or the oil is not found satisfactory, the oil is filtered and dried.

ELECTRIFICATION OF BUILDINGS

25:18. General.—In Irrigation Branch a large number of residential buildings for officers and subordinate staff and non-residential buildings such as offices and rest houses are built. These buildings are electrified either departmentally or through contractor. The general specifications for electrical works in Government buildings, as issued by
Punjab Government with modifications from time to time, are rigidly followed in the Irrigation Branch. The wiring is done on the "distribution system" with branch and main distribution boards at convenient centres. All conductors are run, as far as possible, along the walls and ceiling, so as to be easily accessible and capable of being thoroughly inspected. The cross-sectional area of all conductors inside the buildings is so proportioned to their length that the drop in pressure from the main fuse to the furthest or any other consuming device, does not exceed 3% of the normal pressure of the circuit directly connected to such consuming devices with all the other consuming devices in use. The internal wiring of buildings is generally carried out in three systems, namely:

1. Cleated wiring system.
2. Wood casing wiring.
3. Conduit wiring.

25 19 Cleated wiring — This type of wiring is generally carried out for temporary installations only. The wiring is done in such a way so that it is visible and accessible throughout its length and is kept away from all structural metal work, gas and water pipes. All cleats are made of glazed porcelain and consist of two parts, a base piece and a cap. Cleats are fixed at a distance not greater than 3 ft. apart and at regular intervals. Cleats are fixed on rawl plugs or wooden plugs made of well-seasoned teak wood. There must be no apparent sag on the conductors and the conductors must not be less than ½ inch away from wall, ceiling, etc. A wooden baton is provided and fixed with not less than one plug per foot run where it is impracticable to fix the cleats in a regular manner. The baton is of teak wood, ⅝ thick and one inch wider than the cleat used. It is chamfered on the edges, placed all over the varnished with two coats of varnish. Where cleated conductors cross each other they are fixed on an insulating bridging piece which will rigidly maintain a separation of ⅝ between the poles. No cleat wiring is left unprotected within 6 ft. of floor. A protective covering of conduit or wood casing is provided. For pressures upto 250 volts the cleats of such size that in case of branch loads, conductors shall not be less than 1½ inches apart centre to centre, in case of sub-mains, not less than 1½ inches apart centre to centre; in case of mains not less than 2½ apart.

(15)
25.20. Wood casing wiring.—This system of wiring is generally used in all the buildings except workshops in the Irrigation Branch. The casing is made of teak wood, free from knots, shakes, sap or other defects and has a smooth finish. The casing has grooved body and the grooves are rounded and in no case the width of the fillet between the grooves is to be less than \( \frac{3}{8} \) inch. The thickness of the back under the grooves, capping over the grooves and outer walls of the casing is not to be less than \( \frac{3}{4} \) inch. The dimensions of the grooves are such that the wires shall not require any force to put them in place. The overall width and thickness of casing is not to be less than \( \frac{3}{8} \) inch and \( \frac{3}{4} \) inch, respectively. The casing is fixed to the wall over porcelain round cleats screwed to rawl plugs or seasoned teak wood plugs by means of wood screws at intervals not exceeding three feet. The casing is never buried in walls or fixed in proximity to gas stream or water pipes. The casing and capping is run in lengths as long as possible. All joints are scarfed or cut diagonally in longitudinal section. Joints in casing must break joints with those in the casing. Capping are secured at the joint with two or more screws as may be necessary. Capping is attached to the casing by round-headed screws at intervals not exceeding 9 inches in each edge in all sizes and above 2 inches in width and along the centre fillet in sizes smaller than 2 inches width. All casing and capping is served before erection internally and on the back with two coats of moisture-proof varnish. Wires of opposite polarity are not run in the same groove. The neutral and outer in case of 3 wire D. C. system and neutral and phase wire in case of A. C. system are not run in the same groove.

25.21. Conduit wires.—This system of wiring is usually adopted in electrification of the work-shops in the Irrigation Branch. All conduit is screwed and is electrically continuous from the distribution box to the outlet boxes for the fittings, and switches, etc. The lengths of conduits are joined by means of screwed sockets. Grease or oil should not be used while screwing any fitting on the conduit as these are liable to injure the insulation of the conductors. Sharp edges on the conduits are also not desirable as these are liable to damage the insulation.

The outlets of conduits are properly drained and ventilated in such a way to see that no insects enter into the conduit. The conduit is either buried in the walls or fixed
by means of saddles on the walls. The saddles are fixed at such a distance to see that the conduit is held up rigidly. Interval of 3 ft. between saddles on straight runs is desirable.

The whole system of conduit should be laid before the wires are pulled through. Some sort of approved wire lubricant should be used while pulling the wires through the conduit.

Bends provided in the conduit should not have a radius less than 2½ times the outside diameter of the conduit. The conduit and all the fittings must be painted with two coats of good paint to avoid any rusting.

The earthing of the conduit system is done as required by Indian Electricity Rules.

**25:22. CURRENT RATING IN AMPERES OF VULCANIZED RUBBER CABLES.**

<table>
<thead>
<tr>
<th>Nominal area of Conductor, Sq. inch.</th>
<th>Number and Diameter of Wires, Inch.</th>
<th>Amps.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.002</td>
<td>2/020</td>
<td>5</td>
</tr>
<tr>
<td>0.003</td>
<td>2/036</td>
<td>10</td>
</tr>
<tr>
<td>0.045</td>
<td>7/029</td>
<td>15</td>
</tr>
<tr>
<td>0.007</td>
<td>7/038</td>
<td>20</td>
</tr>
<tr>
<td>0.01</td>
<td>7/044</td>
<td>30</td>
</tr>
<tr>
<td>0.045</td>
<td>7/082</td>
<td>45</td>
</tr>
<tr>
<td>0.025</td>
<td>7/061</td>
<td>55</td>
</tr>
<tr>
<td>0.03</td>
<td>19/044</td>
<td>65</td>
</tr>
<tr>
<td>0.04</td>
<td>19/052</td>
<td>75</td>
</tr>
<tr>
<td>0.06</td>
<td>29/064</td>
<td>102</td>
</tr>
<tr>
<td>0.1</td>
<td>19/088</td>
<td>147</td>
</tr>
</tbody>
</table>
### Nominal area of Conductor

<table>
<thead>
<tr>
<th>Sq. in.</th>
<th>Number and Diameter of Wires</th>
<th>Amps.</th>
</tr>
</thead>
<tbody>
<tr>
<td>.15</td>
<td>37/072</td>
<td>189</td>
</tr>
<tr>
<td>2</td>
<td>37/089</td>
<td>229</td>
</tr>
<tr>
<td>3</td>
<td>37/109</td>
<td>266</td>
</tr>
<tr>
<td>4</td>
<td>61/089</td>
<td>358</td>
</tr>
<tr>
<td>5</td>
<td>61/103</td>
<td>413</td>
</tr>
<tr>
<td>75</td>
<td>91/139</td>
<td>575</td>
</tr>
<tr>
<td>10</td>
<td>127/163</td>
<td>740</td>
</tr>
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</table>

### 25.23. WIRING CAPACITY OF CONDUITS

<table>
<thead>
<tr>
<th>Nominal area of conductor</th>
<th>Approximate overall Diameter in inches</th>
<th>Maximum number of conductors</th>
<th>Size of conduit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sq. in.</td>
<td>1/844</td>
<td>1/8</td>
<td>1 1/16</td>
</tr>
<tr>
<td>0.0015</td>
<td>1/844</td>
<td>0.150</td>
<td>4</td>
</tr>
<tr>
<td>0.002</td>
<td>3/929</td>
<td>0.180</td>
<td>2</td>
</tr>
<tr>
<td>0.003</td>
<td>3/936</td>
<td>0.200</td>
<td>2</td>
</tr>
<tr>
<td>0.004</td>
<td>1/675</td>
<td>0.175</td>
<td>2</td>
</tr>
<tr>
<td>0.0045</td>
<td>7/929</td>
<td>0.210</td>
<td>2</td>
</tr>
<tr>
<td>0.007</td>
<td>7/936</td>
<td>0.225</td>
<td>2</td>
</tr>
<tr>
<td>0.01</td>
<td>7/944</td>
<td>0.270</td>
<td>4</td>
</tr>
<tr>
<td>0.0145</td>
<td>7/902</td>
<td>0.300</td>
<td>3</td>
</tr>
</tbody>
</table>
### Electrical Installations

#### Maximum Number of Conductors

<table>
<thead>
<tr>
<th>Nominal area of conductor, sq. in.</th>
<th>No. and Diameter of Wires in inches</th>
<th>Approximate Overall Diameter in inches</th>
<th>Sizes of conduit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.025</td>
<td>7/064</td>
<td>0.245</td>
<td>2 4 6 8 8 8 8 8</td>
</tr>
<tr>
<td>0.03</td>
<td>10/044</td>
<td>0.280</td>
<td>3 5 7 8 8 8 8 8</td>
</tr>
<tr>
<td>0.04</td>
<td>19/052</td>
<td>0.425</td>
<td>2 4 6 7 7 7 7 7</td>
</tr>
<tr>
<td>0.06</td>
<td>10/064</td>
<td>0.510</td>
<td>3 5 6 6 6 6 6 6</td>
</tr>
<tr>
<td>0.10</td>
<td>10/083</td>
<td>0.630</td>
<td>3 4 4 4 4 4 4 4</td>
</tr>
<tr>
<td>0.15</td>
<td>33/072</td>
<td>0.750</td>
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</tr>
</tbody>
</table>

#### Fuse Wires

**Carrying and fusing currents of copper fuse wires.**

<table>
<thead>
<tr>
<th>Carrying capacity in amperes</th>
<th>Standard Wire gauge</th>
<th>Diameter</th>
<th>Approx. fusing current in Amperes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>34</td>
<td>0.0082</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
<td>0.0124</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td>27</td>
<td>0.0164</td>
<td>30</td>
</tr>
<tr>
<td>20</td>
<td>26</td>
<td>0.018</td>
<td>40</td>
</tr>
<tr>
<td>25</td>
<td>24</td>
<td>0.022</td>
<td>55</td>
</tr>
<tr>
<td>30</td>
<td>22</td>
<td>0.028</td>
<td>65</td>
</tr>
<tr>
<td>45</td>
<td>19</td>
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</tr>
<tr>
<td>45</td>
<td>2–22</td>
<td>2–0.028</td>
<td>95</td>
</tr>
</tbody>
</table>

(19)
## 25-24—25-25 MANUAL OF IRRIGATION PRACTICE

<table>
<thead>
<tr>
<th>Carrying capacity in amperes</th>
<th>Standard Wire gauge</th>
<th>Diameter</th>
<th>Approx. fusing current amperes</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>18</td>
<td>0.048</td>
<td>120</td>
</tr>
<tr>
<td>60</td>
<td>2-20</td>
<td>0.036</td>
<td>130</td>
</tr>
<tr>
<td>80</td>
<td>16</td>
<td>0.064</td>
<td>170</td>
</tr>
<tr>
<td>80</td>
<td>2-19</td>
<td>0.040</td>
<td>170</td>
</tr>
<tr>
<td>100</td>
<td>14</td>
<td>0.080</td>
<td>210</td>
</tr>
<tr>
<td>100</td>
<td>2-18</td>
<td>0.048</td>
<td>200</td>
</tr>
<tr>
<td>200</td>
<td>2-13</td>
<td>0.082</td>
<td>400</td>
</tr>
</tbody>
</table>

### 25-25. Installation and Operation of Electric Motors:

1. **Installation.** The motor should be installed at a clean well-ventilated place.

2. When lifting the motor, it is advisable to lift it by means of slings placed through eye-bolts provided at the top of the motor housing. If there are no eye-bolts slings should be placed under the bearing housings.

3. The foundation should be rigid and solid. Level the motor base and grout it.

4. (a) The motor should be aligned carefully with the driven unit. The adjusting screw head should be placed away from the driven unit when aligning an adjustable base.

5. When the motor and driven unit have four or more bearings flexible coupling should be used. Three bearing construction requires rigid coupling.

6. The pulley sheaves or sprockets not smaller than those recommended by the belt or chain manufacturers should be used to avoid over stressing of motor bearings, chains or belts.

7. For flat belt drive the location of the driving and driven shaft should be made parallel.
The belt tension should be just enough to prevent slippage. Excess tension unnecessarily loads the bearings. Always avoid a vertical drift. An angle of 45 degrees or less between the line of shaft centres and the horizontal is desirable. The distance between the centres should be at least 2½ times the diameter of the larger pulley. Pulley ratio should not exceed 5 to 1. Belt speed should not increase 5000 feet per minute. The smooth side of the belt should be run on the pulleys.

(c) For V belt drive the sheaves should be aligned carefully to avoid axial thrust on the bearings. The belt tension should be just enough to prevent excessive bow of the slack side. V belts do not require as much tension as flat belts. Pulley ratio should not exceed 8 to 1. Belts speeds should not increase 8000 feet per minute.

(5) Motor and starter should be grounded in accordance with Indian Electricity Rules.

25:26. Operation.—1. The insulation resistance should be measured before initial starting. Its value should not be less than $\frac{\text{Rataed voltage of machine}}{1000} \text{ Megohms}$. If the insulation resistance is less than this value the moisture should be dried out.

2. It should be seen that the voltage and frequency stamped on the name plate correspond with that of the line with which it is to be connected.

3. The connections of the motor and control wiring should be checked.

4. The sleeve bearing reservoir should be filled to $\frac{1}{4}$ of the gauge in case of sleeve bearing motor. The new grease bearing motors are usually greased in the factory at the time of shipment.

5. Make sure that motor turns freely and does not rub when disconnected from load. Any foreign material from the air gap should be removed.
6. The rotation of the motor should be checked by closing the starter for a few seconds only. Interchange any two leads in case of a 3-phase A. C. motor if the rotation is wrong.

7. It is desirable to operate the motor without load for about one hour to check any unusual localised heating in bearings and windings. Check that the oil rings on the sleeve bearings turn freely.

**MOTOR CURRENT TABLE**

<table>
<thead>
<tr>
<th>B. H. P. of motor</th>
<th>Alternating Current</th>
<th>Direct Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Approximate Amperes</td>
<td>Approximate Amperes</td>
</tr>
<tr>
<td></td>
<td>per phase taken by modern induction motors, allowing reasonable efficiencies and power factors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>230 V 400 V 440 V 500 V</td>
<td>110 V 220 V 440 V 500 V</td>
</tr>
<tr>
<td>--------------------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>1</td>
<td>2 3 4 5</td>
<td>6 7 8 9 10</td>
</tr>
<tr>
<td>3/4</td>
<td>1 3 3 3</td>
<td>1 3 4 3</td>
</tr>
<tr>
<td>1</td>
<td>1 3 3 3</td>
<td>1 3 4 3</td>
</tr>
<tr>
<td>1 1/2</td>
<td>1 3 3 3</td>
<td>1 3 4 3</td>
</tr>
<tr>
<td>4/3</td>
<td>1 3 3 3</td>
<td>1 3 4 3</td>
</tr>
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<td>1</td>
<td>1 3 3 3</td>
<td>1 3 4 3</td>
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<td>1 3 4 3</td>
</tr>
<tr>
<td>1 1/2</td>
<td>1 3 3 3</td>
<td>1 3 4 3</td>
</tr>
<tr>
<td>4/3</td>
<td>1 3 3 3</td>
<td>1 3 4 3</td>
</tr>
<tr>
<td>1</td>
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<td>1 3 4 3</td>
</tr>
<tr>
<td>1 1/2</td>
<td>1 3 3 3</td>
<td>1 3 4 3</td>
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</table>

(22)
ELECTRICAL INSTALLATIONS

MOTOR CURRENT TABLE—CONCLUDED

<table>
<thead>
<tr>
<th></th>
<th>2</th>
<th>3</th>
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<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<tbody>
<tr>
<td>2</td>
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<td>35</td>
<td>32</td>
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<td>45</td>
<td>40</td>
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<td></td>
</tr>
<tr>
<td>2½</td>
<td>140</td>
<td>43</td>
<td>40</td>
<td>36</td>
<td>23</td>
<td>11</td>
<td>5.5</td>
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<td>175</td>
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<td>43</td>
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<td>27</td>
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<td>60</td>
<td>55</td>
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<td>17</td>
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<td>10</td>
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<tr>
<td>12½</td>
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<td>180</td>
<td>160</td>
<td>100</td>
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<td>25</td>
<td>22</td>
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<td>230</td>
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<td>380</td>
<td>190</td>
<td>95</td>
<td>87</td>
<td>50</td>
</tr>
</tbody>
</table>

Note.—In slip ring Motors, the voltage and current of the rotor are quite independent of those of the stator, and as the rotor current may be much greater than that taken from the line, it is always advisable to ascertain its value in order that connecting rotor cables of suitable size may be provided.

25 28. Maintenance.—Good maintenance means to keep the equipment in satisfactory operating conditions at all times. The first requirement in the satisfactory maintenance of electric machines is competent inspection. General conditions are determined by a thorough initial inspection after which a systematic maintenance schedule is established.
The inspection record of each motor is kept in the following form:

**Motor Maintenance Record.**

<table>
<thead>
<tr>
<th>Male H.P.</th>
<th>A.C. or D.C.</th>
<th>Phase Cycles</th>
<th>Volts Ams</th>
<th>Serial No.</th>
<th>Bearing make &amp; No.</th>
<th>Locations of machine it drives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<table>
<thead>
<tr>
<th>Date blown out</th>
<th>Condition of Bearing</th>
<th>Condition of brushes</th>
<th>Condition of Commutator</th>
<th>Insulation resistance</th>
<th>General condition</th>
<th>Signature</th>
</tr>
</thead>
<tbody>
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Changes of operating conditions or in location of motor should be entered in this card. Dates are very important.

The following rules should be observed to get good service from a motor:

1. Keep it clean.
2. Keep it properly lubricated.
4. Do not wait for motors to squeal for lack of oil or smoke from overheat, before checking their condition.

5. At all times know the condition of the apparatus.

6. Know what loads the apparatus must carry.

7. Correct indication of weak points before the motor fails.

The clean motor will give best and longest service. Not only should the motor be protected against dust and moisture but also against oil, acids, alkalis, chemical compounds and gases, etc., which may cause deterioration of insulation or corrosion of metal parts. High temperature shortens the life of an electric motor. The actual temperature and not the temperature rise should be measured for the safe operation. Unbalanced voltage may seriously affect the operation of a motor and single phase operation is also certain to result in damage to polyphase motors.

Proper care of brushes and current collecting parts is of fundamental necessity. The following points should be observed:

1. Brushes should be accurately adjusted and fitted to the commutator and collector rings.

2. Care should be taken to see that dirt of particles from edges of the brushes have not lodged between a brush and the surface of the commutator or the collector rings.

3. Brushes must move freely in the brush holder but should not be so loose that the clamping will occur when the machine is operating.

4. Check the spring tension.

5. The commutator or collector rings should be smooth and true.

6. There should be no objectionable vibration.

(25)
7. The brushes must be correctly aligned and the commutator brushes must be properly stuggered.

8. The sparking in the brushes should not occur.

25:29. Bearings and lubricants.—Bearings and lubricants are of very great importance in an electric equipment which has rotating parts. Analysis of induction motor failure shows the bearings to be a principal offender. Failure of bearings allows the rotor to rub against the stator. The following types of bearings are generally used:

1. Sleeve bearings.

2. Ball and Roller bearings.

The bearings of electrical equipment should be subject to a careful inspection. The frequency of inspection including the addition of oil and changing of oil is determined by the state of the operating conditions. The angular type of solid sleeve bearings require comparatively very little attention as oil does not become contaminated and oil leakage is negligible. Maintenance of correct oil level is frequently the only upkeep required for years of service with this type of bearing. The old type of sleeve bearings require a great deal of checking for wear and oil changes. Safe temperature rise for bearings is 40 °C above the room temperature.

Bearing is hot due to one of the following reasons:

1. No oil.
2. Excessive belt tension.
3. Failure of oil rings to revolve with the shaft.
4. Rough bearing surface.
5. Improper fitting of journal boxes.
7. Mis-alignment of shaft and bearing.
8. Poor grade of oil or dirty oil.
9. Bolts on the bearing cap may be loose.
10. End thrust due to improper levelling.
11. End thrust due to magnetic pull, rotating part being sucked into field because it extends beyond the field poles farther at one end than at the other.
12. Excessive side pull because the rotating part is out of centre.

If the bearings become hot, first reduce the load if possible and dried lubricants freely, loosening the nuts on the bearing cup and if the machine is belt connected slacken the belt. If relief is not afforded, shut down, keeping the machine running slowly until the shaft is cool in order that the bearing may not freeze. Renew the oil supply before starting again. The new machine should always be run on no load for an hour to see that it operates properly. The bearings should be carefully watched to observe that the oil rings are revolving and carrying plentyful supply of oil to the shaft.

External inspection of the motor at the time of the first greasing soon after it is put into operation will determine whether the bearings are operating quietly and without undue heating. Further inspection will not be necessary except at infrequent intervals, probably at greasing periods.

If practicable, it is desirable for the most satisfactory service, to open the bearing housings once a year, or after every 5,000 hours' operation, to check the condition of the bearings and grease. If difficult to inspect the pulley or pinion end bearing, the condition of the bearing at the opposite end will usually be representative of both.
The following regreasing periods serve as a good guide:

<table>
<thead>
<tr>
<th>Service</th>
<th>1/4 - 7/8 hp</th>
<th>10 - 40 hp</th>
<th>50 - 150 hp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy</td>
<td>7 years</td>
<td>5 years</td>
<td>3 years</td>
</tr>
<tr>
<td>Standard</td>
<td>5 years</td>
<td>3 years</td>
<td>1 year</td>
</tr>
<tr>
<td>Severe</td>
<td>3 years</td>
<td>1 year</td>
<td>6 months</td>
</tr>
<tr>
<td>Vary severe</td>
<td>6 months</td>
<td>3 months</td>
<td>3 months</td>
</tr>
</tbody>
</table>

25:30 How to grease motors:

1. Make sure that no dirt gets into the bearings with the grease-wipe pressure-gun fitting, bearing housings, and relief plug clean.

2. Always remove the relief plug from the bottom of the bearing before using the grease-gun. This prevents putting excessive pressure inside the bearing housing, which might rupture the bearing seals.

3. With a clean screwdriver or similar tool, free the relief hole of any hardened grease so that any excess grease will run freely from the bearing.

4. With motor running, add grease with a hand-operated pressure gun until it begins to flow from the relief valve. This tends to purge housing of old grease. If it should prove dangerous to lubricate the motor while running, follow this procedure with the motor at stand still.

5. Allow the motor to run long enough after adding the grease to permit the rotating part of the bearing to expel all excess grease.
6. Replace the relief plug and wipe the outside housing clean.

If grease deterioration has occurred or if dirt has gained entrance to the housing, the bearing and housing parts should be thoroughly cleaned out and grease added.

A small amount of lubricant is sufficient to maintain a film of lubricant over the surface of the balls and races. Too much grease will cause over heating and grease leakage.

Grease leakage is an indication of over filling. In general the increase in temperature will be temporary and will not be harmful. If it persists more than four or five hours or is excessive, some grease should be removed from the bearing. The ideal quantity of grease in the housing is from \( \frac{3}{4} \) to \( \frac{1}{2} \) full with shaft size up to 3 inches diameter and from \( \frac{1}{4} \) to \( \frac{1}{2} \) full in the larger bearings.

As a guide, it is suggested that grease should be added every three months of operation in amounts as indicated in the following table. If experience indicates that these quantities result in a surplus of grease in the bearing, the quantity should be reduced or the greasing periods lengthened or both.

**Amount of grease for Horizontal motors.**

**Volume of Grease to be added**

<table>
<thead>
<tr>
<th>Shaft extension</th>
<th>gilt</th>
<th>0.5&quot;</th>
<th>1 cubic inch.</th>
</tr>
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<tbody>
<tr>
<td>above</td>
<td>1</td>
<td>1.5&quot;</td>
<td>1.5 cubic inch.</td>
</tr>
<tr>
<td>above</td>
<td>1.5</td>
<td>2.5&quot;</td>
<td>2.5 cubic inch.</td>
</tr>
<tr>
<td>above</td>
<td>2</td>
<td>3&quot;</td>
<td>4 cubic inch.</td>
</tr>
<tr>
<td>above</td>
<td>3.5</td>
<td>4&quot;</td>
<td>7 cubic inch.</td>
</tr>
<tr>
<td>above</td>
<td>4</td>
<td>5&quot;</td>
<td>10 cubic inch.</td>
</tr>
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</table>

1 oz. = \( \frac{1}{2} \) cu. inch.

(25)
Instructions for handling ball bearings during assembly.

1. Do not remove bearings from box until ready to install.
2. Keep hands and tools clean.
3. Do not wash out the grease in which the bearing is packed.
4. Keep grease can covered.
5. Use plenty of clean rags.
7. Use newspaper to lay bearings on, while installing.
8. Be sure shaft and housing seats are perfectly clean.
9. Paint inside of housing to seal in case sand and chips.
10. Cover exposed bearings that must be left over night.

25-31. Maintenance of Starters—

GENERAL RULES.

1. Before removing cover to inspect or adjust starter make sure that disconnecting switch is open and control circuit is dead.
2. Remember that all parts must be kept dry and clean. This is of fundamental importance.
3. Inspection should be made at regular intervals for best results. In general, monthly inspections will be sufficient though in particularly severe service it may be desirable to inspect oftener.


1. Do not lubricate contact tips or bearings.
2. Magnet sealing surfaces should occasionally be wiped with an oil moistened cloth to prevent noise and rust.

(30)
3. Check tightness of all connections, and particularly connections to overload heaters, since a loose connection here will cause local heating that will affect the calibration of the relay.

4. Make sure that shunts are not broken or touching other parts.

5. Contacts should be adjusted so that they will all make at the same time.

6. In general, the contacts will not need attention during normal life. If they become excessively rough or burned in service, they should be dressed with sand paper or a fine file. Do not use emery cloth. Contact tips should be replaced when approximately 1/3 of their thickness is worn away. These are removable, and only a screwdriver is needed for the change.

7. Any excess deposits should be removed from inside surface of the arc boxes adjacent to the contacts, and any broken arc boxes should be replaced.

8. See that all moving parts work freely.

9. Disconnect motor and manually test the start button, the stop button, the over load relay and reset.

10. Most industrial line starters are provided with over load relays whose action depends on the movement of bi-metallic strip under heat. On very small motors the bi-metallic strip actually carries the motor current but on larger ones a separate heater carrying the motor current is placed close to the strip. On still larger motors a current transformer reduces the motor current to a value that can be handled by the heater.


1. Check all connections.
2. Observe wear on removable contact tips and replace when § worn away.
3. Replace oil when it becomes dirty or badly carbonised.
4. See all parts are clean and move freely.

25:34. Safety Rules.—Work on electrical circuits and apparatus of any kind is generally considered hazardous, due to accidents which have occurred, usually resulting in lost time, partial or permanent disability and in some cases death. However with forethought, provision for necessary safeguards and carefulness of the supervisor and workmen, accidents can be practically eliminated.

The following rules are provided for guidance. Do everything possible for the safety of the personnel:

1. An organization diagram or written statement clearly showing the division of responsibility between officials and employees, down to and including the grade of foreman should be posted conspicuously in offices and important stations where the number of employees and nature of work warrants.

2. A list of names and addresses of those physicians and members of organization who are to be called upon in emergencies should also be posted conspicuously at above mentioned places.

3. If more than one person is engaged in work, on or about the same electric equipment or lines at any one occasion, one of the persons should be designated as the foreman locally in charge of the work, or all of the workmen should be instructed as to the work, they have to perform, and the employees instructing the work should be considered in charge of the work.

4. Everybody should wear suitable clothing while working close to live circuits or apparatus. The sleeves should be kept down and wearing of unnecessary articles should be avoided. The key chains, rings, metallic buttons, ragged clothing or shoes with defective soles that may catch or slip are not at all desirable.
5. Personal caution is the greatest safeguard. There is absolutely no reason to take chances that will endanger you or others. The result of each action should be considered. Place yourself in a safe position. Be careful to avoid falling, stumbling, slipping or moving backward against live parts.

6. Always have medical treatment for all injuries because the slightest injury may cause infection.

7. All the electric apparatus should be installed in such a way that the exposed live parts are properly guarded or insulated to provide adequate protection.

8. Rotating or moving parts of the apparatus should be properly guarded to prevent the possibility of catching of the limbs or clothing of the employees.

9. All the circuits should be permanently marked on the switches.

10. The supervisor should see that the workman has the necessary experience of the particular work he has been assigned. He should also see that necessary safeguards have been provided to protect himself and the workman.

11. The workman should determine the condition of the wooden pole at ground level, before climbing up. The pole should be free from cracks and rots etc.

12. There are safety devices available to eliminate the hazardous conditions. The safety devices should be secured before starting the work. Each device should be examined before it is used to make sure that it is in good condition. The proper device should be used for the particular work to be done.

The following is a list of suitable devices and equipment the kinds and number of which will depend on the requirement of each case:

(a) First aid outfits.
(b) Insulating wearing apparel such as insulating gloves, sleeves, boots, shields, covers, mats, stools and platforms.

(c) Protective goggles of suitable materials and construction.

(d) Tools of such special design and insulation as to eliminate so far as practicable the danger of forming short circuits across conducting bars at different tensions or bringing the user into contact with such parts.

(e) "Men at work" tags, log books, operation diagrams or equivalent devices and portable danger signs.

(f) Fire extinguishing devices, either designed for safe use on live parts or plainly marked that they must not be so used.

(g) Grounding devices for making protective grounds.

(h) Fixed or portable lightning equipment

(i) Permanent warning signs forbidding entrance to unauthorized persons should be displayed in all conspicuous places at all unattended and unlocked entrances to electric supply stations, substations and testing rooms containing exposed current carrying parts or moving parts.

13. Safety belts or reliable scaffolding should be provided when a workman has to work at elevated position. It should be seen that snaps are fastened securely before depending on the safety belt.

14. When permanent guards or other safety devices have been removed from the equipment they should be replaced before leaving the job.

15. Good housekeeping is very necessary during the progress of the work. All the surplus material should be returned to the stores and waste material should be properly disposed of after the completion of the job.
16. Rubber gloves should be electrically tested before first use and then tested electrically every month. These should be air tested every time before use.

17. Improper or defective tools should not be used.

18. All tools should be removed by the workmen on completion of the job.

19. The power should be shut off while making any repairs or alteration in power circuits of any voltage. All voltages should be considered dangerous even though the voltages may not be great enough to produce a serious shock. Contact with low voltages have caused workmen to fall from ladders or scaffolding. Dead circuits should be treated as live circuits as this practice develops the caution that prevents an accident if the power is turned on through error of some person.

20. Great care should be taken while locating trouble with the help of series lamp circuits.

21. A permit to start work on any apparatus or line should be obtained from the official in charge of switching power on the apparatus or line before starting the work. The control devices must be locked or blocked after making the circuits dead. After this tag showing "Workmen working on the line" should be attached to the control devices. The tag should remain on the device till the permit to start work has been cancelled by the authorized person. The workmen must short circuit all the conductors to ground at the point where work is to be done before starting the work on the line.

22. All the electrical equipment such as motors, generators, conduits, switches and transformers etc. should be properly grounded at the time of installation.

23. The following precautions should be observed while operating the switches:

(a) Switches should be fully opened when in open
25 34

MANUAL OF IRRIGATION PRACTICE

position and fully closed when in closed position.

(b) The switches should be closed and opened in firm positive manner using sufficient force to see that blades make full contact or do not make contact at all. The blades are burnt by arcing when the switches are opened or closed in hesitating manner.

(c) The fuses should be removed from the switches after opening the switch fully. Proper fuse puller should be used if there is no switch to make the circuit dead.

24. Iron objects such as tools and oil cans should be kept clear of the magnetic fields to prevent their being drawn into moving parts. Only approved dusters brushes or wipers provided with insulated handles should be used to clean switches and other electrical apparatus.

25. Only good ladders should be used on work and these should be examined each time by the workman before use. Make shift extensions of ladders are dangerous and should not be used. The workman should see that the ladder is placed on secure footings before its use. The workman must keep his hands free for use and must face the ladder while climbing up or down a ladder. The ladders should not be painted as paint may conceal defects in the material used for the construction of a ladder. The machine must be shut down whenever a workman has to work from any type of ladder over a machine.

26. In fighting fires near exposed live parts employees should avoid using fire extinguishing liquids which are not insulating. If necessary to use them, all neighbouring equipment should be made dead.

27. Each person receiving an unwritten message concerning the handling of lines and equipment should repeat it back to the sender and secure his full name and acknowledgements. Each per-
son sending the unwritten message should require it to be repeated back to him by the receiver and secure the latter’s full name.

28. Workmen should avoid working on equipment or lines from any position by the reason of which a shock or slip will tend to bring the body towards exposed live parts. Work should therefore generally be done below rather than from above.

29. When working overhead, keep tools and materials not in use in proper receptacles. Tools or materials should not be thrown to or from the man on the pote but should be raised or lowered by means of a handline, using proper receptacles where practicable.

30. Pole holes and obstructions along public roads and other frequented places should be protected by watchmen or by suitable guards or danger signals so located as to be conspicuous to traffic.

31. When working overhead, or hoisting and lowering materials above places where frequent traffic occurs, a man should be stationed to warn the passers by.

32. Do not unnecessarily stand where you can be struck by materials dropped by men working overhead.

33. Never change the strains on a pole by adding or removing wires until assured that the pole will stand the altered strains.

34. Report promptly to your immediate superior any observed dangerous conditions, of your own or other utilities, arising from defective insulators, pins, crossarms and abnormally sagging wires etc.

35. ‘Never string wires near live circuits,'
CHAPTER 26
Oil Engines only—Punjab Public Works Department, Irrigation Branch.

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CHAPTER 26.

EVOLUTION OF OIL ENGINES

Before studying the working principles of an oil engine, it is essential to know something about its original and valuable developments made in its design now and then by various engineers and scientists. The biggest task before an engineer is to convert natural resources into mechanical energy for use in industry, in agriculture, in transport and in meeting the innumerable demands of modern civilization. Wind and water power satisfied man's simple requirements in the form of the passage of small ships and grinding corn for centuries and centuries. Then came the steam engine which revolutionized the industries and had no serious rival until the close of the 19th century. This rival was the I.C. Engine which required on separate furnace to convert water into steam but products of combustion were made to act directly on a piston within the piston cylinder.

In 1673, principle of burning fuel directly in cylinder engine was first applied by the Dutch Scientist Christian Huygens. In this experiment, he, by an explosion of gun powder was successful in throwing a piston upwards. When the resultant hot gases had cooled down atmospheric pressure pushed the piston down thus constituting the well known stroke (Working Stroke). From practical point of view this engine was a failure, it only served to show the principle of internal combustion. Atmospheric pressure was a limitation for efficient working of an engine.

In 1860, the well known French Engineer J. J. E. Lenoir patented the first successful I.C. Engine. In this the piston of the first half of its stroke drew in a mixture of gas and air which was burnt by an electric spark. After the hot gases had been expelled in the atmosphere the piston began its return journey helped by a flywheel. During the first half of the return stroke the cylinder was again charged at the opposite end and then again followed the explosion and working of the return stroke. This was a great achievement in the field of an I.C. Engine. Scientists and Engineers were working hard and many developments have since been made
in the mechanical details resulting in fuel economy. Dr. N. A. Otto in 1876 with his new I. C. Engine based on well known four stroke principle brought a complete change in the design of an I. C. Engine. This was extremely important development. This Otto cycle shall be dealt in details in the next chapter. In 1885, Francis Bunsen made the first successful oil engine. In this engine, the oil was sprayed under pressure together with a jet of air into a separate vaporizer heated by the exhaust gases. This vaporized oil mixed with air was then compressed in the cylinder in the same manner as that of the engine running on petrol or coal gas. This engine had its own limitations. High compression ratio could not be obtained. But in 1880 Mr. H. Arkroyd Sturat solved the problem, and this development in the oil engine field ranks high in importance. In his engine, only pure air was drawn in the cylinder on the suction stroke and thus there was no risk of pre-ignition as with a compressed explosive mixture. The compression stroke came with the help of the flywheel, at or near the end of this stroke fuel was sprayed by a pump in the bulb shaped extension at the end of the cylinder. This extension was only heated externally for starting purposes only. Mr. Sturat's use of mechanical pump to spray the oil into the combustion chamber was the biggest development and is known as Solid Injection fuel supply system which is practically in universal use today. Inspite of this splendid and revolutionary development of solid injection, the oil engine still could not be called a perfect compression ignition engine i. e. production of heat by compression only to ignite the sprayed fuel. After two years, i.e., in 1892, Mr. Rudolph Diesel a famous German Engineer made his first engine of compression ratio sufficiently high to cause combustion without the aid of external heat. In 1898 after performing numerous experiments, the diesel engine was evolved as a practical prime mover.

It is interesting to note that Mirreless Engine was developing 20 H.P. at 200 R. P. M. the first diesel engine to be manufactured in Great Britain in 1897. Now big industrial engines of capacity 3500 B. H. P. at the same speed i.e. 200 R. P. M. are being manufactured in Great Britain. What a contrast? Look at the various stages of development between 1873 and 1895 and up to this time. The modern oil engine is a thing of beauty and power, capable of producing mechanical energy above 35 to 40 % of the fuel burnt without recovery of the exhaust and cooling water heat. There is a tremendous amount of development on the
metallurgical side and many complicated and intricate problems in the form of finding alloys of various metals capable of standing intense heat and temperature and pressure, corrosion and wear and tear have successfully been solved. Heat treatment of various components in an oil engine such as cylinder liners, rings, crankshafts, gears, valves, components of fuel injection pumps etc. etc. is being done on scientific lines and with absolute control of temperature and time. All these things combined together have made the modern oil engine very popular and is generally found as prime mover of every equipment. Engineers and Scientists are struggling hard to make further improvements to increase its efficiency.

WORKING PRINCIPLES

26.2 As already described in the previous para, combustion of the fuel takes place in the cylinder, and this is the most important factor of an internal combustion engine which distinguishes from other heat engine.

DIESEL FOUR STROKE CYCLE

First Stroke. During this stroke inlet valve remains opened and piston moves down-wards and thus draws pure air through the air cleaner and through inlet valve opening into the cylinder. This stroke is known as ‘Suction Stroke’.

Second Stroke. During this stroke the air is compressed to a pressure of about 500 lbs. per square inch by the piston, the heat of compression raising air temperature to a point above the ignition temperature of the fuel. Just before piston reaches T.D.C. (Top Dead Centre) fuel is sprayed into the cylinder by a timed pump operated by the engine.

Third Stroke. The oil spray becomes mixed with the compressed air and almost immediately begins to burn because the temperature of the air in the cylinder is considerably higher than the spontaneous ignition temperature of the fuel oil. Pressure rises accordingly and the piston is forced out-ward on the power stroke.

Fourth Stroke. During this stroke the piston goes up and thus expels all the burnt gases through the opening of the exhaust valve and as the piston...
reaches T.D.C. exhaust valve closes, the inlet valve is opened and the cycle is repeated.

So in a four stroke cycle engine we see that in four strokes we get only one power or working stroke and these four strokes are completed in two revolution of the crankshaft. In other words there is one working stroke during two revolutions of the engine.

**TWO STROKE CYCLE ENGINE**

In this two stroke cycle, all the operations i.e. suction, compression, expansion and exhaust take place during one revolution of the engine. Hence in this type of cycle we get one working stroke for one revolution of the crankshaft.

The two stroke cycle engine needs a pump to force the charges of air into the cylinder. Generally two stroke cycle engines are valveless and all the operations are carried out by ports cut through the cylinder walls.

A series of ports cut into the circumference of the cylinder wall, above the piston, in its lowest position, admits the air from the blower into the cylinder as soon as the top face of the piston uncovers the ports, as shown in figure. The unidirectional flow of air towards the exhaust ports produces a scavenging effect, leaving the cylinders full of clean air when the piston again covers the inlet ports.

As the piston continues on the upward stroke, the exhaust ports close and the charge of fresh air is subjected to the final compression as shown in figure. In any internal combustion engine, the higher the compression ratio the greater the efficiency.

Shortly before the piston reaches its highest position, the required amount of fuel is sprayed into the combustion space by the unit fuel injector, as shown in figure. The intense heat generated during the high compression of the air ignites the fine oil spray immediately, and the combustion continues as long as the fuel spray lasts. The resulting pressure forces the piston downward until the exhaust ports are again opened. As shown in figure, the burnt gases escape into the exhaust manifold as the downward moving piston is about to uncover the inlet ports. When these ports are uncovered, the cylinder volume is again swept with clean scavenging air, as shown in figure.
This entire combustion cycle is completed in each cylinder for each revolution of the crankshaft, or, in other words, two strokes, hence, the 'TWO-STROKE CYCLE'.

FOUR STROKE VERSUS TWO STROKE CYCLE ENGINE

26.3 This is a question of big controversy and the views expressed by experienced engineers and engine builders are conflicting.

Take the case of a single acting single cylinder two stroke cycle engine. It has twice as many working strokes as the four stroke cycle engine for the same speed of the crankshaft and has therefore got much more uniform turning efforts on the crankshaft. A light flywheel therefore will be used on a two stroke engine. Power of two stroke cycle engine of the same size is double that of four stroke cycle.

Four stroke cycle engine is more economical in fuel consumption. But with latest developments and improvements, fuel economy of two stroke cycle engine is approaching quite close to the four stroke cycle engine.

There is greater wear and tear of moving parts in the two stroke cycle engine. In large engines, absence of exhaust valves is of great advantage. For stationery engines of small and medium power four stroke engine on account of its simplicity and improved economy is generally used. In marine engines on account of reduction of weight and less space two stroke engine is used.

COOLING SYSTEM

In a closed cooling system, water is circulated by a Centrifugal Type Water Pump driven by the engine, either through belts or gears. The water circulates around water jackets in the cylinder block, through the cylinder heads. The engine cooling solution is cooled by a radiator through the fan driven by the engine.

To have efficient cooling system, it is most essential to have soft and clean water free from impurities and under no circumstances muddy and dirty water be used which would result into overheating of the engine. A considerable amount of trouble in connection with cracked cylinder heads, warped valve stems, and stuck piston rings in both Diesel and Gas Engines has been traced out to improper functioning of the
cooling system. The continued use of hard water in the cooling system causes deposits of lime and magnesium salt to accumulate in the water jackets.

CLEANING THE COOLING SYSTEM

The following recipe is suggested in cases where radiators and water jackets are in bad condition due to deposits of lime and magnesium salt:

- 5 Parts of muriatic Acid
- 1 Part of Formaldehyde
- 48 Parts of soft water
- 54 Total

(This mixture is equivalent to 5 pints muriatic acid, a pint formaldehyde, and 6 gallons of water).

The mixture should be made by stirring the formaldehyde into the water and then stirring in the muriatic acid, using a container such as a wash-tub. Caution should be exercised to prevent formaldehyde and acid from coming in contact with clothing or person.

1. Operate tractor three hours under load
2. Open drain plug and drain off solution rapidly and thoroughly.
3. Add solution of handful washing soda and soft water.
4. Drain and refill with soft water.

Be careful about adding cold water too quickly.

LUBRICATION

264. Correct lubrication may be defined as the use of the right oil applied in such carefully regulated quantities as will result in maximum economy in oil consumption consistent with efficient operation. Advantages of correct lubrication are:

1. Continuous and reliable operation so that involuntary stoppages are avoided.
2. Avoiding the sticking of piston rings in I. C. Engine.
3. Extending period between overhauls.
5. Low cost of repairs and renewals.
6. Extend life of machine due to the absence of premature wear and tear therefore less depreciation losses.
7. Lowest ultimate lubrication costs.

A full pressure lubricating system is provided to meet a wide variety of working conditions and this system should be inspected occasionally to see that it is functioning properly. A diagram showing the lubricating system generally used on oil engines is attached.

Oil flow through filters: To have proper lubrication, it is very essential to filter the lubrication oil before it goes to main gallery for the lubrication of bearings and liners and pistons and for this purpose various type of filters have been designed by engine builders. The sketch attached shows a type of filter used on Caterpillar Engines.

Bearing lubrication: Bearing lubrication presents no special difficulties in itself as long as an adequate supply of oil reaches the bearings, this is because the rotation of the journal tends mechanically to build up and maintain an oil film between the bearing and journal surfaces. Bearing failures are due generally either to restriction in the supply of oil as the result of mechanical faults or blocked oil-ways, or to break-up of the bearing metal under the repeated pounding to which it is subjected by the power strokes. This latter effect is most likely to occur if there is an abnormally high rate of pressure rise caused by faulty ignition, the use of low grade fuel, incorrect timing, etc.

Circulating system in internal combustion engines are necessarily enclosed and the oil is exposed to air at moderately high temperatures in the crankcase. Heated air has a very definite oxidising effect on all oils, an effect which is most pronounced when the oil is in a fine state of dispersion, as it is in the crankcase of an engine during operation. It is therefore desirable that the oil should have high resistance to oxidation, otherwise rapid deterioration of the oil may take
place with consequent thickening, sludging and production of acids. With the development of certain alloy bearing metals which are more susceptible to corrosion than white metal, the need for oils having high oxidation stability has increased especially in the case of engines running under heavy duty conditions.

The more common trouble in the bearing lubrication system of I. C. Engines are that the oil thickens up, turns out, solidifies, or throws down black deposits. These last, by lodging in oil ways and filters, may interfere with the circulation of the oil and, in extreme cases, cause bearing failure. Troubles of this nature can occur irrespective of the quality of oil used through contamination of various kinds. Thus, thinning of the oil is caused by unburnt fuel reaching the relatively cool cylinder walls and hence finding its way into the crankcase. Partially burned fuel and carbon, which are the results of imperfect combustion, increase the viscosity of the oil and in time are deposited as sludge. Water may be present as the result of a leak in a gasket or condensation of combustion products due to low operating temperatures, this may lead to sludging through formation of oil-and-water emulsions, particularly if dust or other solid foreign matter is present, even in minute quantities.

It will be seen from these considerations, that to get the maximum life out of a good lubricating oil, it is necessary to pay great attention to conditions of combustion and to prevent the entry of impurities.

Cylinders Lubrication. High temperature and pressure conditions in the combustion chamber, provide circumstances particularly unfavorable to the maintenance of a continuous oil film between the piston rings and the walls of the cylinder. Cylinder lubrication is therefore a far more difficult problem than that of lubricating the bearings.

For cylinder lubrication the oil must be fluid enough to reach the cylinder walls without delay on starting up from cold, and to spread over the surface rapidly. Thick oils may fail in this respect, moreover they have a greater tendency to form carbon. The oil must be chemically stable to avoid the formation of gummy deposits, and should burn away without producing carbonaceous deposits once it has reached the combustion chamber.
Many of the operating troubles with the cylinders of internal combustion engines are, however, connected now with the lubrication oil itself, but with the combustion of the fuel. Thus, in gasoline, kerosene and gasoline/kerosene engines, the formation of carbon and other deposits may often be traced to faults such as incorrect carburettor adjustment, low vaporising plate temperature and faulty ignition timing.

Oil engines are inherently sensitive to cylinder operating troubles because the mixing of fuel and air is achieved after the introduction of the fuel into the combustion chamber. Troubles may arise from any of the following causes:

- Incorrect metering of the fuel or incorrect timing of the fuel injection or of valves.
- Dripping or leaky fuel nozzles.
- Insufficient injection pressure.
- Incorrect orientation of the injection nozzle (Direct injection only).
- Incomplete scavenging (In two-stroke engines).
- Low operating temperatures.
- Excessive light load periods.
- Overloading.

Efficient running of the engine is dependent on effective sealing of the combustion chamber. This in turn depends on the lubricating oil film and the proper functioning of the rings. Deposits of soot and gummy substances interfere with free action of the rings and cause blow by. This will reduce compression, cause incomplete combustion over-heating, and permit hot gases, partially burnt fuel and impurities to reach the rings, and grooves more easily. These conditions tend to cause stuck rings, increased wear and poor engine performance.

Keeping the pistons, rings and ring grooves substantially free from lacquer and deposits is an important function of the lubricating oil. To do this properly an oil must be able to keep lacquer-forming materials in solution and to prevent agglomeration and deposition of insoluble impurities—such as particles of soot and carbonaceous material—by holding them in suspension in a finely divided state in which they can do no harm. Oils with good properties in this respect can be produced by careful selection of the base stock and use of special...
refining processes. Additive type oils specially formulated to give unusually strong properties in this direction are generally recommended where conditions conducive to ring sticking are particularly severe, for example in many modern high speed oil engines having high piston and crankcase temperatures. Successful operation of certain high rated engines has, in fact, been made possible only by the use of these so-called ‘Heavy Duty’ oils.

Piston Cooling. Owing to the combination of thermal and mechanical stresses in pistons of large oil engines a system of piston cooling is often employed. The aim is to maintain the pistons at substantially uniform temper tures and to achieve this, given good mechanical design, the cooling medium should circulate freely. The present general tendency is to employ oil as the medium for cooling.

It would be preferable to have separate systems for crankcase lubrication and piston cooling but, in general, the arrangement is one in which the crankcase oil is fed to the pistons. High temperatures in the piston promote oil deterioration and deposit formation, and this is a further reason for using an oil of high stability.

To have efficient and free trouble operation of a Diesel Engine, use of good grade of oil is always recommended. In high speed engines, heavy duty grade oil containing additives that impart detergent, anti-oxidant, anti-wear and protective properties of a high order should be used. Maximum benefit from these additives has been obtained by applying them with the mineral base oil that showed best response in actual engine performance tests.

Bearing Metals:—For least wear the bearing material should be soft so that any abrasive particles reaching the bearing will become completely embedded and not project out and wear the shafts. Also the softer metals better conform to any shaft misalignment or machining irregularity. Tin, by itself, is too soft but when hardened by the addition of antimony and copper (babbit) it meets these requirements. Tin has a fairly low melting point so that, when Localized overheating occurs, the tin melts relieving the high spot before the oil film is burst off. Tin babbit is non corrosive and has ideal anti-friction qualities but, as engine speeds and pressures increased, the babbitt in some installations quickly

(10)
cracked due to fatigue resulting from the more frequent applications of higher peak loads. It was found that adding a small amount of lead or bismuth lowered the bearing strength, while adding more copper or antimony embrittled the bearing, lowering its resistance to shock. It was necessary, therefore, to investigate base metals other than tin.

Lead, always more plentiful than tin, has been subjected to intensive study by bearing manufacturers. In the pure state, it is too soft and is subject to corrosion by some of the acids formed by the lubricating oil in service. Lead-base babbitt is made by adding antimony and tin to increase hardness and corrosion resistance. Arsenic and copper are also used as hardening agents. Silver may also be added to increase the fatigue resistance. The lead base metals have nearly the same hardness and load carrying ability as the tin base babbitts, ordinarily difficulty due to corrosion is encountered.

Lead, hardened by the addition of a small amount of calcium, is as hard as tin-base babbitt and more resistant to fatigue especially at higher temperatures. It is more susceptible to corrosion but this is partially overcome by the addition of a small amount of tin. Too much tin in this case, however, seems to weaken the structure. As the thermal conductivity of lead is rather low lead bearings are often furnished with bronze backs. By reducing the thickness of the soft metal, there is less deflection under load and the fatigue resistance is increased so that lead and tin-base bearings can be used in engines when loads and speeds are not too high. When the tilt bearings are used, overloading and over-speeding cannot be tolerated and firing pressures should be kept down by properly adjusting injection timing and using high cetane fuel.

Since the maximum allowable bearing pressures for tin and lead base bearings are around 2000 lbs. sq. in. for 4 cycle engines, it is obvious that a different type of bearing had to be found for the high speed engine. The most promising materials having higher load-carrying ability are silver, copper, aluminum and cadmium when suitably alloyed.

Cadmium plus a little silver or nickel produces a bearing which is a good compromise between the high fatigue resistance of copper and silver and the good anti-friction properties of tin.
and lead. Comparative tensile strengths at various temperatures in lb. /sq. in. are:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Tin base babbitt</th>
<th>Cadmium Silver</th>
</tr>
</thead>
<tbody>
<tr>
<td>100°F. (38°C)</td>
<td>9,700</td>
<td>16,700</td>
</tr>
<tr>
<td>200°F. (93°C)</td>
<td>7,000</td>
<td>12,500</td>
</tr>
<tr>
<td>300°F. (149°C)</td>
<td>4,900</td>
<td>8,200</td>
</tr>
</tbody>
</table>

Cadmium, however, is subject to oil corrosion. By keeping oil and bearing temperatures low, the possibility of corrosion is reduced and the bearing strength and life increased.

Aluminum, alloyed with tin, is harder and somewhat stronger than babbitt but does not have the fatigue resistance of either silver or copper. That it has good bearing properties for certain applications is evidenced by the fact that aluminum pistons are not fitted with wrist-pin bushings. The anti-friction qualities of aluminum are not well established, but freedom from corrosion, good heat transfer and light weight encourage its use.

Silver has the best fatigue resistance and heat transfer of any of the metals considered. It is much softer than copper but harder than babbitt. Its tendency to score under certain conditions and the high cost, however, have limited its use.

Bronze bearings of copper alloyed with tin and lead have been used where temperatures are high and shock loads severe, as in wrist-pin bushings in cast iron pistons. Rather poor conformability, embeddability and anti-friction qualities have discouraged its use in connecting rod or main bearings.

To take advantage of the high load-carrying ability of copper and the good anti-friction characteristics of lead, the copper-lead bearing was developed. The lead, of course is subject to corrosion and only corrosion-resisting oils should be used. This bearing, while proving very satisfactory in many high speed engines, still does not possess the conformability and embeddability of babbitt; therefore, shafts must be hardened, larger bearing clearance employed, oil carefully filtered and care exercised when fitting bearings.
Tri-metal bearings are also being used to obtain the desired qualities of both the hard and soft metals. A lining of metal having high resistance to fatigue and fair friction qualities, such as silver copper-lead or bronze is first bonded to the bearing backing. Over this basic lining a thin coating of soft metal, having good anti-friction characteristics, is applied. These surface coatings may consist of lead or tin-base babbitt, hardened lead or even very soft lead with a little tin added to inhibit corrosion.

**FUEL INJECTION EQUIPMENT**

26-5 The function of the fuel injection pump is to measure and deliver the fuel into the engine cylinder in quantity proportional to the most minute degree to the load at a predetermined moment [Approximately 8° to 15° before T. D. C. at high speed and at a pressure of 1800 to 4500 lbs. per sq. inch as may be required. Accuracy is essential because the power output and speed of the Diesel Engine are controlled by varying only the amount of fuel supplied. It is most desirable that every cylinder of a multi-cylinder engine should contribute the same proportion of the total power.

The fuel injection pump, in a modern engine, has to work under high speed and deliver fuel with exact accuracy both as regards quantity and time. Let us take an example of a four stroke diesel engine developing 60 B. H. P. from four cylinder running at 3000 R. P. M. with a fuel consumption of 45 lbs. per B. H. P. per hour.

Fuel consumption per hour : 45 x 50 = 2250 lbs.
Fuel consumption per second : 2250/60 x 60 = 0.00625 lbs.
Fuel used in each cylinder per second : 0.00625/4 = 0.001563 lbs.
Revolution of the crankshaft 3000/60 = 50
in one second : 25 cycles second.
Fuel consumption per cycle per second : 0.001563/25 = 0.000062 lbs.

The pumps has to deliver this amount of fuel during exceptionally short period.
The most widely used method of effecting the injection of fuel mechanically is that by employing the timed pump. This method is often called the fuel pump system and comprises a high pressure variable delivery pump. Many firms have specialized in this line of manufacture. Generally this equipment is manufactured by the engine builder to his own design. But fundamental principles remain unchanged. A few examples of famous fuel injection pumps are given below:

C. A. V. Fuel Injector Pump

This pump is of the constant stroke type employing one pumping unit for each engine cylinder. It is available for multi-cylinder engines. The following important components make each pumping unit:

1. Pump element (Plunger and Barrel)
2. Delivery valve and seating

Plunger and Barrel, valve and seating are of hardened and ground alloy steel, being finished to the finest limits and with the highest degree of precision to permit of accurate operations at high speeds and pressure. It is not desirable to interchange the pairs of plungers and barrels. Each pair, therefore, may be regarded as inseparable.

Fuel may be supplied from a tank preferably placed higher than the pump or by means of a fuel transfer pump, the latter being the most usual arrangement. The plunger moves vertically in the barrel with a constant stroke. To enable the pumps to vary the quantity of fuel delivered per stroke, the plunger is provided with a vertical channel extending from its top edge to an angular groove. The upper edge of which is cut to the form of a helix.

Each pump measures the amount of fuel to be injected into its particular cylinder and produces the pressure for injection. The injection pump plunger is lifted by a cam and always makes a full stroke. The amount of fuel pumped during any one stroke is varied by turning the plunger in the barrel. The plunger is turned by the governor action through a rack which meshes with a gear segment on the bottom of the pump plunger.

Figures A, B, and C illustrate the functioning of an injection pump as the plunger makes a stroke.
In figure A the plunger is down and the inlet port is uncovered. Fuel flows into the space above the plunger through the slot and into the recess around the plunger.

In figure B the plunger has started up and the port is covered. The fuel is trapped and will be forced through the check valve, fuel line and injection valve as the plunger moves upward.

In figure C the plunger has risen until the port is uncovered by the recess in the plunger. The fuel can now escape back through the port into the fuel manifold and injection will cease.

It will be noted that the recess in the pump plunger forms a helix around the upper end of the plunger. Figure D, E and F illustrate how rotating the pump plunger affects the quantity of fuel injected.

In figure E the plunger has been rotated into the idling position. The narrow part of the plunger formed by the helix will cover the port for only a short part of the stroke. This permits only a small amount of fuel to be injected per stroke.

In figure F the plunger has rotated into the full load speed position. The wide part of the plunger formed by the helix covers the port for a longer part of the stroke. This permits a larger amount of fuel to be injected per stroke.

Worn fuel injection pumps will result in loss of power and hard starting. These same conditions may be present if the piston rings and cylinder liners are badly worn. However, in the case of worn piston rings and liners, the hard starting and loss of power will be accompanied by poor compression, a smoky exhaust and excessive blow by gases from the crankcase breather.

Ordinarily if one fuel injection pump on an engine is not supplying sufficient fuel it will be found that all of the injection pumps are worn and need replacing.

It is interesting to note that while plunger stroke remaining constant the part of the pump which is actually pumping is variable. The helical edge which runs around the plunger and which can be rotated in the barrel is capable of cutting off the fuel depending upon the load conditions. Position C, D and F show full load, half load and idling respectively.
The engine is stopped by turning the plunger so that its vertical slot coincides with the barrel port (F).

Control of fuel supply is controlled by the pump control rod having the word 'Stop' and an arrow engraved on it indicating the direction it must be moved to stop pumping and to stop the engine. A pump element at position 'Stop' will not deliver fuel to the injector. The vertical channel of the plunger will cover the barrel ports and no fuel would be delivered.

The control rod should be brought to the 'Starting' position so that the plunger will be in the starting position. During this position of the plungers, excess fuel will be going and it is necessary for starting purposes. When the engine starts the control rod should be released to the position giving the desired engine speed.

**Autodrilble Device** — We have seen that the pressure of the fuel drops when the helical edge of the pump plunger uncover the barrel part near the end of the delivery stroke. Delivery valve is at once closed and cuts a communication between the pump and nozzle until the next delivery stroke takes place. In coming to its seat to act as a non-return valve the delivery valve is made to perform the other highly important function of pressure pipe release. This double function is achieved by means of a novel, but entirely simple construction of the delivery valve unit. This is an ordinary valve with a guide which have circular groove cut in it, dividing the guide into parts. The lower part has four longitudinal grooves communicating with the circular groove.

The upper part of the guide forms a small piston which is a highly ground plunger fit for the valve seating. When the pump is on its delivery stroke, as the pressure of the fuel reaches the delivery valve, it is pushed up until the pressure fuel can escape through the longitudinal grooves over the valve face to the nozzle. Immediately the pump plunger releases the pressure in its barrel, the delivery valve under the action of its spring and the difference in pressure between the pump barrel and the delivery pipe resumes its seat, causing the small piston parts to the guide to sweep down the valve seating with a plunger action, thus increasing the space in the delivery pipe, before the valve actually seats itself. The effect of this increase of volume in the delivery pipe is to
reduce the pressure of the fuel suddenly so that nozzle valve in the nozzle can ‘Snap’ to its seat, thus instantaneously terminating the spray of fuel in the cylinder entirely without ‘Dribble’.

266. Fuel Injection Nozzles:—The fuel needs to be converted with a condition suitable for consumption in the combustion chamber to get perfect performance of all internal combustion engine. For maximum efficiency of an engine, it is essential that the engine be not only provided with a fuel injection pump, i.e., the fuel in quantities, exactly timed, and proportioned to the amount of work it is required to do, but also that it should receive each charge of fuel in a condition, such that it can be completely consumed, without smoke in the exhaust. Therefore the function of the spraying nozzle is to direct the metered quantity of fuel delivered from the injection pump into the engine combustion chamber in a definite spray pattern and in such a manner as to produce the most efficient engine performance. As the nozzle has to deal with many hundreds of charges per minute and to operate over long periods of time with maximum efficiency and with widely varying conditions of pressure and temperature the unerring precision necessary in production of these parts is very essential.

Spray nozzles consists of two parts:

1. Nozzle body.
2. Nozzle valve.

These parts are made of special steel alloy, heat treated by special methods to minimize wear and tear and promote durability. The body and valve are lapped to closest possible fit within which it will work perfectly. It is, therefore, advisable that body and valve are inseparable and must be kept together at all times.

Fuel is fed to the mouth of the nozzle through small tunnels bored vertically in the nozzle body which terminate in an annular reservoir or ‘Gully’ just above the valve seat. The nozzle valve is raised from its seat in the nozzle body by the pressure of fuel being fed from the injection pump and the accumulated fuel in the gallery is forced by the upwards movement of the plunger in the pump, through the hole or holes in the nozzle thus forming a spray in the engine combustion chamber.
Nozzle Holders:—Its function is to hold the nozzle in its correct position in the engine cylinder and to promote a means of conducting fuel oil to the nozzle. The holder also contains the necessary spring and means of pressure adjustment to provide proper action of the nozzle valve.

It consists of a steel forged holder body with drilled passages for conducting the fuel from the inlet connection to the nozzle. The lower end of the body is provided with a ground and lapped surface which makes a leak proof and pressure tight seal with the corresponding lapped surface at the upper end of the nozzle. The nozzle is secured in its position by means of a cap nut. Adjustment of nozzle valve pending pressure is done by means of the spring pressure adjusting screw.

FUEL INJECTION MAINTENANCE

Dirty fuel oil containing impurities and dirt particles is the biggest enemy of the piece of equipment and all possible efforts should be made to have fuel free from suspended matters and other foreign particles. For this purpose fuel oil filters are provided and filtered fuel goes to the fuel injection pump and injectors. A diagram showing a general fuel oil pumping lay out is attached.

The fuel injection system is the most important part of the diesel engine for upon it depends how well the fuel is burned. If the fuel is injected at the proper time and with the right spray characteristics a clean, smooth-running engine will usually result. If the fuel is not injected properly the engine will be rough, noisy and dirty. An engine with a good injection system is not difficult to lubricate. Poor injection can cause any number of lubrication difficulties.

Improper timing of the injectors can cause lubrication trouble. If the fuel is injected too early, before the air in the cylinder has been compressed sufficiently to ignite the fuel, a large quantity of fuel will be injected before ignition occurs. Then, when the charge finally does ignite, a heavy explosion high occurs within the cylinder producing excessively high pressures which can cause ring sticking and bearing failures due to fatigue. If the fuel is injected too late, sufficient time may not be available to burn all the fuel, and excessive soot deposits form in the engine. Early injection
will be evidenced by a noisy, rough-running engine, while late firing can be detected by a smoky exhaust.

The injectors must be properly equalized so that each delivers the same amount of fuel. If some cylinders get more fuel than others, they will carry more than their share of the load and may develop ring troubles. These cylinders that get the least amount of fuel will be apt to miss when the engine is idling, causing fuel varnish formation on the piston and dilution of the crankcase oil.

It is desirable, of course, to test all injectors periodically carefully following the engine manufacturer's instructions.

Operating pressure, spary pattern and dribbling tendency should be checked when testing the injectors. Improper injection can cause washing away of the lubricant resulting in ring or cylinder wear. Poor atomisation can cause ring sticking and carbon contamination of the lubricating oil.

Engine manufacturers use different methods of inquiring against too much fuel being injected. These mechanisms should not be tampered with, allowing more fuel to be injected will produce more power but at the expense of ring and bearing difficulties and usually cause an objectionable exhaust condition.

**CUMMINS PT SYSTEM**

26.7 To cut down maintenance costs on the fuel injection system and to simplify the construction of equipment, eliminating the need for a Diesel Fuel Specialist, Cummins Engine Company in the United States have come out with a much simplified fuel system known as 'Cummins PT System'. The identifying letters 'PT' are abbreviations for 'Pressure-Time'.

The principle of the PT Fuel System is based on the fact that by changing the pressure of a liquid flowing through a pipe you change the amount of liquid coming out of the open end. Increasing the pressure increases the law or the amount of liquid delivered, and vice versa. In applying this simple principle to the diesel fuel system it was necessary to provide:

1. A fuel pump to draw fuel from the fuel tank and
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deliver it to individual injectors for each cylinder.

2. A means of controlling the pressure of the fuel being delivered by the fuel pump to the injectors so the individual cylinder would receive the right amount of fuel for the power required of the engine.

3. Fuel passages of the proper size and type so that the fuel will be distributed to all injectors and cylinders with equal pressure under all speed and load conditions.

4. Injectors to receive low-pressure fuel from the fuel pump and deliver it into the individual combustion chambers at the right time, in equal quantity and proper condition to burn.

The PT Fuel System consists of the fuel pump (with governor), the supply and drain lines, and the injectors.

268 The PT Fuel Pump: The PT fuel pump is made up of only five functional parts and assemblies. These are:

1. A gear pump
2. A pressure regulator
3. A throttle control shaft
4. A governor which controls both idling and maximum speed
5. A shut-down valve.

A schematic diagram illustrating the functioning of the fuel pump and its components is shown in figure—. The gear pump picks up the fuel directly from the tank and moves it through a strainer, pressure regulator, throttle valve, governor control valve, shut-down valve, and on to the injector. The fuel oil provides all the lubrication necessary for the fuel pump.

Gear Pump: The gear pump picks up the fuel from the tank and builds up the pressure and flow for the entire fuel
system. Surplus fuel is by-passed by the pressure regulator and returned to the suction side of the pump.

**Pressure Regulator**: The pressure regulator is a by-pass valve to regulate the fuel, under pressure, supplied to the injectors. By-passed fuel flows back to the suction side of the gear pump.

**Governor**: Mechanical governor action is provided by a system of springs and weights, and it has two functions. First, the governor maintains sufficient fuel for idling with the throttle control in idle position and second, it cuts off fuel above maximum rated E. P. M.

During operation between idle and maximum speeds, fuel flows through the governor to the injectors in accord with the engine requirements as controlled by the throttle and limited by the pressure regulator. When the engine reaches governed speed, the governor weights move the governor plunger and fuel passages to the fuel supply manifold are shut off. At the same time another passage opens and dumps the fuel in the supply manifold back into the main pump body. In this manner engine speed is controlled and limited by the governor regardless of throttle position. Fuel leaving the governor travels through the shut-down valve, inlet supply lines and on into the injectors.

**Injectors**: In this system the injector is made to perform the metering as well as injection function without adding any complications to the injector itself. The check valves in the inlet line and in the injector are eliminated completely.

Fuel under continuous pressure from the pump enters the passage at the right. During the power, exhaust and a portion of the intake strokes, the plunger remains seated, cutting off the flow of fuel at point A.

On the intake stroke of the engine piston, the plunger begins to retract uncovering point A and allowing the fuel to circulate around the injector and up the drain passage at the left. A metering orifice, B, which is of different size for various models leads from the fuel passage to the injector cup. These holes are broached to a plus and minus tolerance of 0.0005 inches as a single piece. At the plunger continues to rise, this
small orifice leading into the cup is uncovered and fuel flows into the cup for as long as the opening remains uncovered.

When hole A is open, but the metering orifice, whole E, is closed, fuel circulates around the injector and returns to the tank. Normally 4/5 of the fuel delivered to the injector is returned to the tank. This gives the operator one important advantage. The fuel absorbs enough heat in passing through the injector that during cold weather operation the problems of fuel freezing or coagulating in the fuel tank, lines or filter are minimized. This flow also makes the system self-purging of air and no priming is necessary even when replacement injectors or a pump have been installed.

It is obvious, that with a given time interval, the amount of fuel delivered through metering orifice B to the cup will be increased when pressure is increased and decreased when the pressure is decreased. However, since the time interval available varies inversely with the R. P. M. of the engine, a pump was necessary that would recognize this fact and produce the proper ratio of pressure at full throttle and all engine speeds, thereby producing the desired torque-ve. Also the pump must change the pressure and consequently the fuel charge-in response to the throttle and governor. The PT fuel pump is designed to provide these functions.

Since the primary metering function has now been transferred to the injectors, the function of the fuel pump is simply one of controlling pressure and delivering adequate quantities of fuel. Consequently, the pump is greatly simplified in design.

The new 'Cummins PT Fuel System' can be considered as a big revolution in the fuel injection technique and has considerably reduced the operation and maintenance cost due to its simple construction and less moving parts involved in its operation. The following figures would show the difference in weight and No. of parts in the three types of pumps:

<table>
<thead>
<tr>
<th>Type of Pump</th>
<th>Single Disc Pump</th>
<th>Double Disc Pump</th>
<th>PT Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>104 pounds</td>
<td>33 pounds</td>
<td>13 pounds</td>
</tr>
<tr>
<td>Total No. of different parts</td>
<td>216</td>
<td>246</td>
<td>122</td>
</tr>
</tbody>
</table>
The entire fuel system, including the governor, has considerably fewer parts than the gasoline engine carburetor and ignition system or other diesel fuel systems.

In as much as the injection timing is obtained from a normal push tube and rocker arrangement operated by the engine camshaft working the injector plunger, the fuel pump of the PT system serves only as a source of fuel and pressure. Hence it need not be timed to the engine.

This simple system, to a great extent has eliminated the need of diesel fuel specialists as its mechanism is very simple as compared to other type of fuel systems. Also ordinary tools are needed to work on this system and its simplicity inspires confidence in drivers and operators as well as mechanics. Adjustments to the system are very simple, and since there are no timing, fuel rack or injector adjustments necessary other than a regular setting of the injector tagsets. Since there are no check valves or float chambers, these sources of trouble are eliminated.

26-9. COMMON FUEL INJECTION PUMP TROUBLES AND THEIR REMEDIES.

Possible cause, Location, Condition or suggested remedy.

1. Engine will not start.
   1. Pump does not deliver fuel.  
      (a) Fuel cock Must be open.
      (b) Fuel tank Must contain an adequate supply.
      (c) Filter Clean—examine and if choked replace cloth or clean felt pads.
      (d) Air in pump Air should be expelled by bleeding the fuel system.
      (e) Feed pump See that it is delivering fuel.
      (f) Pump plunger If worn, have elements changed.
      (g) Accelerator pedal Inspect for breakage or looseness.
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Possible cause.  Location.  Condition or suggested remedy.

1. Engine will not start—concl.
   (a) Driving shaft to pump  Inspect for breakage or sheared key, Clean.
   (b) Delivery valve spring.  Replace if broken.

2. Pump injects too late or too early.
   (a) Plunger guide and roller.  Check timing.
      If worn, due to lack of lubrication obtain replacement.
   (b) Camshaft  If cams badly worn out, replace it.

2. Engine starts, but stops after short time.

1. Fuel feed intermittent.
   Fuel pipe to pump  Open cock or clean pipe and check for its leaks.

2. Filter choked
   Filter  Clean.

3. Air to pump
   Suction pipe  Must be intact. Check all joints. If defective and fuel column broken repair air vent pump.

4. Feed pump does not feed fuel.
   (a) Filter in front of feed pump.  Clean.
   (b) Feed pump valves.  Clean.
   (c) Feed pump plunger.  Clean.

5. Vent of main tank choked.
   Main tank vent.  Clean.

3. Engine 'knocks' regularly.

1. Opening pressure of nozzles too high.
   Nozzles  Test nozzles and adjust pressure with nozzle setting outfit.

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OIL ENGINES

Possible cause. Location. Condition or suggested remedy.

3. Engine 'knocks' regularly—could.

3. In the case of multihole nozzles some holes are stopped up.
   4. Engine smokes and knocks in retard condition.


4. One or more holes in multihole nozzle choked up. Nozzle body Clean.

5. Compression spring in nozzle holder broken. Nozzle holder compression spring Fit new spring.

6. Nozzle valve sticks in guide so that fuel is injected without being sprayed. Nozzle valve Test to see whether badly clamped when fitted in the engine or packing joint compressed so much that it experts pressure on nozzle body. Remove nozzles, clean nozzles and re-fit.

(25)
Possible causes. | Location. | Condition or suggested remedy.
--- | --- | ---
4. Engine smokes and knocks in retard condition—concluded.
7. Nozzles leaky through overheating or being badly carbonised. | | Remove carbon from nozzle and clean. If no response to cleaning by recommended methods change nozzle and renew seating washer.

5. Engine operates irregularly.
2. Feed pump does not work properly. | Feed pump | Clean.
4. Air in pump | Pump | Air vent.
5. Plunger spring broken. | Pump plunger spring | Replace if broken.
6. Delivery valve spring broken. | Delivery valve spring | Replace.
7. Delivery valve does not function. | Delivery valve and seating | Clean or replace both valve and seating.
8. Nozzle leaking | Nozzles | Clean in oil or replace.
### Checking Mechanical Problems

<table>
<thead>
<tr>
<th>Problem</th>
<th>Probable Cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Engine fails to turn.</td>
<td>1. Starting switch inoperative (when used on machine). 2. Battery charge too low to turn engine fast enough. 3. Engine oil too heavy. 4. Internal seizure. 5. Cranking motor inoperative.</td>
<td>1. Inspect for faulty cables and terminals. 2. Charge battery or install new one. 3. Use correct grade lubricating oil. 4. Hand-crank engine with spark plugs removed, engine clutch disengaged, and compression release lever in starting position. If engine does not turn easily, seizure due to internal damage is indicated. 5. Inspect cables and terminals. Check for tightness of mounting screws. Inspect commutator for damage.</td>
</tr>
<tr>
<td>B. Engine will not operate as a diesel engine.</td>
<td>1. Injection pump does not deliver fuel. 2. Compression release faulty (Starting control).</td>
<td>1. Fuel system be checked. 2. Adjust linkage.</td>
</tr>
</tbody>
</table>
C. Engine does not develop full power.

1. Moisture in fuel tank.
2. Fuel filter and strainer clogged.
3. Air cleaner clogged.
4. Pre-cleaner clogged (when used).
5. Insufficient fuel.
6. Poor fuel.
7. Injection pump not properly timed to engine.
8. Injection pump not operating properly.
9. One or more cylinders misfiring.

D. Engine turns but will not start.

1. Fuel system inoperative

Probable cause.

1. Drain entire system including water trap and filter. Refill with fuel, and vent air from system.
2. Disassemble and clean each unit.
3. Remove and clean oil cup.
4. Clean the pre-cleaner.
5. Check fuel tank.
6. Use good grade diesel fuel.
7. Remove pump gear cover and make proper timing adjustments.
8. Remove injection pump and test it.
9. Locate and correct cause.

Remedy.
2. Ignition system inoperative
3. Intake or exhaust system clogged.

E. Poor compression.
1. Piston rings worn, broken or cracked.
2. Cylinder sleeve worn.
3. Valves damaged.
4. Broken valve spring.
5. Worn cylinder head gasket.
6. Valve seats worn or cracked.
7. Worn pistons.
8. Excessive valve guide wear.
10. Faulty valve action.

2. Test ignition system and make necessary repair.
3. Remove air flow restriction and clean exhaust system.
1. Install new rings.
2. Install new sleeves.
3. Install new valves.
4. Install new springs.
5. Install new gasket.
7. Install new pistons.
8. Install new valve guides.
10. Adjust valve clearance.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Probable cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>F. Engine overheats</td>
<td>1. Insufficient water in cooling system</td>
<td>1. Check water level in radiator and add water if necessary.</td>
</tr>
<tr>
<td></td>
<td>2. Cooling system clogged</td>
<td>2. Clean out radiator and engine.</td>
</tr>
<tr>
<td></td>
<td>3. Fan and water pump bolt slipping</td>
<td>3. Check tension and make proper adjustments.</td>
</tr>
</tbody>
</table>
|                         | 5. Engine oil diluted with fuel          | 5. Change oil and inspect fuel connec-
|                         |                                          | tions on injection nozzles.          |
|                         | 6. Defective thermostat                 | 6. Remove and test thermostat. Re-
|                         |                                          | place if necessary.                  |
| G. Engine misses on one or more cylinder | 1. Insufficient air to engine           | 1. Remove and clean air cleaner and air cleaner pipe. |
|                         | 2. Injection nozzle valve dirty or stick-
|                         |                                          | 2. Remove and clean nozzle valve. If defective, replace with serviceable unit. |
3. Air lock in fuel pump.
4. Poor fuel.
5. Air leaks around manifold.

**H. Excessive oil consumption.**
1. Piston ring worn or broken.
2. Oil level in crankcase too high.
3. Crankcase gasket leaking.
5. Cylinder sleeves worn.
6. Front and rear crankshaft oil seal leaking.
7. Piston rings not seating.
8. Clogged oil ring.
9. Oil pan drain plug loose or worn.

3. Bleed air from system and check all fuel connections for leaks.
4. Use good grade diesel fuel
5. Remove and install new manifold gasket.
1. Install new rings.
2. Maintain proper oil level.
3. Install new gasket.
4. Install new valve guides.
5. Install new sleeves.
6. Install new oil seals.
7. Install new rings.
8. Remove and inspect and, if necessary, replace.
9. Tighten plug.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Probable cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Engine does not idle properly</td>
<td>1. Plunger spring broken.</td>
<td>1. Install new spring.</td>
</tr>
<tr>
<td></td>
<td>2. Governor springs loose or broken.</td>
<td>2. Repair, replace spring.</td>
</tr>
<tr>
<td></td>
<td>3. Plunger scored, stuck or worn.</td>
<td>3. Install new plunger.</td>
</tr>
<tr>
<td></td>
<td>4. Loose governor spring levers on control lever shaft.</td>
<td>4. Tighten screw and nut.</td>
</tr>
<tr>
<td></td>
<td>5. Restriction to fuel deliver.</td>
<td>5. Inspect fuel lines and valve, inspect for proper level in fuel tank.</td>
</tr>
<tr>
<td>J. Engine knocks</td>
<td>1. One or more cylinders misfiring.</td>
<td>1. One or more cylinders misfiring.</td>
</tr>
<tr>
<td></td>
<td>2. Loose connecting rod.</td>
<td>2. Tighten connecting rod.</td>
</tr>
<tr>
<td></td>
<td>3. Poor grade of fuel, or water in fuel.</td>
<td>3. Use good grade of fuel and check for water in fuel.</td>
</tr>
<tr>
<td></td>
<td>4. Injection pump timed incorrectly.</td>
<td>4. Time the injection pump correctly.</td>
</tr>
</tbody>
</table>
5. Incorrect engine temperature.

K. Excessive smoke.
   1. Too much oil in air cleaner.
   2. Air cleaner pipe clogged.
   3. Improper fuel.
   4. Defective injector.
   5. Worn pistons, rings and sleeves.
   6. Pre-cleaner clogged.
   7. Injection pump not properly timed.
   8. Incorrect valve adjustment.

L. Bearing failure
   1. Low oil pressure.
   2. Lack of oil.

5. Keep temperature in working range of heater dicator.

1. Remove air cleaner cup and remove any excess oil.
2. Remove air cleaner and clean the pipe.
3. Use good grade of diesel fuel.
4. Repair or install new injector.
5. Install new parts.
6. Remove and clean. If defective, install new parts.
7. Time injection pump.
8. Adjust valves properly.

1. Keep proper oil pressure.
2. Maintain proper oil level.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Probable cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td>Motor runs too hot.</td>
<td>3. Keep engine at normal operating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>temperature.</td>
</tr>
<tr>
<td>4.</td>
<td>Loose bearings.</td>
<td>4. Install new bearings.</td>
</tr>
<tr>
<td>5.</td>
<td>Lack of proper lubricating oil.</td>
<td>5. Use a suitable oil of non-corrosive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>type, correct grade and viscosity.</td>
</tr>
<tr>
<td>6.</td>
<td>Foreign materials entering</td>
<td>6. Use clean oil containers when</td>
</tr>
<tr>
<td></td>
<td>engine.</td>
<td>filling engine with oil and see that all</td>
</tr>
<tr>
<td></td>
<td></td>
<td>gaskets on engine are in good condition.</td>
</tr>
<tr>
<td>7.</td>
<td>Oil lines clogged.</td>
<td>7. Clean all oil passages.</td>
</tr>
<tr>
<td>M. Valves sticking.</td>
<td>1. Valve springs weak.</td>
<td>1. Install new springs.</td>
</tr>
<tr>
<td></td>
<td>2. Valve springs broken.</td>
<td>2. Install new springs.</td>
</tr>
<tr>
<td></td>
<td>3. Gummy deposits from inferior</td>
<td>3. Clean, and use a proper fuel or oil.</td>
</tr>
<tr>
<td></td>
<td>fuel or oil.</td>
<td></td>
</tr>
</tbody>
</table>
4. Valve stems scored or carboned.
5. Insufficient clearance between valve stem and guide.

N. Piston and cylinder sleeve wear.

1. Oil of unsuitable grade or viscosity.
2. Piston rings stuck or broken.
3. Lack of oil.
4. Foreign materials entering engine.
5. Piston rings not fitted properly to cylinder.
6. Dirty containers used for lubricating oil.

O. Improper fuel pressure.

---

5. Ream guides for proper clearance.

1. Change to oil of suitable specifications.
2. Install new rings.
3. Keep oil at proper level.
4. Inspect and service air cleaners and pre-cleaners. Proper care of these cleaners is very important.
5. Install new rings and fit properly.
6. Lubricating oil should be kept in a clean place and clean containers used when filling engines.

1. Inspect fuel pump.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Probable cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. Low engine RPM.</td>
<td>1. Linkage, binding or damaged</td>
<td>1. Repair and install new parts needed.</td>
</tr>
<tr>
<td></td>
<td>3. Governor control rod improperly adjusted.</td>
<td>3. Adjust rod to proper length.</td>
</tr>
<tr>
<td>Q. Low fuel pressure.</td>
<td>1. Fuel low in tank.</td>
<td>1. Fill tank.</td>
</tr>
<tr>
<td></td>
<td>2. Broken fuel lines.</td>
<td>2. Repair or install new lines.</td>
</tr>
<tr>
<td></td>
<td>3. Clogged line.</td>
<td>3. Clean or install new lines.</td>
</tr>
<tr>
<td></td>
<td>4. Improper grade of fuel.</td>
<td>4. Use correct fuel.</td>
</tr>
<tr>
<td>S. Engine runs unevenly and</td>
<td>1. Faulty valve action.</td>
<td>1. Repair or install parts needed.</td>
</tr>
<tr>
<td>vibrates.</td>
<td>2. Incorrect injection pump timing.</td>
<td>2. Time injection pump correctly.</td>
</tr>
</tbody>
</table>
OIL ENGINES

RING AND CYLINDER WEAR.

26.11. Many of the causes of ring and cylinder wear are well known, such as lack of lubrication, improper oil or other abrasive matter in the fuel, intake air or lubricating oil.

Ring sticking permits excessive blow-by to destroy the lubricating oil film.

Distortion piston or cylinder may also cause metallic contact and wear.

Excessive piston clearance allowing the piston edge to scrape the cylinder wall will cause rapid wear.

Residual fuels of high carbon residue usually cause more wear than distillate fuels. Tests indicate water in the fuel causes cylinder wear. Corrosive substances in the fuel combustion products may cause wear.

Water, one of the products of combustion, will condense on cold cylinder walls and interfere with lubrication. Hence cold starts, over-cooling by jacket water, or continuous light load operation may be the cause of wear.

The cause of cylinder wear other than dust and other abrasive material has been studied by several investigators. There is considerable evidence indicating cylinder wear is largely dependent on the temperature of the cylinder walls which should be maintained at temperature well over 130°F (55°C). At lower temperatures, water, which is one of the products of combustion, condenses on the cylinder walls. Carbon dioxide, one of the other products of combustion is absorbed by the condensed water forming carbonic acid, in a similar manner sulphur dioxide will form sulphurous acid. Both corrode cylinder walls, causing wear. Also, the condensed water interferes with lubrication. Slightly over one gallon of water is formed by the burning of every gallon of fuel. Ordinarily, this water passes from the engine as steam but during the starting and warming up period the cylinder walls are cool enough to permit condensation, and it has been noted that the engines that are started most frequently have the greatest cylinder wear.

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26:11—26:12 MANUAL OF IRRIGATION PRACTICE

Fuel dilution in lubricating oil is an important wear factor during the warming up period but is less serious in the diesel than in the gasoline engine since diesel fuel is a better lubricant than is gasoline.

RING BREAKAGE.

Ring breakage is not an uncommon failure in engine operation. There are many causes of this problem:

1. Excessive ring side clearance, causing unnecessary ring fluttering.
2. Excessive cylinder taper, causing ring flexing.
3. Hard carbon ash deposits non-uniformly located in ring grooves.
4. Wavy or warped ring lands.
5. Combustion knock caused by improper timing.
6. Continuous overload or overspeed operation.

Dirt Entrance into the Engine.

26:12. Let us start from the basic and undisputable fact that dirt is the most common and destructive enemy of pistons, rings, and liners and therefore of an engine.

This may be due to:

1. Loose welds on the upper housing of a cleaner.
2. Interference of the hood and improper mounting of the cleaner.
3. Absence or faulty gasket or packing ring to seal the oil pan to the cleaner.
4. Incorrect level of oil in the pan.
5. Faulty air pipe from the air cleaner to the engine. This includes loose connections, holes in the tube, improper hose which do not fit the metal tubes. Tight enough to prevent leakage or clamped carelessly loose.

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8. **Faulty breather.**—Crankcase breather is the normal path for air entrance into the crankcase during its normal ventilation.

7. Oil filter opening. Use of spring filter caps should be avoided as they are short-lived. Use screw type cap.

8. Oil gauge opening.

The problem of maintaining the crank case and intake air system air tight at all times is a Must that requires a constant vigil because of the possible damage that can result at any time.

Oilt is the biggest Enemy of the Engine.

**MAJOR SERVICE ON ENGINE.**

26.13. **Cylinder block.**—The cylinder block is one piece alloy casting with main bearing caps which are considered as an integral part of the block. Main bearing caps must not be interchanged or turned from end to end and should not be faced at any time as facing the cap changes the shape of the bearing hole. A thorough steam cleaning of the cylinder block and all oil passages is recommended. Only half bearings are generally cast within block.

**Main Bearings.**—The main bearings are generally steel backed, precision type and lined with suitable bearing metal for long life. Main bearings are assembled to the block and caps with crankshaft clearance as recommended by the engine builder. The rear main bearing is designed to take the crankshaft thrust and must have clearance between the bearing and flange on the crankshaft as per recommendations of the engine builders.

Should a bearing burn out, the bearing metal should be carefully removed from all oil holes in the crankshaft, and in the cylinder block. Improper cleaning of these holes will result in another bearing failure. If the remaining bearings had considerable service, it is recommended that all bearings be replaced. All main bearings studs, nuts should be tightened with torque wrench as per recommendations by the engine builders.
Connecting rod and bearings.—The upper end of the connecting rod is bushed with a hard bronze bush, bored to accurate size. The rod is rife drilled from the crank pin hole to the wrist pin hole to distribute oil under pressure to the wrist pin and bushing. Bearing shells are of precision type, accurately machined, and require no scraping. All connecting rod bearings should be fitted for crankshaft clearance as recommended by the engine builders. Bearing caps must not be interchanged or turned end for end. All the connecting rod nuts should be tightened with the help of torque wrench as per recommendations furnished by the engine builders.

Pistons.—The function of the piston is to receive the force of combustion pressure and transmit it to the connecting rod and crank throw. These are made of special alloy and are carefully balanced and matched for weight. Ring grooves should be carefully examined.

Piston Rings.—The function of the oil regulating ring is to provide an even circulation of lubricating oil, and, therefore, an all over lubricating and cooling action for the piston and sleeve. Excess oil is wiped by the rings back down to the crankcase. The remaining rings are termed “compression rings.”

Piston Pins.—The piston pin or wrist pin is a cylindrical shape and is made of steel. Its purpose is to anchor the piston to the connecting rod. The pin is retained in the piston by retainer rings that lock into grooves of the piston pin bore. The pin is allowed to float in its bushing in the upper end of the rod. The aluminum of the piston is an excellent bearing material, and no bushing is provided, therefore, between the pin and the piston.

Connecting Rods.—The connecting rods serve the links between the piston and the crank throw. The surfaces of the rods must be kept free of scores and dents because of the high stresses under which these engine parts function. The rod has a bearing at each end, the one at the upper end being for the piston pin which anchors it to the piston, this is a bushing.

The bearing at the crankshaft or lower end is provided by an inserted bearing in two halves which fit around
the crankshaft and are secured by a bearing cap. The rods are drilled to provide passage for a lubricating oil flow to the piston pin bushing. Both halves of each bearing are identical. The connecting rods should be inspected for straightness and should be free of twist and be parallel to the pistons.

_Cylinder liners._—These are made of special alloy. It is very important that all surfaces that come in contact with cylinder liner be thoroughly cleaned before inserting new liners. Cylinder liners should be removed by a puller furnished by the engine builders. These liners should be replaced if the wear is more than the recommendations by the engine builders.

_Cylinder head._—The cylinder head is cast in one piece. When cylinder head is removed, care must be taken not to nick or mar the surface of the head. It is a good practice to replace the head gasket once the head is removed. Valve guides, head gaskets, injector seats should be thoroughly examined before putting the head on.

_Camshaft._ The camshaft is a one piece steel forging. Bushings are generally steel backed and babbit lined. The camshaft should have a running clearance as recommended by the Engine Manufacturers.

_Value Reconditioning._ The engine valves and their condition are critical factors in engine performance and in economy of operation. With faulty valve action, the value of high compression power and operating economy is lost.

Carbon deposits on the valves and valve seats are normal effects of the fuel-burning engine and cannot be avoided completely. However, such deposits are detrimental to engine efficiency and valve assembly life as the amount of carbon in the engine increases.

An engine that has large amounts of carbon adhering to the valves and to the areas surrounding the seats will ultimately develop valve sticking, valve warping, and pitting due to the carbon preventing the valves from seating correctly, and will develop excessive temperatures, within the cylinders due to the prevention of heat dissipation by the insulating layers of carbon.
Whenever possible—and most certainly whenever the cylinder head of an engine is removed for service—all carbon should be removed from the surfaces of the parts affected. Valves and valve seats should be examined for pitting, burning, warping and other defects.

If the formation of carbon cannot be avoided, it certainly can be held to a minimum by the use of only good grade fuels and by attention to accurate engine timing.

Warpage, burning and pitting of valves is mainly directed against the exhaust valves as these are exposed to the high temperature flow of exhaust gases. Such defects are generally caused by valves failing to seat tightly and evenly, permitting exhaust blow-by. This in turn can generally be traced to hard particles of carbon being present on the slopes of the valve seats. It may, however, be due to weak springs, insufficient valve clearance, or warpage and misalignment of the valve stem or guide.

Warpage chiefly occurs on the valve stem due to its exposure to heat. Out-of-round wear will follow where the seat has been pounded by a valve the head of which is not in line with its stem or guide.

Misalignment is a result of wear, warpage and distortion. Wear, when accentuated by insufficient lubrication, will eventually create sloppy clearances with resultant misalignment.

Before disassembly of the engine for removal of the cylinder head, examine the engine for signs which may indicate the reason for the need of valve reconditioning. Dry and rusted valve springs are an indication that the oil passages to the valve levers may be blocked, causing wear on the valves and guides, and resulting in improper valve action.

Valves: Inspect each valve to decide whether it is fit for further use. Remove all carbon from the valve face head and stem. A wire brush or buffing wheel can be used to good purpose for this operation. Valve stems should be lightly polished with an extremely fine abrasive cloth sufficiently to remove the carbon deposits only.

Inspect each valve to see that the stem is not worn excessively, and that the head is not burned or warped. Check
the grooves in the stem to see that they have not but the shoulders through wear, which would prevent the valve spring retainer locks from fitting snugly.

All valves having bent, worn or warped or seriously pitted stems should be replaced with new. Scrap and replace any valve that cannot be satisfactorily refaced with a definite margin maintained. The amount of grinding necessary to true the valve face is a definite indication of the valve head warpage from the axis or centerline of its stem. With excessive warpage, a knife edge will be ground on part or all of the valve head due to the considerable amount of metal that must be removed to completely reface. Maximum bevels in a valve head is required for strength and to provide as large an area as possible for heat dissipation. Knife-edged valves lead to breakage and warpage.

Clean all valve springs thoroughly and examine them for rust, pitting, broken or slit cords. Test each spring against the spring specifications.

Clean all valves spring retainers with solvent, and examine them for rust, cracks and bending characteristics. Replace parts as necessary.

Remove all carbon from the cylinder head. Inspect all valve seats for cracks or loose valve seat inserts on engines so fitted. Replace inserts if found loose or burned. Be certain that all carbon is removed from the valve seat recesses or counterbores.

Valve seats in the cylinder head should be reground. Proper seating can be checked by making light soft pencil marks across valve face and then rotating the valve under pressure, part of a turn. The rubbing or smearing of all pencil marks indicate proper seating. If seats are not smooth or do not prove out as indicated, repeat regrinding until properly finished. When replacing head to block tighten all nuts with a torque wrench as per recommendations of the Engine Builders.

Fuel Injection Equipment: Fuel injection pumps and injectors should be serviced by competent men who have specialized in the branch. Injector spray testing machines and fuel pump calibrating machines are most essential to achieve good results in the servicing of this important piece of equipment.
INSTRUCTIONS REGARDING RUN IN PROCEDURE OF AN ENGINE

26.14 After the installation of new pistons and rings we should give the break-in procedure of an engine the proper consideration. Piston rings, though manufactured under highly precision operations and extreme care, do have extremely minute high spots on the faces of the rings and if these rings put to high load immediately after installation, there is a danger of the high spots on the rings breaking through the oil film resulting into metal to metal contact with the cylinder wall. This would obviously develop high temperature on the ring at the point of contact and may reach the melting point of the ring material at that particular spot. When this condition happens, the metal pulls out of the ring and leaves a void through which oil would pass.

The complete run in procedure is divided into two parts. The first part is composed of four different phases of run in which ranges from one hour to 3 hour each at which the time and the load and speed of the engine is gradually increased through a six hour period until 75 % load and 85 % speed is reached.

Briefly these steps are:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time hours</th>
<th>H. P.</th>
<th>R.P.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1 hour</td>
<td>25 %</td>
<td>of rated H. P. 60% rated R. P. M.</td>
</tr>
<tr>
<td>2.</td>
<td>1 hour</td>
<td>50 %</td>
<td>&quot;</td>
</tr>
<tr>
<td>3.</td>
<td>1 hour</td>
<td>75 %</td>
<td>&quot;</td>
</tr>
<tr>
<td>4.</td>
<td>3 hour</td>
<td>75 %</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

The second point of the run in procedure consists of additional running of the engine and the taking of intermittent power check is made as follows:

First open the throttle wide open and then start adding load on the engine till the tachometer shows a slight reduction in R. P. M. below the governed speed of the engine. Do not operate the governor at this load more than 5 minutes. After five minutes of operation on full load, reduce the load to 75 %, run the engine for about an hour or so. Continue these
cycles of intermittent power checking till all the rated power is obtained from the engine.

Check water temperature, oil pressure, through this running.

In the past, it has been a very popular practice to break in the engine at idle speed with no load applied. This is a dangerous practice and should not be recommended, running the engine at idle speed following the installation of new pistons, rings for more than one hour or no more than is necessary to warm up the engine to determine water or oil leaks. The engine should have a load applied gradually as per schedule in the first four phases of part one of the run in schedule so as to build up pressure on the rings gradually as they seat to the liner. Idle running of the engine forms a glaze on the walls of the liner and makes further running in of the rings very difficult. If the engine is allowed to run idle the lubricating oil escapes by the rings before they have properly seated.

The other method of breaking in an engine, when it can’t be put under constant load, is to dilute the engine oil with fuel oil. This does two things. It breaks down the viscosity of the lubricating oil causing the liner and rings to wear faster. Extreme care must be taken not to dilute the oil sufficient to cause bearing failure. The fuel oil will burn away from the liners under the heat keeping them dry. The extent to which we can dilute the oil also depends upon the temperature. For example sake, if it is a 60 degree day, you can dilute the oil as much as one third, but if it is 80 or 100 it may be necessary to dilute only 1/4. Under no circumstances should the pressure be allowed to drop to danger point. This test should be carried out under the supervision of a competent hand.

26.15. SERVICE AND MAINTENANCE SUGGESTIONS.

Periodic Service.

1. Adjust injectors and valves every 5,000 automotive miles or 300 working hours (industrial). Check valves.

2. Clean screen in injector fuel inlet connection. Quality of fuel will determine time for this.

3. Drain water from fuel tank frequently.

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5. Examine rooster arm assembly to see if lubricating oil is coming through.

6. Tighten all cap screws and nuts occasionally to prevent oil leaks.

7. Check for any fuel oil or water leaks.

8. Drain fuel filter. This is determined by the quality of fuel that is used.

9. Regrind and reface valves and seats when necessary.

10. Clean oil breather cap. This is controlled by working conditions.

A few Don’ts.

1. Don’t ream or lap injector plunger or body.

2. Don’t run the engine with loose bearings.

3. Don’t clean injector cups except when necessary, and use drills furnished by engine builders.

4. Don’t use cheap or inferior lubricating oil.

5. Don’t run the engine too cool.

6. Don’t run the engine idle for long periods. Shut it off unless it is working.

7. Don’t operate at overload.

8. Don’t tamper with the governor setting.

9. Don’t race the engine.

Failing off in power.

1. Dirty fuel pump screen.

2. Spray holes in injector cup stopped up.

3. Incorrect valve or injector adjustment.

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4. Leaky intake or exhaust valves.
5. Low fuel oil pressure.
6. Air filter stopping up due to accumulation of dust and dirt.
7. Insufficient lubrication:—
   (a) Low oil pressure.
   (b) Insufficient quantity of oil.
   (c) Poor quality of oil.
   (d) Diluted or worn out oil.
8. Overheated engine:—
   (a) Overfuel.
   (b) Insufficient cooling water.
   (c) Loose fan belts.
   (d) Failure of water pump.
   (e) Radiator stopped up and not cooling properly.
9. Clogged fuel lines.
10. Muffler or silencer stopped up or of insufficient size.
11. Stuck piston rings or excessive cylinder wear.
13. Improper grade of fuel.

   If engine stops:
1. Roll engine over by hand to see if it is free.
2. Check fuel level in tank.
3. Check fuel line for obstructions.
4. Check oil level in crankcase.

**Failure to start**

1. Fuel supply exhausted.
2. No fuel pressure. (Fuel line broken or leaks at fittings).
3. Emergency fuel shut off cock or fuel pump closed.
4. Fuel pump screens may be stopped.
5. Fuel lines full of air.
6. Battery low, giving insufficient cranking speed.

**Fuel not of Starter**

If the engine does not start after running over a short period of time, do not continue to crank as further cranking would be an excessive drain on the battery.

**Engine Missing.**

1. Leaky check valve in injector or fuel inlet connection.
2. Dirty injector spray holes.
4. Injector plunger sticking.
5. Valve sticking.
6. Valve clearance too close.
7. Valves leaking and need regrinding and refacing.
8. Air in fuel lines.
10. Distributor disc, scored (Cummins Engine).
11. Injector cup leaking.
1. Dirty injector cup spray holes.
2. Valves leaking or clearance too close.
4. Injector adjustment set improperly.
5. Check all fuel lines to see that they lead to their proper connections.

**Engine Smoking**

5. Engine over-loaded. Fuel setting has been altered. If more fuel is injected then the amount of air in the cylinder will support incomplete combustion, the engine is being overloaded and surplus fuel will not burn.

7. Engine running too cool. Running temperature should be maintained.

8. Suction lines on pump admitting air. Check fuel line for leaks.

9. Injector cup spray tip cracked.

**Engine knocking**

1. Overload.
2. Dirty injector cup spray holes.
3. Air in fuel lines. Tighten all fuel lines and check for leaks.
4. Injector push rod bent from improper injector adjustment and striking cylinder block.
5. Loose piston pins.
6. Piston slap, due to worn pistons and cylinder walls.
7. Loose fly-wheel.
8. Injector cup spray tip cracked.
Engine Overheating.

1. Insufficient amount of cooling water.
2. Stoppage of cooling system.
3. Insufficient amount or poor quality of lubricating oil.
4. Loose water pump belts.
6. Overloading.
7. Sludge or lime formation in water jacket.

Locating weak cylinder.

Loosen the fuel supply line at the fuel inlet connection. This will cause the cylinder to miss.

Set the throttle to turn the engine about 700 to 800 RPM. Loosen each line separately and listen to the exhaust to see if any change occurs. Before proceeding to next cylinder tighten fuel line again. Check all cylinders in this manner:

1. Check valve leaking in fuel inlet connection or injector.
2. Leaking or sticking valves.
3. Sticking injector plunger.
4. Injector spray hole stopped up.
5. Fuel-inlet connection gasket leaking at injector body.
7. Improper injector plunger adjustment.
8. Injector cup gasket leaking.
Dilution of lubricating oil.

1. Stuck piston rings.
2. Injector cup gasket leaking.
3. Fuel inlet or drain connections leaking.
4. Injector drain line and manifold not draining properly to fuel pump.
5. Worn injector plunger permitting excess bypass of fuel.
6. Vacuum in crankcase caused by air-tight or dirty breather cap.
7. Injector cup spray tip cracked.

Low lubricating oil pressure.

1. Lubricating oil diluted.
2. Insufficient lubricating oil.
3. Loose suction line or defective gasket.
4. Excessive wear in lubricating pump.
5. Gauge line stopped up. Remove and clean out.
6. Loose main and connecting rod bearings.
7. Insufficient amount or improper quality of lubricating oil.
8. Excessive oil leaks around valve tappets and rocker levers.

Excessive use of lubricating oil.

1. Oil leaks. Check engine for external leaks.
2. Improper quality of lubricating oil.
4. Excessive wear on cylinder walls.
5. Scored piston or sleeve.
6. Overload.

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Avoid Dilution and Sludge formation.

Dilution and sludge are enemies to any internal combustion engine. The diesel engine is no exception.

Change oil according to your observations and working conditions. Each engine and its operation has its own lubricating problems and must be treated as such.

Use only a good quality of lubricating oil.

Flush engine with a good quality fuel oil. This must be done while the engine is hot to obtain satisfactory results. Dust and sludge are hard to break loose when cold.

Use a good, clean quality of fuel oil.

Keep injector cup spray holes open and spraying an even pattern.

Use proper size drill for cleaning the injector cup spray holes.

Use proper injector cup gaskets.

Keep injector adjusted according to instructions laid down by the manufacturer.

Use proper gaskets for the injector fuel inlet and drain connections. Check to see that they are tight.

Operating with stuck rings accumulates sludge rapidly. Change lubricating oil filter as recommended.

Drop in Fuel Pressure.

1. Improper quality of fuel oil.
5. Water in fuel freezing in cold weather.

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CHAPTER 30
KACHHA ROADS

INTRODUCTION

30.0 Almost all canal roads are kachha or unmetalled. They are maintained along irrigation channels primarily to facilitate inspection of irrigation works and canals, and as such are usually designated as canal inspection or patrol roads.

Canal roads are the property of the Irrigation Branch and are not open to public except with the permission of the Irrigation Branch.

To maintain their legal status as private roads belonging to the Irrigation Branch, all canals roads are closed to public traffic for one full day from midnight on the 30th of June to midnight on 1st July each year in accordance with the following instructions:

1. Each length of canal road, between public roads, should be specially closed off for full 24 hours.
2. Portable barriers placed in position by the gang-men serve the purpose.
3. Sectional Officers should report the steps taken by them to close the roads and should also certify that all roads in their charge were closed to the public for the prescribed period. These reports must be submitted by them to the 5th of July and a consolidated report for the circle should reach the Chief Engineer's office each year by 1st August.
4. In order to establish a right of way, it has to be shown that people have been using the roads, as of right, for a particular period. A mere notice forbidding traffic is not enough, for a person who goes past the notice may be disregarding it, because he considers himself entitled to use the road. There is need to worry about pass-holders, for any one who obtains permission cannot establish a right of way, but does exactly the opposite.

GENERAL DESCRIPTION

30.11. Canal roads may be divided into three classes:

classification.

(a) Roads carried on banks of channels or on top of embankments called inspection roads.
(b) Roads more or less on natural surface, called Boundary Roads.
(c) Link roads to serve as approaches to or as connecting links between roads along two or more different channels. Such link roads are very few in number.

Inspection roads carried on canal banks are more expensive to construct and maintain than boundary roads, but the former are more useful, inasmuch as they afford for greater facilities for inspecting channels. Inspection roads are provided along main and branch canals and important distributaries. Channels in heavy embankment are particularly susceptible to cuts and breaches. Such channels should invariably be provided with inspection roads, and along large channels, on both banks.

30.12. For roads on canal banks, a width of fifteen feet exclusive of dowie is to be preferred, out of which ten to twelve feet should be maintained in good condition, leaving the remaining width as a roughly dressed berm.

For boundary roads on natural surface a roadway of twelve feet is considered sufficient.

30.13. A good cross slope of 1 in 40 to 1 in 60 should be provided in the road surface to drain off water rapidly. In the absence of such a cross slope, it becomes almost impossible to drive along the road during or immediately after a shower of rain. A good cross slope also minimizes formation of rain holes in canal banks.

30.14. Where a road is in cutting or passes through a spoil bank, catch-water drains should be provided to carry off the rain water. Such drains should be from twelve to eighteen inches wide and at least a foot deep. Such catch-water drains, usually outfall into the canal.

30.15. The patrol bank should be provided with a dowel on the canal side of the road. The dowel should be one foot to 1.25 feet wide on top and at least a foot high with 1:1 side slopes. Dowels provide additional safety so far as free-board is concerned and also ensure greater safety for wheeled traffic.

30.16. The width of slope of ramps to culverts and bridges is determined by the class of the road. Full details in this respect will be found in Chapter 9. For ramps on roads along main canals and branches, the minimum slope should be 1 in 20. For boundary roads along distributaries and minor canals, the ramp slopes should not be less than 1 in 20. In constructing such ramps, ease should always be taken to avoid sharp angles at the top and at the foot of the slope of the ramp, as shown in Fig. 1.

Fig. 1.
A certain minimum level portion between the bridge and the beginning of the slope of the ramp has been prescribed in Chapter 9 for the various classes of roads. For boundary roads along distributaries the level portion on top of the culverts should not be less than 10' in Length.

**CONSTRUCTION**

30.21. For a proper appreciation of the factors governing the behaviour of a road surface, it is necessary to know something of the characteristics of the soil it is made of and its classification.

The first natural division is by gradation, and this has been detailed in chapter 36. Gradation, however, is only one of the factors which have their effect on the value of a soil used in construction. The Bureau of Public Roads, United States of America, has outlined five basic physical characteristics, each of which has a direct bearing on the performance of soil. These characteristics are internal friction, cohesion, compressibility, elasticity and capillarity.

"Internal friction and cohesion tend to resist all movements of particles thereby increasing the stability of the mixture. High internal friction and cohesion when combined with the density of compaction will give a compression resistant soil. Elasticity makes such compaction impossible since an elastic soil cannot sustain a load. Capillarity causes trouble, since stability cannot be maintained unless the flow of water through the mixture is reduced to a minimum."

The statement attached gives a resume of the various types of soils, with their characteristics and value as soil binder material.

A study of this statement indicates that the best material for road surface is group A-1, in which sand (particles over .05 mm. diameter) is 70 to 85 per cent, silt (particles between .05 mm. and .005 mm. in diameter) is 10 to 20 per cent, clay (particles between .005 mm. and .001 mm. in diameter) is 5 to 10 per cent and colloids (particles under .001 mm. in diameter) are 0 to 5 per cent and the grading is uniform. Such a soil or one which satisfies the above conditions as closely as possible should be selected for the top 1 foot of the road.

30.22. Where a road is made in filling, the bank should be laid in 6" layers, compacted at optimum moisture content as specified in chapter 36, the top two layers being of specially selected earth, as detailed above.

30.23. After the bank is constructed, the surface should be divided into compartments with small dowels along both edges and cross dowels about fifty feet apart, so that rain water seeps into the bank and all possible settlement takes place. The dowels should be allowed to
30.24. Dowels should be similarly compacted in 6 layers at optimum moisture content. Where possible, these should be turfed or grass encouraged to grow on them.

30.25. When a road passes through a sandy tract, the following measures should be adopted in order to provide a firm road surface:

(a) Good hard soil approximating to group A1 or A2 as classified in paragraph 30.21, is generally obtainable either by digging deep borrow-pits or at some distance, and one foot layer of such good soil should be laid on top of the road.

(b) Where the soil is very sandy and a sufficient quantity of suitable earth is not available, a good road can still be made by a six inch thick layer of Rolls of jungle brushwood filled in with sand and laying from six to eight inches of good earth on top.

(c) Where suitable earth is not available, the top surfacing can be done by spreading sarkanda, long grass or similar stuff in a layer from three to six inches thick, loaded with earth at both ends.

(d) Where kankar is available, it can be used to give a really good lasting road surface.

(e) Where none of the above treatments is possible, wheeled tracks of dry-brick, 1.5 to 2 feet wide and 0.4” to 0.65” deep should be provided to carry wheeled traffic.
30.31. A dry road surface disintegrates rapidly and it is therefore, necessary that roads should be regularly watered. On main canals and branches where the strength of gangmen employed on maintenance work is sufficient, the road surface after watering should be worked with rings to give a good even surface. Where, however, the soil is too poor for this treatment, the road surface should be properly levelled by means of kallis, after watering, and subsequently scraped with a scraper and then rolled over.

30.32. On distributary roads where the strength of gangmen is limited to one in six miles or so, the watering of road surface should still be resorted to as frequently as possible. In the case of boundary roads, it is usual to construct a small dowell along the outer edge of the road and to arrange for watering the road from the adjoining water course or by means of small pipes fixed in the distributary bank for this purpose. After such watering, the boundary road should be properly scraped by means of a scraper.

In the case of boundary roads affected by kallar an ordinary shovela dragged over the road while water is still standing on the road, is very effective in suppressing kallar.

30.33. Kachha Canal roads should be closed to traffic following rainfall. Not only is the surface badly damaged by traffic immediately after rainfall, but it may also be unsafe for traffic owing to rain cuts, and on account of the road being soft and greasy.

Ruts should be repaired as soon as formed. Rain holes and rain cuts should be thoroughly opened out and then filled in layer by layer, each layer being thoroughly water and rammed as described in Paragraph 8.622.

After each shower of rain, it is good practice to get all catch water drains cleared.

As soon as the road is firm enough after rain, but before it is too dry, it should be scraped and then rolled over with a fairly heavy roller.

30.34. Where kallar exists on top of the bank, the top one foot of earth should be removed and six inches layer of good sand from the bed of the canal laid in its place. This should be covered over with six inches of good earth from the canal berm.
30.41. Control gates should be provided at suitable points on canal roads to prevent trespass. See paragraph 8.47. If possible, control gates should be located at sites where they can be looked after by gauge readers or chowkidars, living near by. The gates should be provided with a uniform pattern of lock, and master keys should be provided to canal officers. Control gates should be painted white and a circular sheet of metal in the centre painted red, to ensure good visibility. In reaches where only lorry traffic is to be excluded, overhead barriers should be provided as described in paragraph 8.47.

30.42. Caution boards should be provided at a suitable distance both upstream and downstream of a control gate or a railway crossing. Parapets of boundary road culverts should be at least six inches above the road level and their ends white-washed for proper visibility. Similarly, the projecting wings of bridges should be white-washed.

Where a road crosses form one side of the canal to the other, over a bridge, clear caution boards with suitable signs should be provided on both banks of the channel.

Where a road is under repair or where the earth is soft and not yet consolidated, the reach should be closed to traffic by means of suitable barriers and caution boards, and diversion roads laid for traffic provided instead. It is the duty of Sub-Divisional Officers personally to verify that measures described above have been taken before starting work in any reach, and that they are properly maintained during the course of the work.
# CHAPTER 32
RECLAMATION OF THUR LANDS

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CHAPTER 32
RECLAMATION OF THUR LANDS

INTRODUCTION

32.0. The term reclamation as used in the Punjab may be defined as the process of restoring to cultivation lands which were once fertile but have since deteriorated to such an extent as to make cultivation uneconomical or impossible.

SOIL CHARACTERISTICS

32.10. Before describing the causes responsible for deterioration of land and the process of reclaiming it for cultivation, it is necessary to understand the nature of soils met in the Punjab and some terms used in the study of soil physics.

32.11. The texture of a soil is determined by its clay content. The finer the soil, the swifter the percolation and the less moisture is retained in the surface layers for the sustenance of the crop. The heavier the soil the more suitable it is from the irrigation point of view. Briefly, the soils in the Punjab may be divided into three classes as below:

1. **Light Soils.**—These contain from 2 per cent to 7 per cent of clay and are useless for crops other than barani grain, moth, etc.

2. **Medium Soils.**—These contain 7 per cent to 15 per cent of clay. Crops like cotton, wheat, maize, vegetables, Oil-seeds, etc., give their best yield in such soils. Broadly speaking, the average soil in the Punjab contains 12 to 15 per cent of clay.

3. **Heavy Soils.**—These contain 15 per cent and upwards, sometimes as much as 40 per cent of clay and will raise crop such as sugar-cane, rice, some species of cotton and wheat. Except for sugar-cane the yields are likely to be below normal.

32.12. The general characteristic of soils in arid or semi-arid countries is the presence of sodium salts. The Punjab soils are no exception to this rule. Soil is a general characteristic of the soil crust in the area of Ferozepore, Kasauli, Roltaik, Amritsar and Gurdaspur and throughout the area there is a pre-disposition to the condition called "thur". The principal salts found in the Punjab soils are sodium chloride, sodium sulphate and sodium carbonate. The salt usually responsible for the damage to land is sodium sulphate.
Experiments based on the yield of wheat and rice indicate that soils may contain up to 0.18 per cent of total salts without detriment to the yield of the crop. Thereafter the yield falls off rapidly and at 0.25 per cent the soil may be called infertile due to toxicity. The average salt content in the Punjab varies from 0.05 per cent to 0.15 per cent.

32.13. The "pH value" of soil is an indication on a logarithmic scale of the degree of 'consistency'. The scale ranges from 0 to 14 of which the figure 7 is neutral in the sense of chemical reaction. Below 7, the soil is acid; above 7, alkaline.

Sour or acid soils can be brought back to neutral if they are treated with lime dressing.

The alkaline soil are very different: their treatment and reclamation is long process. The results of the investigations carried out so far indicate the following:

(a) Soil having a pH value of 7 to 8.5 will give normal yield with the Principal crops.

(b) A pH value of 8.5 to 9 will result in a decline of the yield.

(c) At pH 9 rice must be introduced into the crop rotation if normal yields are to be regained. Generally one rice crop is enough for reclamation.

(d) In soils having a pH value of 9 to 9.5, rice can be grown and will in time improve the soil to normal. Such soils are locally known as "mild rakkar soils".

(e) Above 9.5 the soil will yield nothing and is known as "rakkar soil". The reclamation of this type takes a much longer period than types (b) - - - - (d).

In the Punjab, the pH value of the soil is everywhere above 7. It varies from 7.2 to 11.0 with an average in the cultivated area of about 8.5.

Combining the effects of salt content and pH value of soil, it may be said that the normal crop yield is limited to soil of which the total salt content does not exceed 0.18 per cent and the pH value is not above 8.5.

SOIL DETERIORATION

32.21. If the soil crust in an area, which has never been irrigated, is examined, it will be found that salt is distributed throughout the thickness of the crust. The introduction of irrigation results in the washing of the salt from the surface layers of the soil and in its accumulation.
32.22. **Reclamation of Thrux Lands**

At some depth usually 5 feet to 6 feet below the surface. Unless the irrigation is heavy, the evaporation of water from the soil surface tends to draw up the salt saturated water and thus produces a movement of the accumulated salt in an upward direction. A rise in the sub-soil water-table has also been known to produce an upward movement of the salt on the surface. The final concentration of the salt solution results in the deposition on the surface of the sodium sulphate as white crystals which are a familiar feature of the country in winter.

32.22. The accumulation of salt on the soil surface may be regarded as the first stage of deterioration. In order to determine whether the soil should be considered fertile, it is essential that the clay in the soil should include calcium in its composition. When the salt accumulation has reached the surface, rain or irrigation water may wash it to a small distance below the surface and evaporation will again cause it to rise. This upward and downward movement results in the sodification of the salt replacing the calcium in the clay of the fertile soil. The result of this replacement is the production of an alkaline soil known in the Punjab as “rakkar.”

“The development of alkalinity is a gradual process and it follows that after the first stage of appearance has been reached the longer the land is left before reclamation the greater will be the approach to the second stage of alkalinity. As the alkalinity increases reclamation becomes more and more difficult and finally economically impossible.”

32.23. This alkaline soil is impermeable to water and air. Impermeability to water means that no water given its irrigation can reach the plant roots and the absence of air prevents the bacteria responsible for the production of plant food in the soil from carrying out their functions. The conditions in an alkaline soil are thus unsuitable for crop production.

**The Technique of Land Reclamation**

32.31. Since water required for the growth of rice is sufficient to maintain the salt at a depth below the surface where it will not be injurious to crops, the obvious method of salt control is the introduction of rice cultivation. The growth of rice is the first step in the reclamation process.

32.32. In addition to providing water for the control of salt movement, the growth of rice performs another important function. During its growth, rice generates carbon dioxide on the soil by means of its roots. This carbon dioxide attacks the sodium which has replaced the calcium in the clay and finally removes it in solution to the deeper soil layers. The removal of sodium reduces the alkalinity and restores the permeability of the soil to water and air.
22.33. After the removal of the soil alkalinity, one factor determining fertility still remains to be restored. Nitrogen is an essential plant food. During the growth of rice, the available nitrogen is considerably reduced owing to the temporary absence of air due to the high water content of the soil. To restore this nitrogen, a leguminous crop is grown during the rabi season. Leguminous crops have the power with the aid of bacteria of fixing nitrogen in their roots. The nitrogen compounds thus formed can be decomposed by bacteria after the removal of crop and converted into forms of nitrogen which can be used by succeeding crops.

22.34. The reclamation process may thus be summarised as follows:—

Summary:

(1) the reduction in salt content of the soil by leaching and the cultivation of rice.

(2) the reduction in soil alkalinity by the roots of the rice crops,

(3) the restoration of nitrogen to the soil by the growth of a leguminous crop.

Reclamation Operations

22.40. Before undertaking reclamation, it is necessary to frame a Preliminary programme for the whole of the canal system in general and for specific channels in particular. For this the following information must be available:—

(a) The total additional water-supply that can be made available during the summer (no additional supplies ordinarily are available in the winter), the exact period for which it will be available and the manner in which it can be distributed amongst the different channels on which reclamation is to be carried out.

(b) The areas that require treatment.

There are many factors which determine the additional supplies of water that can be made available for reclamation, and Chief Engineer issues instructions every year allotting reclamation supplies to different canals.

As regards areas that require treatment the most reliable method is a scientific soil survey of the area, for which soil samples are taken and examined in a laboratory. A field method of carrying out a soil survey has however, been developed which gives an indication of the stage of deterioration of soil. Such surveys are known asthur girdawaris. Orders exist on many canals for the Irrigation Branch Patwaries to do the thur girdawars during the course of their normal work. Detailed instructions for recording all types of
32.41—

Reclamation of Thur Lands

Land deterioration have been issued. Zilladars, deputy collectors and the land reclamation officers are required to check the thur girdawris carried out by the Irrigation Branch patwaris. From the results of the thur girdawris, areas that require treatment are selected.

Having selected the areas for reclamation, the next step is to carry out a detailed soil survey of the area. Soil samples should be taken by the land reclamation officers and sent to the laboratories at Amritsar. From the results of analysis it is possible to determine the number of rice crops required for the complete reclamation of the different fields.

In canal colony areas where cultivated fields are going out of cultivation due to the formation of thur, areas which require treatment for wheat seasons should be given preference. For such areas a programme of reclamation for the whole of a distributory should be framed so as to finish reclamation of such areas on the distributory in not more than ten years.

32.41. Fields for reclamation in any particular area should be selected in proportion to the total thur area on the outlet and if possible in each square. In preparing schemes, efforts should be made to start reclamation on all outlets from head to tail of a distributory. This will avoid remodelling of individual outlets.

The zamindars are required to apply for reclamation supplies on a standard application form.

32.42. Having determined the area and the period of reclamation, the extra discharge required should be worked out on the basis of 45 acres of rice per cusec of extra water supply. The executive engineer should ascertain if the distributory is capable of taking the extra discharge during kharif without heavy remodelling or upsetting the regime. If the distributory cannot take the extra supply, proposals for remodelling the distributory, raising its banks and alterations in control points should be forwarded to the superintendent engineer before the first of May. This will give sufficient time to the superintendent engineer to frame proposals and have them sanctioned so that the remodelling can be carried out during the winter season.

There will always be some increase in the water level in a distributory on account of the increased water supply during the reclamation period. Overdrawals by the existing outlets should be worked out. The balance of the extra discharge is to be supplied to the areas concerned through additional sheets or pipes made of wood or iron. From a series of experiments carried out in the Irrigation Research Institute, charts showing the relationship between the working head and the discharge obtained both under free fall and submerged conditions, have been prepared for two different sizes of barrel type outlets. These should be freely used.
32.43. On most of the colony canals warabandis are framed on seven
short periods to twelve day periods. For efficient leaching and successful
reclamation it is necessary to maintain saturated conditions in
the soil crust. This requires more frequent waterings. Warabandis are,
therefore, reduced to five-day periods. These warabandis remain in force
from the date the extra water supply is given, upto the date it is withdrawn.
During the winter season zamindars must revert to their normal warabandis.

The normal waris on an outlet are proportional to the cultruable
commanded area owned by each cultivator. For the reclamation of thr landlords
additional supply is given in proportion to the thr area. For calculating
reclamation warabandis, the following methods may be used:

Let the number of days in the war be = N (here 5).
Let C.C.A. be = A acres, with full supply factor = t.
Let thr be = T acres, with full supply factor = t.

Then the war for C.C.A., W = \frac{1440 N}{t^2} minutes per acre.
Therefore the war for thr WT = \frac{1440 N T}{(t+A)^2} plus T/(t+A) minutes per acre.

As the framing of short period warabandis requires a large number
of calculations, facilities for such calculations have been provided in the Irri-
geration Research Institute. The executive engineers and the land reclamation
officers are advised to make use of them.

The land reclamation officers and, in certain cases, the assistant land
reclamation officers have been empowered under the Canal and Drainage
Act of 1873 to sanction and announce warabandis for the reclamation period.
These warabandis remain in force for the period the extra water supply is given.
All reclamation warabandis must be announced before April, 1st.

32.44. The lay-out of fields and water-courses will depend upon the
layout of fields and
depth of the water-table, variations in water-table, the texture of
the soil and the cropping that will be most suitable after reclamation.
In areas where the water table is at a depth of more than ten feet from the
natural surface, each acre field should be divided into four sub-plots, the
water-course running in the middle of the field. This will enable each quarter
plot to be irrigated independently from the water course. Field ditches should
be strengthened and made one foot high. For high water table areas, advice
must be obtained from the Direc. of Land Res. at Amritsar.

32.45. The reclamation patwari must see that the thr fields get their
turn of water after every five days according to the sanctioned warabandi.
It is the duty of the land reclamation staff to see that the extra water allotted
for reclamation is on no account used by zamindars for irrigating, or increas-
ing the area under normal crops. If on account of the zamindars’ neglect
to carry out the reclamation process according to instructions, the rice crop
32.46—

RECLAMATION OF THIN LANDS

Soil in a field, no kharaba should be given. The refusal of kharaba should be supported by evidence that the share holder has not watered the field according to the special watered area in force supplemented by weekly or monthly reports of the Ptiward, on record in the office of the land reclamation officer.

If the reclamation supply is used in fields other than those fields for which it was allotted, the irrigation done should be treated as unauthorised irrigation, and suitable towaon levied by the land reclamation officer on the area on which the supply has been used.

32.46. As soon as the fields have been laid out in accordance with the crop, Paragraph 32.44 and water supply become available, leaching should be started. During the process of leaching, weeds and grass should be allowed to grow. They should not be cut or grazed.

The period for the sowing of rice nurseries and transplanting of rice depends upon the dates between which extra water supplies are available and the condition of fields during the leaching period. On no account should two rice crops—one early and the other late—be sown on the same water supply in one kharif season. The early crop of rice affords favourable conditions for the breeding of the pest known as "rice borer" which attacks the late crop. The damage resulting from attack of the "rice borer" is sometimes as high as 80 per cent.

32.47. In order to restore the nitrogen balance of the soil which is depleted by leaching and the growth of rice during the kharif season, it is necessary to sow a leguminous rabi crop after rice. The most suitable crops are gram, senji and berseem. The two latter crops require irrigation during the rabi season. The area under these crops is, therefore, limited to the water supply that is available in rabi and also by the quantity of fodder that can be consumed. Gram crop sown in the wash-setter of rice, without subsequent irrigation, has been a remarkable success. With reasonable care, zamindars have been able to secure a yield of as much as fifteen maunds of grain per acre.

32.48. After a reclamation rice crop has been cut, soil samples should again be taken to determine the depth to which the soil salts have penetrated. This has been washed out and the extent to which the alkalinity of the soil has been reduced. Further Programme of reclamation should be based on the results of these soil analyses.

RECLAMATION BY GYPSUM

32.5. Attempts have been made, at various times, to alter the sodium clay base by exchange with solutions of calcium salts. The salts which have been tried are calcium sulphate and calcium chloride.
Calcium sulphate or gypsum was tried originally because it was supposed that sodium carbonate was present in the alkaline soils. The reaction between calcium sulphate and sodium carbonate would lead to the formation of calcium carbonate and sodium sulphate. The former would be precipitated in the soil and the latter could be removed by further leaching. As it is now known that sodium carbonate is not present, this theory of the action of calcium sulphate does not hold. It is now supposed that calcium sulphate and the sodium clay react to form a calcium clay which can be cultivated and sodium sulphate which can be removed by leaching.

Case 1: plus Sodium Clay = Na₂SO₄ plus Calcium Clay.

Unfortunately calcium sulphate is very slightly soluble in water and the base exchange is slow. The reaction is reversible and calcium clay is formed if the sodium sulphate is removed by leaching. With the formation of calcium clay conditions in the soil become aerobic and the soil permeable. As soon as the quantity of calcium sulphate is reduced below the amount necessary for flocculation, the land reverts to its former condition and further dressing of calcium sulphate becomes necessary. Thus reclamation by the use of gypsum is expensive.

Calcium chloride is more soluble than calcium sulphate and, therefore, a solution can be forced sufficiently concentrated to produce base exchange. The quantity required is, however, large and unless the soil is light the methods is not economical.

It has also been found that Gypsum does not act in the presence of excess of sodium salts which abound in the soil and thus gypsum cannot act to bring about the desired base exchange. When, however, the salts have been reduced or removed by leaching and growth of rice, the addition of gypsum is helpful in reducing the residual alkalinity. Methods to ascertain the gypsum requirements of soils from which excess of sodium salts have been removed, are still under investigation.

BIBLIOGRAPHY

32.9. The earnest student will find much useful information on the subject in the annual reports of the Irrigation Research Institute, proceedings of the waterlogging board, and the seasonal notes of the Department of Agriculture, Punjab. In addition the following publications will be of interest:

Land Reclamation in the Punjab—Broadcast talks.

The formation and the reclamation of land in the Punjab.—Punjab Engineering Congress Paper No. 235 (1940) by M.L. Mehta.

Colleidal properties of Soils by Dr. A.N. Puri, Published in the Punjab Engineer for July, August and September, 1939.
CHAPTER 34

Compaction

INTRODUCTORY

36.1 The science of compaction of soils has developed only in recent years. Its application is found in the construction of earth dams, lined reservoirs, airport runways, etc., for imparting stability, durability, and impermeability to the structures. The correct technique of compaction is, therefore, of vital importance to the Engineer.

Soil compaction means the forcing of smaller particles of soil into the voids between the larger ones by the expulsion of air, thereby increasing the soil density and improving the stability and impermeability.

METHODS OF COMPACTING OF SOIL

(a) By Vibration,

(b) By Watering and Rolling.

36.2 Vibration. Vibration can be produced in a primitive manner by tamping with hand or pneumatic tools or by dropping heavy weights on the soil from a height of several feet. However, the compacting effect of these procedures is extremely variable, because it depends to a large extent on the frequency of the vibrations. If the frequency of the vibrations is less than about one half the critical
frequency of the soil, the pulsating force produces relatively little settlement. Further increase of the frequency causes a rapid increase of the settlement and a corresponding decrease of porosity. If \( f_1 \) is approximately equal to \( f_2 \), the settlement is 20 to 40 times greater than that produced by a static load equivalent to the pulsating force. The frequency at which a vibrator must operate in order to produce maximum compaction is somewhat different for different soils. Therefore, attempts have been made to develop vibrators with adjustable frequency. In Germany these attempts led to the construction of 24 ton variable-frequency vibrators mounted on tractors. During operation the vibrators are transmitted to a base plate having an area of 40 square feet. By means of this equipment layers 7 feet thick can be compacted at the rate of about 5,000 sq. ft. per hour.

The above technique has not developed in India yet. Here the compaction is done by Watering and Rolling.

Watering and Rolling. In the compaction by the above method, the soil is given the necessary optimum moisture for the production of minimum volume and maximum density at the borrow-pit sites. The earth is generally carried with the help of heavy transport machinery like, Endicks, DW-10, dumpers, etc. The earth loads are deposited at the site of compaction at suitable intervals so that when spread they give a certain specified thickness. The spreading is done with the help of dozens of suitable sizes. Any water lost in transport is made up by sprinkling the water on each layer. The compaction is then done with the help of sheep-foot rollers. As a result of experiments in the laboratory, it is generally known, how many passes of the roller with a certain weight are required for compacting the soil to the maximum density. After the necessary number of passes have been done, the dry bulk density is observed. If it comes to the desired value, a second layer is deposited as described above. If, however, the density is less than specified, further passes are done till the layer assumes the correct density.

The above method is practically fool proof so long as the Research Staff is careful to see that the optimum moisture is put in and the soil is compacted to the correct density.
COMPACTON

363. Moisture in soil acts as a lubricant and reduces the frictional resistance between the soil particles. It enables the finer soil particles to easily move into the pores of the larger particles with lesser mechanical effort. There is, however, a limit to the quantity of moisture for increasing the density and decreasing the volume. If the moisture percentage is more than the above value, the density again decreases. The minimum percentage of moisture which permits maximum density and minimum volume is called the optimum moisture. The optimum moisture is different for different soils. It is not only the function of the soil, but also the weight of the compacting equipment. The greater the compacting force the lesser will be the optimum moisture for a given density.

DETERMINATION OF OPTIMUM MOISTURE AND MAXIMUM DENSITY

364. No general formula exists for determination of the optimum moisture content in terms of percentages of the constituents of soils. However, the following approximate formulae have been evolved as a result of laboratory experiments and as confirmed in the field.

For predominantly sandy soils (30 per cent or more sand), optimum moisture content is given by

\[ D = 24 - 0.14S, \]

where

- \( D \) = Optimum moisture content by weight
- \( S \) = Percentage of sand.

For predominantly silt soils (85 per cent or more silt), better results are got by using the formula

\[ D = 24 - 0.14S - 0.1, \]

where

- \( D \) = Optimum moisture content by weight, and
- \( S \) = Percentage of silt by weight.

Both the above formulae do not apply to the predominantly clayey soils (80 per cent or more clay) and also to what may be called neutral soils where no single constituent predominates.
Generally tests are made in the laboratory to determine the relationship between the moisture content and the dry-bulk density. From the data obtained from these tests, the maximum obtainable density, optimum moisture content and the range of moisture content which will cause only very small variation, and resultant dry-bulk densities are worked out.

The dry-bulk densities to be aimed at in the field should not be less than 90 per cent of the densities worked out in the laboratory.

For big embankments, the best and the efficient course is to have a test-run where actual experiments on the field-scale with the comparison units are performed and the correct optimum moisture, the maximum density attainable with the equipment and the number of passes necessary are worked out. It is advisable to keep the moisture content a little, say 1 to 2 per cent, on the dry side of the theoretical optimum as determined in the laboratory.

In the case of compaction of the pervious material, it is necessary to practically saturate the material just before rolling, as that gives the best results.

### Rolling Equipment

36.5 The selection of the type of construction equipment should be made after the desired density of the compacted fill has been determined. Rollers of the sheep foot type are superior to the flat wheel type, because each sheep foot penetrates into the layer underneath and gives it effective compaction. It exerts greater unit pressure and also keeps the top surface reasonably roughened to enable the next layer to have a proper contact and bond with the previous one. With the modern crawler type tractors, it is possible to use the heavier type of such rollers. The number and degree of tamplings can be controlled by using the drums in single, double or triple units or tandem combination. Pressures as high as 200 lbs per square inch can easily be attained with such rollers.

The sheep-foot rollers designed in the Government Central Workshops, Amritsar, and conforming to the following
COMPACTATION

specifications have been found very useful for compaction work:

(i) Weight of the single drum sheep-foot roller unloaded ... 3\frac{1}{2} ton

(ii) Weight when loaded ... 14 ton

(iii) Length of the single drum sheep-foot roller without frame ... 4'-3"

(iv) Diameter of the sheep-foot roller up to the base of the teeth ... 4'-8"

(v) Height of the teeth ... 9"

NUMBER OF ROLLINGS NECESSARY

36.6 After fixing the moisture content and the size of the compacting device, the problem resolves itself into finding the number of rollings which must be given in order to arrive at a particular dry-bulk density. This can be determined by experiments in the field after laying 6" layer of soil at optimum moisture on a test track. Rollings are given by a sheep-foot roller, driven by a tractor, and having an intensity of pressure of about 110 lbs per square inch. The dry bulk density is determined at various intervals of rollings. Enough water is sprinkled during the process of compaction so as to compensate for the loss of moisture content due to evaporation. The results obtained for a typical soil are embodied below:

<table>
<thead>
<tr>
<th>Number of rollings</th>
<th>Per cent moisture</th>
<th>D. B. D. obtained in Grams/C.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>13.0</td>
<td>1.38</td>
</tr>
<tr>
<td>1</td>
<td>13.5</td>
<td>1.34</td>
</tr>
<tr>
<td>3</td>
<td>13.7</td>
<td>1.32</td>
</tr>
<tr>
<td>5</td>
<td>14.0</td>
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<tr>
<td>10</td>
<td>14.0</td>
<td>1.17</td>
</tr>
<tr>
<td>15</td>
<td>13.5</td>
<td>1.09</td>
</tr>
<tr>
<td>20</td>
<td>13.7</td>
<td>1.02</td>
</tr>
<tr>
<td>30</td>
<td>13.8</td>
<td>1.05</td>
</tr>
</tbody>
</table>
The field experiment with the above results disclosed, that ten rollings were required to achieve about 90 per cent of the laboratory density for the typical heavy soil. Further rollings do not produce any appreciable improvement in the resultant density.

As a result of number of field experiments, it has been found that clayey soils require comparatively greater number of rollings to compact them to the desired density than the sandy soils.

DAnger of Over-Rolling

The rolling equipment these days are so heavy and unit pressures obtainable are so high that it is possible to over compact the impervious embankment of an earth dam. In particular, the travel of the heavy hauling equipment over a cohesive embankment, such as one high in clay, should not be allowed to follow established ruts but should be spread out over a wide area.

In order to avoid over-rolling of cohesive material with possible shear failure, one should—

(i) keep the soil material slightly on the dry side of optimum moisture content;

(ii) make frequent tests to determine dry unit weight, so that rolling beyond the point which will give the desired unit weight, is avoided;

(iii) watch the action of the roller on the embankment. Excessive weaving of the embankment under equipment is generally indicative of excess moisture and possible trouble;

(iv) require the heavy hauling equipment to follow diverse routes across the impervious section and avoid continually tracking in the ruts formed by prior passage of equipment.

Observation of D. B. D. in the Field

A simple method of measuring the dry-bulk density is given below:

An iron box in the form of an inverted wedge 6" square at the base and 6' high with two wooden strips attached on
COMPACTION

the open side is used. The surface of the compacted soil should be cut away to give as accurate a flat level as possible and the soil specimen removed with sharp in the shape of a wedge so that the volume excavated is slightly larger than that of the box mentioned above.

The box is then lowered in the hole with the two wooden strips on the top resting on the sides of the hole. The space between the box and the sides at the hole should then be filled with dry sand, from a graduated cylinder so that its volume can be ascertained. The volume of the hole would thus be the volume of the box, which is already known plus that of the sand as measured by the graduated cylinder. The cylinder containing the sand as well as the wedge should be well vibrated so that the degree of compactions attained in the two cases is the same. The whole of the specimen should then be carefully dried and weighed, and the density (which would be the weight in grams over the volume in cel) calculated.

In a shingle soil with cobbles up to 8", the volume of the whole specimen should be measured as above and the sample should then be passed through a 1 mesh screen to separate the oversize stones, and their volume measured in a graduated cylinder partly filled with water. The volume of the specimen which passes the screen would thus be the volume as measured above, minus the volume of oversize cobbles, and this should then be carefully dried and weighed and density calculated as above.

FIELD SPECIFICATIONS FOR COMPACTION

36-9 (i) Before starting compaction, samples of soils should be taken 1,000 feet apart or nearer, as the case may be, all along the canal or embankment and maximum density and optimum moisture for each reach determined in the laboratory. The dry-bulk density at site should be about 90 per cent of the laboratory dry-bulk density.

(ii) The earth to be used for compaction should be free from grass, shrubs or other organic materials.

(iii) Soils that are poorly graded and lack wholly in fine particles should not be used for compaction. Soils with very high clay contents, say 25 per cent or above, are not suitable for compaction.
The soils in the proposed borrow-pits should receive the proper moisture content well in advance of the time that they are to be placed in the embankment. The moisture content available originally in the soil should be taken into account when adding further moisture.

The earth should be placed in continuous approximately horizontal layers not more than \( \theta \) inches in thickness, in case compaction is to be done with the help of heavy equipment and \( \theta \) inch in case it is to be done with the help of light equipment pulled by bullocks, etc. In the rainy season, the layers should be sloped away from the centre of the dam. This slope should be from 1 in 20 to 1 in 30, enough to shed water readily. This is particularly necessary when the soil to be compacted has a considerable percentage of clay. If the slopes are kept as suggested above, the water drains off rainy days and permits the work to be started quickly. On the other hand, embankments which are allowed to slope towards the centre line get so wet and mixed up from even a little rain, that the pool thus formed has to be ditched and drained away and several days are lost before embankment operations can be resumed.

Places where the roller cannot reach such as behind abutments, wings, etc., should be tamped in thin layers with compressed air tampers to a density equal to that obtained from rolling.

The combined excavation and placing operations should be such that the materials when compacted should get blended reasonably to give the best practicable degree of compaction, stability, and impermeability.

The distribution and gradation of materials throughout the earthfill should be uniform so that there are no pockets, lumps or layers of materials differing substantially in texture or gradation from the surrounding materials.

Stone, gravel or kankar of a size bigger than \( \theta \)\( \text{in} \) should not be allowed to be dumped in the earth fills. The total percentage of such gravel or kankar should not exceed 20 per cent of the embankment and should be uniformly distributed.
The soil should arrive at the embankment site with the proper moisture content. Any further addition required to correct conditions of higher evaporation, particularly during summer season, should be sprayed at the site of the earthfill. The moisture content of the soil should be frequently checked by the Research staff and deficit should be made up, if required.

On the canal embankments, usually a dry-bulk density of 1.8 to 1.9 is found suitable. As a ready rule, about one gallon of water is sufficient for 1 c.f.t. of soil to attain the optimum moisture, where the initial moisture content in the soil is of the order of 5 per cent.

Generally a 14 ton cylindrical steel sheep-foot roller having teeth 7" to 9" high in staggered position is found suitable for compaction of the canal embankment. Double-drum, or tandem combinations as per requirements can also be used for increased progress.

The rollers are generally driven by crawler type tractors. The intensity of pressure that such rollers give is between 100 lbs. to 125 lbs. per square inch. The intensity can be increased where necessary by addition of sand or water in the hollow steel rollers.

The use of dry clods for compaction is strictly prohibited because they eventually can completely break and can be brought to optimum moisture. It is for this purpose that soils with high clay percentage are to be avoided.

To have proper bonds between the layers, it is essential to sprinkle water lightly on the first layer after the compaction has been completed.

In compacting the banks of the canal to be lined, it is essential to have about 3' of additional compaction on the lining side of the canal. The observations of dry-bulk density must be taken 3" from the compacted core of the embankment. If this is done, it will be ensured that by cutting 3' of extra width, thoroughly compacted portion is obtained for the subgrade on which the lining is to rest.
36.9— MANUAL OF IRRIGATION PRACTICE

(xiii) In the case of lined channels, the 'mishra' of the excavation or filling of the embankment must be given with a Thedolite. If this is not done, it is generally found that the alignment of the canal is not properly done with the result that many a time the lining comes in the fill thereby requiring superficial and slip-shod compaction being done in small widths and leading to damage to the lining when the water runs.

(xiv) If some period is to elapse between the main excavation and lining, excavation to full section should never be done, as during the rains, the rain cuts go below the subgrade. At the time of start of lining such rain cut sites are never compacted properly, with the result that when the canal runs, there are damages to the lining at such sites.

It is important, therefore, that in the cutting reaches of the canal, if the lining cannot be started immediately after the excavation, 3' to 4' cover must be left to be removed immediately before the start of work of lining.

(xv) When cutting finally the slopes for start of lining, great care should be taken that the cutting and dressing of subgrade is strictly to correct lines. Any slight overcutting should be better filled with extra concrete rather than with uncompacted earth.

(xvi) Sometimes the slopes of earthen dams are left without being trimmed to the neat lines of the upstream and downstream faces as designed. To leave a mass of material on either face at an incline steeper than that at which it will safely stand after the dam is placed in service is very dangerous procedure, as it leaves a superimposed load on the face of the dam and may later on lead to serious slips. It is most essential that all slopes should be trimmed properly according to the designed lines.
## CHAPTER 37
LINING OF CHANNELS

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CHAPTER 37
LINING OF CHANNELS

INTRODUCTION

37.0. Although the Punjab is served at present by an extensive network of canals, additional water is needed for reclamation of their areas and for extension of irrigation operations, and one of the main sources that can be tapped is the water set free by the saving in absorption losses, obtained by the "lining" of channels.

Lining of channels can be conveniently carried out to any extent desired, and the return on money spent on it will be immediate and proportionate to the expenditure.

The most profitable schemes or those where the maximum benefit to waterlogged areas can be expected may be taken up first.

ADVANTAGES OF LINING

37.1. The main advantages of lining are:

(a) The saving in water other wise lost by absorption which can be used for extension of irrigation or increasing the water supply in areas already irrigated.

(b) The reduction in seepage from the canals reaching the water table and raising it, thus avoiding waterlogging and retarding the deterioration of land by thur.

In this connection, it may be observed that waterlogging generally can be dealt with at small cost, by drainage. The important question, however, is whether a high water-table expedites the damage done by the formation of thur or not, and on this opinion differ. If it can be demonstrated that the sub-soil water is appreciably responsible for thur formation, then the very considerable areas of high water-table indicate the possibility of great benefit resulting, could be water-table be lowered by lining.

(c) The improvement of command owing to the flatter slopes possible. A lined channel can be designed to a very flat slope with a normal value of "Y". It may be noted that it is generally desirable to keep as steep a slope as possible, as this results in high velocities with a proportionate saving in cross-sectional area and land width with corresponding savings in excavation and cost of bridges.

*Based on Irrigation Branch Paper No. 13, Class "A" by K.K.S.L. Habib, I.E.E
37.21  MANUAL OF IRRIGATION PRACTICE

(d) The stability of section, which in the case of distributaries should reduce remodelling and alteration of outlets.

(e) Reduction in maintenance costs.

This reduction would be substantial only if the cost of maintenance of the lining itself is negligible.

DESIGN OF LINED CHANNELS

37.21. The Principal factors which have to be considered in deciding the suitability of any design are:

(a) Permeability, i.e., reduction in absorption losses. Generally speaking any suitable form of concrete or brick lining would reduce these losses appreciably.

(b) Co-efficient of rugosity, which will determine the carrying capacity of the channel.

(c) Durbility.—This may be described as the resistance to weathering, chemical attack and wearing by the flow of water.

(d) Cost, both initial as well as subsequent maintenance. This would vary with the locality and the availability of various materials.

(e) Structural stability.—The following factors may be considered under this head.

(f) Reinforcement.—This is designed to reduce the size of contraction cracks and to assist in preventing failure of the lining due to settling of the sub-grade or to back pressure from a saturated sub-grade.

On the other hand, this may delay relief being obtained by local failure in small patches, in case of heading up of water pressure, thus causing extensive damage.

(ii) Thickness of lining.—In the worst condition, the lining is subject to pressure due to saturated soil and the differential water head across it. Lining of 6" to 9" thickness can, however, withstand only a slight different of hydrostatic pressure on the two sides. This clearly indicates the importance of proper drainage to keep the difference of hydrostatic pressure across the lining, as low as possible.
Lining of Channels

(iii) Strength of lining.—The compressive strength is not of much importance if the materials used are such that they do not deteriorate in the course of time.

(iv) Earth backing.—To avoid any subsequent settlement the lining should only be placed on undisturbed material or thoroughly compacted back-fill.

37.22. For the various types of lining the reader is referred to irrigation type at Branch Paper No. A-33. The two main types which have been successfully tried in this province so far are concrete and brick lining on the Gang and Havell canals respectively.

Experiments to determine the best from of lining are at present in Progress. If it is proposed to use brick-lining, then for distributaries with discharges up to 500 cubic, one layer of 10” bricks laid flat over 3/8” thick, 1:3 plaster on top of another 1/2 layer of 1:5 plaster will suffice. For channels with higher discharges, however, two layers of flat bricks separated by 3/8” thickness of 1:3 plaster should be provided, the lower layer to be laid on 1/4” of thickness 1:6 plaster.

37.23. The best form of lining section would seem to be an arc having sloping sides, more or less at the same slope as the angle of repose of the soil. The arc in the bed should be tangential to the side slopes. It can be easily shown that this gives the most economical section, i.e., the maximum area for the minimum wetted perimeter, if the centre of the arc is at the F.S., Line.

This section is also useful because it has a higher silt carrying capacity than one with a horizontal bed, based on Lacey’s

\[ Y = 0.75 \]

During low supplies, heading up may have to be done at off-take site, which would cause some silting. This in turn reduces the velocity and also the value of \( Y \). In the section proposed, however, with no level bed, the silt can deposition and affect the roughness coefficient of a relatively small portion of the perimeter and hence cannot greatly affect the velocities. The effect on \( Y \) also would thus be correspondingly less.

The side slopes may be designed at a slope of 1:1 for radii less than 12’ and 1:1.5 for radii over 12’, provided the angle of repose of the soil is not flatter than 30°, as shown below.
The sectional data would be given by the following formula:

\[ \text{Side slopes} \quad \frac{1}{1} : 1 \]
\[ \text{Sectional area} \quad 1.78 \, r^2 \quad 1.925 \, r^2 \]
\[ \text{Wetted perimeter} \quad 3.56 \, r \quad 3.85 \, r \]
\[ \text{Hydraulic mean radius} (R) \quad 0.5 \, r \quad 0.5 \, r \]

The mean velocity \( V \), according to lacey’s formula is

\[ \frac{1.3458}{N_{d}} R^{\frac{2}{3}} S^{\frac{1}{3}} \] —— side paragraph 5.44 of this manual.

Manning’s formula for mean velocity, viz.,

\[ V = \frac{1.4858}{N_{i}} R^{\frac{2}{3}} S^{\frac{1}{3}} \]

is also sometimes used for calculating the mean velocity.

Where \( S_i \) is the fall in 10,000

With \( N = 0.018 \) we have

\[ V = 0.826 \, R^{\frac{2}{3}} S_i^{\frac{1}{3}} \]

Discharge = \( AV \times 0.92 \, r^{2\frac{2}{3}} S_i^{\frac{1}{3}} \) for side slopes \( 1 : 1 \)

And = \( 0.92 \, r^{2\frac{2}{3}} S_i^{\frac{1}{3}} \) for side slopes \( 1\frac{1}{2} : 1 \)

Lacey’s \( f = 0.75 \, V^{2} \quad = 0.40 \, R^{\frac{2}{3}} S_i \)

Graphs connecting \( Q, S, r, f \) and \( V \) for side slopes \( 1 : 1 \) and \( 1\frac{1}{2} : 1 \) with \( N = 0.018 \) are given in Irrigation Branch Paper No. A-33.

The free board generally allowed, varies from 1 foot to 2 feet and may be expressed in terms of \( r \) the radius as \( 0.5r = 0.5 \) so that when \( r = 4 \) ft., the free board is 1 ft., and when \( r = 16 \) ft., the freeboard is 2 feet.

37.24. The limiting depth of the section evolved above for all practical purposes may be taken as 15\({}^{\prime}\) and so far discharges exceeding say 2,000 suces, an alternative type as shown below may be adopted—
In this, the sectional data is given by the following formulae:—

Where $K = \frac{b}{d^3}$, $C = \frac{R}{d}$, and $N$ (Manning) = 0.018

Side slopes $= 1 : 1$

Sectional Area $= d^2 (K + 1.785)$

Wetted perimeter $= d (K + 3.571)$

Velocity $= 0.926 R^{\frac{3}{2}} S_1^{\frac{1}{2}}$

Discharge $= (K + 1.785) 0.826 (K + 1.926) 0.826 c^\frac{5}{2} d^{2\frac{3}{2}}$

Lacey’s $f = 0.75 \frac{V^2}{R}$

$C = \frac{K}{R + 1.785}$

$C = \frac{K}{R + 1.925}$

$C = \frac{K}{R + 3.571}$

$C = \frac{K}{R + 3.850}$

Graphs with $N = 0.018$ for side slopes 1 : 1 and 1.5 : 1 correlating the various data given in irrigation branch Paper No. A-33 and will be found useful in designing any section.

This section is better than a trapezoidal section, as it is more stable and economical and also does away with the need of having a toe wall to support the sides.

The slope may be kept the steepest practicable, subject to a maximum velocity of 6 ft per second and a minimum value of “1” = 1.2.

CONSTRUCTION

37.31. The banks against which the lining has to rest should be rolled in 6” layers at optimum moisture content as prescribed in Chapter 36. This moisture content should be determined beforehand in the laboratory after analyzing the soil. Samples should be taken 100 feet apart or closer if the soil constituents differ appreciably.

As it is not possible to roll the ends properly, an extra width of 1½ feet on the inner side should also be compacted. The excess width of imperfectly compacted earth can then be removed before lining.

The density of the finished bank should be checked, measuring it in one sample from approximately every 3,000 c. feet bank.

37.32. The sub-grade should be thoroughly moistened to avoid its absorption moisture from the adjoining mortar or concrete which would make it spongy and permeable. According to the bureau
of Reclamation, U.S.A. the proper moisture penetration is 12" in sandy soil and 6" in other soils except when this much moisture causes the sub-grade to become muddy.

Other alternatives are:

(a) Use of oil paper.
(b) spreading of any crude oil.
(c) A 1 : 5 cement plaster on the sub-grade.
(d) Spreading 1/8" layer of 1 : 4 cement sand slurry couple of hours before laying the mortar or placing the concrete

37.33. Detailed specifications for brick lining are contained in Irrigation Branch Paper No. 33, Class A. The following are the main precautions which should be observed:

(i) The earth to be used in the manufacture of bricks should not have a salt content above 0.3 per cent and the quantity of calcium carbonate should not exceed 2 per cent. Clay content should range from 10 per cent to 20 per cent.

(ii) Great care should be observed in the moulding and burning of bricks. No Pila bricks should be allowed to be used in any circumstance.

(iii) The bricks should be thoroughly soaked before use. This is important as bricks which absorb water quickly, lose it as quickly when taken out of water. Each mason should thus be provided with a kerosene oil tin of water in which the immediate requirements of bricks can be kept.

(iv) Sand should have a fineness modulus of not less than 1.2, and should be free from organic impurities. The percentage volume of silt in it should not exceed 6 per cent.

(v) The consistency of mortar should be properly regulated by slump tests. The masons should never be allowed to mix water in the mortar pan at site.

(vi) The plaster should be allowed to set properly for about two days before laying the masonry on top.

(vii) The sub-grade should be properly moistened or wetted to avoid absorption of water from the bottom layer of masonry or plaster.
LINING OF CHANNELS

37.34. The consistency of concrete used in lining is a very important factor. The United States Bureau specifications for canal lining lay down that this consistency is critical. The concrete must be fluid enough to compact well, especially under the reinforcement and yet stiff enough to stay in place on the slopes. The slump must be carefully regulated. If it is too low, honey-comb is difficult to avoid and if it is too high, a bulging or wavy concrete surface may be produced. A properly designed mix, using well graded aggregate containing enough of the fine strips to allow adequate finishing but not so much as to cause crazing of the finished surface, is necessary for satisfactory canal lining.

The concrete should be laid in compartments limited in size to 20 feet by 20 feet or 15 feet by 20 feet. Alternate blocks should be laid. Preferably an interval of 7 days should be followed, so that the setting contraction may take place. Alternatively, strips 5 feet wide may be left around the blocks and these strips may be concrete after a week.

"The concrete can be levelled and compacted by means of heavy "screeds or tampers fitted with handles." The weight of the tampers should not be less than 7 lbs. per lineal foot. These should not be less than 3' wide and should have "thick flap iron fixed on their bottom surface. These can then be floated with a flat board 18 feet long and about 8 inches wide. The concrete in the bed can also be rolled if necessary by light rollers weighing 10 to 12 lbs. per feet run.

A butt joint ½ wide underlaid by a 1:4:8 concrete sleeper one foot wide and of the same thickness as the lining should be provided between adjacent blocks.

37.35. For canals and branches it will generally be advisable to construct a new lined channel alongside the old one, as lining of the old channels cannot be carried out without interrupting irrigation supplies.

Concrete Manual by U.S. Bureau of Reclamation
37.41. **MANUAL OF IRRIGATION PRACTICE**

**FINANCIAL FORECAST**

37.41. The revenue may be based on the divisional contract supply.

In cases where the supplies can be allotted to new areas, the direct receipts can be estimated by the usual method based on designed intensity, average water rate and working expenses. In the case of crown waste areas, indirect receipts may be taken as Rs 8 per season per acre of the area served, if more accurate figures are not available.

Assuming the average value of a case of capacity Rs 600 in Kharif and Rs 550 in rabi and allowing interest per cent on the sale proceeds of crown land at Rs 200 per acre, the expenditure that would be justified per case of capacity with a 75 per cent intensity and a khairif full supply factor of 8, would be approximately as follows for various conditions:

<table>
<thead>
<tr>
<th>Waste Saved Utilised</th>
<th>Waste Saved Utilised</th>
<th>Waste Saved Utilised</th>
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<tbody>
<tr>
<td>Waste Lands Given on</td>
<td>Waste Lands Which Are</td>
<td>Areas Already Receiving Irrigation</td>
</tr>
<tr>
<td>Temporary Cultivation</td>
<td>Sold</td>
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<tr>
<th>Expenditure Incurred to Effect Saving</th>
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<th>Expenditure Incurred to Effect Saving</th>
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<td>2,20,000</td>
<td>3</td>
<td>1,50,000</td>
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<td>50,000</td>
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</tr>
<tr>
<td>1,60,000</td>
<td>4</td>
<td>1,15,000</td>
<td>4</td>
<td>45,000</td>
<td>4</td>
</tr>
<tr>
<td>1,35,000</td>
<td>5</td>
<td>92,000</td>
<td>5</td>
<td>36,000</td>
<td>5</td>
</tr>
<tr>
<td>1,20,000</td>
<td>6</td>
<td>77,000</td>
<td>6</td>
<td>30,000</td>
<td>6</td>
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</tbody>
</table>

37.42. The absorption in an unlined channel may be evaluated approximately as under:\[QA = 0.0133 \times L \times Q^{0.5625}\]

Where L is the length of channel in thousand feet.

The rate of absorption in the lined channel may be assumed as 1.25Q 0.065 per million square feet.

Where \(Q_A\) is the loss in absorption in cusees.

L is the length of channel in thousand feet and Q is the discharge of the channel in cusees.

Distributable savings may be taken in full but canal savings should be reduced by 20 per cent to allow for distributary absorption thereon to obtain the effect at outlet.
CHAPTER XLI

RATES

41.1. To facilitate the preparation of estimates, etc., a Common Schedule of Rates applicable to all Branches of P.W.D. has been prepared and published. A copy of this Schedule should be kept in each Division and Circle Office and the Schedule should be kept up to date in accordance with the amendments and modifications made from time to time. This Schedule provides rates for various items of work commonly executed by the Departments. The rates entered in the estimates should normally be in accordance with this Schedule. In case, however, where for any reasons these are not considered sufficient, or in excess, a detailed statement must be given in the report showing the manner in which the rates used in the estimate are arrived at.

Rates cannot be absolutely uniform throughout the State for non-schedule items as these depend upon the nature of work, labour-wages, the availability of labor, material and the local conditions. These factors vary from district to district and therefore, the rates will also vary. Therefore the authorities competent to accord sanction of such rates should keep all these factors in view while determining rates for non-schedule items.

There can always be variations in the market prices of materials and the wages of labour can also fluctuate with time and with locality. The common Schedule of Rates, will, therefore, work with either premium or abatement depending upon the working conditions and the locality. The power to fix abatement or premium over the common Schedule of Rates for a particular Zone will vest in the Committee of Superintending Engineers of various Branches of P.W.D. nominated as Members of that Zone.

41.2. Works in the Irrigation Department are commonly carried out as 'Piece work' the agreements for which should be in the form of 'work order' on Irrigation Branch I.B. Standard Form No. 9. Such agreements are not contracts and should contain only a description of the work to be done and the rates to be paid for it, without any reference to the total quantity to be executed or to the time within which it is to be executed.

(a) Specification of the work may be issued with the work order but must contain no reference to quantity or time.

(b) When on large construction works a general rate for a certain class of work has been fixed by higher authority, Divisional Officers may permit their Sub-Divisional Officers to issue work orders for that class of work at the rates fixed without reference to the probable amount of the resulting payments.
(e) In order to ensure that the rates given in work orders are current rates, Superintending Engineers should order that tenders be publicly called for rates for specific works from time to time and at least once annually in each Circle.

(e) Sub-Divisional Officers giving out work likely to result in payment exceeding Rs. 250 should issue a work order before the work is commenced. No work order need be issued for a work likely to result in a payment of Rs. 250 or under.

41.3 The recognised systems of carrying out work, otherwise than by the employment of daily labour, are 'piece work' and 'Contract work'. For explanation of the term 'piece work' see paragraph 279 of the P.W.D. Code.

The term 'Contract' as used in the P.W.D. Code, does not include agreements for the execution of work by piece work (see para 279 of P.W.D. Code) nor does it include mere ordinary purchases of materials or stores. All other work done under agreement is termed 'contract work' and in the agreements for such works, which should invariably be in writing, there should generally be a stipulation as to the quantity of work to be done, and the time within which it is to be completed.

In the absence of any specific instructions, Superintending Engineers, Irrigation Branch, are empowered to order the execution of works by contract or by work order as may appear, in the circumstances of the case, most suitable. 'Contract' may be of three kinds, viz. "lumpsum", 'Scheduled' or a combination of these two.

In a 'lumpsum' contract the contractor engages to execute the work with all its contingencies for a fixed sum.

"Scheduled" contracts are those in which the contractor undertakes to execute the work at fixed rates, the sum he is to receive depending on the quantities and kind or work done or material supplied.

The third kind contract is a combination of both these. Thus a fixed sum is proposed for the completion of the work as specified and a schedule of rates is agreed upon by which to regulate the price to be paid or to be deducted for additions or alterations.

41.4 There are generally two methods of getting the work done from the contracting agencies i.e.

(a) On through rate basis.

Through rates will be worked out for each individual estimate, for all items of work given therein on the basis of actual carriage involved, labour rates to be paid and the cost of the material to be supplied by
41.5 Rates

the Department/Contractor. The labour rates include all handling of materials at the site of work and no payment is due to the contractors on this account. The through rates also include the wastage or breakage of various materials during construction. The cost of all materials which have to be arranged by the contractor should include carriage to site of work and also all Octroi Charges, Toll Tax, Sales Tax and other local taxes, etc., to be paid by him. Labour rates also include the cost of water, tools and plants, labour and material for scaffolding and cost of good earth for mad mortar, wherever required.

Whenever work is to be executed on Piece work basis the estimate should be framed as per premium/abatement fixed for the Zone according to rates provided in the Common Schedule of Rates and as modified from time to time.

41.5. The labour rates for various items of work include handling of materials within three chains. The labour rates include the cost of water, tools and plants, labour and material for scaffolding and cost of good earth for mad mortar, wherever required.

(1) Daily Wages

41.6 Daily wages of labour should be governed according to provision in Chapter 1 of the Common Schedule of Rates. If the prevailing rates in a certain locality are lower than the rates provided in the Schedule, the Executive Engineer will authorize employment at the prevalent rates and not at the scheduled rates. On the other hand, if in a certain locality, prevailing conditions necessitate payment at higher rates, the Superintending Engineer can increase the rates suitably up to a maximum of 50% above the schedule rates. This increase in rates shall be for a specified period not exceeding six months after which the rates shall be reviewed and revised.

Charges for labour should be carefully scrutinized, and the head 'daily labour' should not include charges of any other kind. However trifling, the Divisional Officer and the Sub-Divisional Officer should devote special attention to this subject as expenditure on daily labour paid against a muster roll is not supported by ordinary vouchers or receipts for payment.

(2) The payment of daily labour through a contractor instead of by muster roll is objectionable in principle, but if in case of emergency, it be found necessary to employ daily labour through a contractor, the Subordinate incharge must submit to the Sub-Divisional Officer a daily report in LB Standard Form No. A 24 detailing the number of men
employed through each contractor or daily labour. These reports will be
retained by the Sub-Divisional Officer and will form the basis of the
payment made to the contractor.

(3) When daily labour is paid through a contractor, the labour
reports should be headed 'labour supplied by—contractor'. To
avoid disputes with the contractors, they should be encouraged to sign
the daily reports in token of their acceptance as correct.

(ii) Monthly wages

All classes of work-charged establishments engaged on monthly
wages shall be regulated in accordance with the provision made in Chapter
2 of the Common Schedule of Rates and as amended from time to
time.

41.7 (a) The supplies of all stores will normally be arranged
through the Controller of Stores. In other cases Tenders
shall be invited for supply of materials. In the case of
bricks and tiles, the rates for supply shall not be more than the control-
led rates fixed by the Deputy Commissioner of the respective districts.

(b) The rates for stone, buri, concrete, sand, etc., include royalty
and 'Malkana' and nothing extra is payable over and above the rates
for these items because in most of the cases the quantities for stone, buri,
sand, etc., are taken on lease by the quarrying contractors who pay the
royalty and malkana. Contractors do not operate the quarries themselves
but purchase the materials as a finished product from quarrying contractors
and they cannot be expected to produce receipts for royalty etc. although
the same has been included in the rate charged by the quarrying
contractors.

41.8 There are two classes of rates for—

(i) Special quality paints, and
(ii) Ordinary quality paints.

The special quality paints will be those which have been approved
as such by the Chief Engineer.

Measurement and Stacking of Stone Boulders and
Coarse Aggregate

41.9 (i) The following specifications shall be adhered to in respect
of stacking and measurements of boulders and coarse
aggregate for concrete,
41.10 RATES

(a) BOULDERS

The boulders shall be stacked compactly on level ground in stacks not more than 3 ft (0.9 metre) in the height or such other height as may be prescribed by the Executive Engineer. The actual dimensions of stacks shall be measured and the total quantity reduced by 1/7th to arrive at the net quantity for payment.

(b) To allow for loose stacking, all stacks of coarse aggregate of nominal sizes more than 3/4 in. (20 mm.) but up to 3 in. (75 mm.) shall be measured and paid as 12 inches for every 13 inches height. In metric units, 27 cm. high stacks shall be measured as 25 cm.

No deductions be made in case of aggregate of nominal size of 3/4 inch (20 mm.) or less.

In this connection reference is invited to the relevant specifications of materials given in Chapter No. 3 of the Punjab P. W. D. Specifications, 1963.

(ii) When slack coal is received, it should be weighed wherever weigh-bridges are available. Where no weigh-bridges are available, it should be measured in stacks at the receiving station and converted into tons on the basis of weight given in the railway receipt. If the measurement is made in open stacks, the conversion factor would vary between 39 to 42 cubic feet to the ton depending on its grade.

41.10: The rates for loading and unloading of materials shall be regulated in accordance with the instructions given in separate explanatory memo to Chapter 4 of the Common Schedule of Rates (1962).

41.11. (a) The rates for carriage shall be regulated in accordance with the provision in Chapter 5 of the Common Schedule of Rates and Explanatory memo thereto. The rates for carriage should include the labour for loading, unloading and stacking for the purposes of measurements. Where material is unloaded from wagons and then carried, separate payment shall be made for unloading the material from wagons. Provision for extra payment of 25% over and above the basic rates of the mile concerned be made for carriage of materials on river/choke beds.

(b) While making measurements of materials and stacking of stone boulders and coarse aggregate the following specifications shall be adhered
to in respect of stacking and measurements of boulders and coarse aggregate for concrete:

(i) Boulders

The boulders shall be stacked compactly on level ground in stacks not more than 3 ft. (0.9 metre) in height or such other height as may be prescribed by the Executive Engineer. The actual dimension of stacks shall be measured and the total quantity reduced by 1/10th to arrive at the net quantity of payment.

(ii) Coarse Aggregate.

To allow for loose stacking, all stacks of coarse aggregate of nominal sizes more than 2 in. (20 mm.) but up to 3 in. (75 mm.) shall be measured and paid as 12 inches for every 13 inches height. In metre units 27 cm. high stacks shall be measured as 25 cm.

No deduction be made in case of aggregate of nominal size of 2 inch (20 mm) or less.

41.12. (a) The basic rate has been fixed for soils having dry bulk density up to 1.6. For dry bulk density higher than 1.6, additional rates will be paid as per provision in Chapter 6 of Common Schedule of Rates. Hardness allowance shall be paid with the approval of Superintending Engineer. For dry bulk density more than 1.8, notable rates shall be fixed by the Superintending Engineer which shall not exceed Rs. 85% of the basic rate.

(b) Where rehandling of recently deposited earthwork and gravel work is done, payment shall be made at the normal rates of earthwork reduced by 20%. Earthwork which is deposited before monsoon season and which has had the full monsoon on it, will be considered as normal earthwork in execution and paid for at full rates.

CONVERTING LIFT INTO HORIZONTAL LEAD

For converting lift into horizontal lead, the lift up to 12 feet will be multiplied by 10 and from above 12 feet to 20 feet, it will be multiplied by 20. No crosses whatever shall be measured and paid for.

Measurement of Lift.—The lift shall be measured from the centre of gravity of the excavated earth to that of placed earth. This shall constitute the mean lift for that section. When earth has to be carried over a spoil bank and dumped beyond it, the mean lift would be the difference in level between the centre of gravity of the excavated earth and top of the spoil bank omitting the dwell.

41.13. The method of measurement of lift and converting lift into a horizontal lead is the same as for earthwork. The definition of various types of rock cutting be made as per prescribed specifications before applying the rate for any item.
41.14 \textbf{RATES}

41.14. Where stone pitching or stone bajri filling, etc. has to be dismantled while under water, rates in the schedule may be increased by 60%.

41.15. The rates for courting and shuttering are considered to be for a normal storey of 13 ft. (4 metres). Wherever any storey height exceeds 13 ft. (4 metres) the rates for courting and shuttering will be increased as per note given in Chapter 9 of Common Schedule of rates.

41.16. It has been established from practical observations that vibrated concrete consumes greater quantity of materials specially cement due to greater density. Vibrated concrete therefore, costs more than ordinary concrete. An increase of Rs. 10/- per 100 cft. on through rates may be provided for chemical vibration.

41.17. In case of building work, it is easy to define the work in foundations and plinth but in case of engineering works and also in case of boundary walls there is no plinth level. It is therefore, necessary that in such cases the rates for brick work up to 4½ ft. (1.3 metres) above the top of foundations concrete should be considered as work in foundation and plinth.

41.18. The storey height for stone work in superstructure should be kept as 20 ft. in case of ashlar masonry and 13 ft. in case of other types of masonry. In case of Ashlar and block in concrete masonry, no rate need be provided for work in foundations and plinth as this type of work is normally done in superstructure. If need be, rates for foundation and plinth can be worked out by reducing the rates for superstructure by Rs. 10/- per 100 cft.

41.19. For bridge girders having spans more than 50 ft. special rates will be worked out and paid for on the merits of each case.

41.20. The rates for plastering a wall and ceiling should be for storey heights of 13 ft. (4 metres) whether in first storey or in subsequent storeys. Where any single storey height exceeds 13 ft. the labour and through rates shall be increased by 25 Paise per 100 cft. of plaster for every additional height of 13 ft. or part thereof. Refer Explanatory memo to Chapter 15 of Common Schedule of Rates.

41.21. Painting work should be broadly classified according to the nature of surface to be painted, namely woodwork, metallic surface and plastered or concrete surfaces—separate rates should be provided for all these items of work.
41.22 (a) Wooden boundary gates shall be paid at the rates of roof trusses.

(b) Charges for fixing tower bolts to wire-gauge shutters whether of deodar, kail or teak wood are included in the rates as per departmental Schedule of Rates but the cost of labour for fixing springs is not included and has to be paid for separately.

(c) Where in case of glazed doors and windows of fixed glazing, frosted glass panes are used instead of ordinary panes, the through rate shall be increased by 10 Paise per sq.ft. of the actual area of frosted glass pane.

(d) Separate rates should be provided for fixing glass panes.

41.23 Labour rate for bigger size bars should be reduced because the work involved in bending, bending and placing in position is less for bigger diameter bars, weight for weight. The through rate is still lower because the bars of larger diameters are cheaper than those of small diameters. Refer to explanatory memo to Chapter 18 of Common Schedule of Rates.

41.24 After rip-cutting, the dressing of bed and preparation of sub-grade is to be done for which separate rates should be provided for the bed and sides.

41.25 For earthwork for dismantling open flumes, A.P.M. or O.S.M. outlets, rates should be given according to H of the outlet. Refer Explanatory Memo to Chapter No. 20 of Common Schedule of Rates.

41.26 No firm rates for this type of work can be adopted because the work varies according to the local conditions and the nature of the soil.

41.27 (a) In case of sandy soild where excavation cannot be restored to beyond 14 ft., dry sinking will have to be done. Therefore, separate rates for dry sinking of wells should be provided up to 45 ft., depth from ground level and beyond.

(b) In certain areas near the foot hills of the mountains, boulders are met with during well sinking. In such cases well sinking is likely to be more difficult and costlier. Special rates should be framed in such cases by Superintendent Engineer keeping in view the results of trial bores in all such cases.

41.28 No payment for making sakinda rolls should be made over and above the rates of these items as provided in the Common Schedule of Rates.
Separate labour rates should be provided for brick soling, stone soling, stone metal wearing coat, kerb or brick-ballast soling and wearing costs. Water allowance is payable where water is not available within half a mile of the nearest point of the mile and it is to be paid in slabs of half furlong/feet in excess of half a mile distance per mile of 12 feet wide road.

(b) Rates for surface painting should be provided separately for bitumen tar and for first coat, second coat and subsequent coats.

RATES

Rates for spirit or wax polishing of items like tables, sideboards, armchairs, book-shelves, etc., should be based on superficial area of top or front elevation. Other items like chair, peg tables, stands, etc., where there is no variation in the surface area, rates should be provided for each article of furniture without reference to surface area.

(A) JUNGLE CLEARANCE

The actual rates are to be fixed by the Executive Engineer according to local conditions and the amount of work involved. The work should normally be done through Departmental labour.

(B) WATER ALLOWANCE

Water allowance rates are payable only when water is not available locally and fixing of hand pumps at the site of work is not feasible nor possible and water is actually carried by cart or by mechanical transport from a lead greater than half mile, in case of plains and exceeding one furlong in hilly tracts.

Extra rates should be provided for disposal of surplus soil beyond one mile lead in case of water supply works inside the towns.

(a) Separate rates should be provided for painting of ventilating shafts, both for ordinary and special quality paints.

(b) In case of constructing brick or concrete sewers, the rates should be for 15 feet depth below ground level where depth is greater, additional rate is to be provided in slabs of 2 feet additional depth or part thereof.

Separate rates should be provided for different types of fittings, pipes, and specials, tects, bends, sockets, elbows, etc., of different sizes.

The rate of various materials for electric installations should invariably be based on the lowest quotations invited on detailed specifications.