# Technical considerations for design of Effective Drainage System in Station Yards

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**Synopsis**
*Absence of effective drainage system, to drain away the water coming to track formation, may not only lead to problem in maintenance of track but in case of station yards it may lead to track circuiting failures also. In many cases, it is observed that even after construction of a drainage system, the water does not get effectively drained way from the track formation. Therefore, design of an effective drainage system, taking into account all relevant technical considerations, is very important. In this Paper, various relevant technical parameters for effective yard drainage system have been listed out and a typical drainage arrangement has also been designed for a typical station yard with Four (4) tracks. The principles/approach given in the paper can be used for design of drainage system in any other station yard with different yard layout, where it has been decided to provide a drainage system in the yard.*

## 1. Introduction

The water coming to track from various sources (e.g. from rain, from water booths or from platform surface etc.) has to be drained away from the track formation because in absence of adequate drainage the track formation may become saturated leading to its' weakening, which manifesting itself in mud pumping and problem in maintaining line & level of track. In station yards, effective drainage system is necessary for proper working of track circuiting arrangements also.

## 2. Concept followed for design of drainage system

For existing yards as well as new yards being constructed, the yard layout, centre to centre distance between tracks and topography of the yard location vis-a-vis adjacent area varies from one yard to another yard. Thus, it may not be possible to exactly stipulate yard drainage system which can be used for all the yards. However, to serve as guidance, duly considering various relevant technical parameters for an effective yard drainage system, typical yard drainage arrangements have been worked out for a station yard with 4 lines (Two Main Lines and Two Loop Lines) which is very common in the double line sections. The concept followed in detailing these yard drainage arrangements is as follows:

(i) The water coming through track ballast, on top of the formation, will be collected in the longitudinal drain(s) between the tracks.

(ii) Along the length of the longitudinal drains, Chambers will be provided at the suitable locations, based on various relevant considerations.

(iii) The water will be drained out from these Chambers, by the cross drains, to suitable outfall arrangements.

Based on the above concept, the typical drainage system layouts for 4 line yards, with different yard line layouts, have been shown in Fig. 1A, Fig. 1B and Fig. 1C.

## 3. Provisions of various Standards/Codes/Guidelines

Provisions of various relevant Standards/Codes/Guidelines, for deciding the important design parameters of yard drainage system, are summarised as under:

### 3.1 Australian Rail Track Corporation (ARTC) Specification Nos. RTS-3432 of March'2006 (Track Drainage – Inspection and Maintenance) and RTS-3433 of June'2013 (Track Drainage – Design and Construction)

For Cess (Side) drains in cuttings:

(i) A Cess (side) drain should be constructed with minimum gradient of 1 in 200. Surface drains can be constructed at flatter grades, as they are easily cleared of any sediment which may collect in them.

(ii) The minimum distance between centre of drain to the gauge face of the nearest track shall be 1500mm. *This requirement is for Standard Gauge (1435mm), which when used for Broad Gauge (1676mm) will become 1741mm, say 1750mm.*

(iii) The minimum depth of drain invert level, from rail level, shall be 850mm.

### 3.2 Public Utilities Board (PUB) Singapore's "Code of Practice on Surface Water Drainage"

(i) The surface drains shall be designed as per Manning's Formula, as following:

$$Q = A \times (1/n) \times R^{0.67} \times S^{0.50}$$

Where, Q = Discharge capacity of drain (in $m^3/s$)
n = Roughness coefficient of drain surface
= 0.013 to 0.017 for Concrete (generally taken as 0.015)
A = Flow Area (in $m^2$)
P = Wetted Perimeter (in m)
R = A/P = Hydraulic Radius (in m)
S = Bed Gradient of Drain

In terms of Velocity of Flow (V), this equation is expressed as following:

$$V = Q/A = (1/n) \times R^{0.67} \times S^{0.50}$$

(ii) Velocity of flow in drain shall not be lower than 1.0 m/s, for self-cleansing action to take place.

To avoid excessive scouring or hydraulic jumps, the velocity of flow in a concrete lined drain shall be limited to 3.0 m/s or below the critical velocity, whichever is lower.

(iii) In case of flow in channels, when Froude Number is equal to 1 (One), it is called "Critical State of flow". In open channels, flow at or near the critical state shall be avoided as under such a condition, the water surface is unstable and wavy. To ensure greater flow efficiency, flow shall be so designed as sub-critical flow with the Froude number within the range of 0.8 decreasing to such value as to achieve a practical flow depth and permissible flow velocity.

Froude Number, $F = V / (g \times d)^{0.50}$

where, V = Flow velocity
g = Gravity
D = Hydraulic Depth (Cross sectional area of flow/top width)

(iv) Sufficient free board shall be provided to prevent waves or fluctuation of the water surface from over flowing the bank. Generally free board equal to 15% of depth of drain shall be provided.

3.3 IS:1742 – 1983 - "Indian Standard Code for Building Drainage"

Chambers shall be of such size as will allow necessary examinations or clearance of drains. The size of manholes shall be adjusted to take into account any increase in the no. of entries to the manhole. The minimum internal size of the chambers (between faces of masonary) shall be as follows:

| | |
|---|---|
| (a) For depths of 1m or less | 0.8m x 0.8m |
| (b) For depths between 1m and 1.5m | 1.2m x 0.9m |
| (c) For depths more than 1.5m | Circular chambers with a minimum diameter of 1.4m or chambers with minimum internal dimensions of 1.2m x 0.9m are recommended. |

3.4 Recommendations in JICA Report for "High Speed Railway Corridor" between Ahmedabad-Mumbai)

(i) The gradient of side drain in cutting shall be 0.3% (1 in 333.33) or over.

(ii) The minimum size of side drain in cuttings shall be 0.3m x 0.3m.

3.5 Provisions of Indian Railway Works Manual (IRWM)

Para 608 of IRWM stipulates various parameters for drainage of sewage. Though these provisions are with regard to sewage but conceptually they are relevant for drainage of water also. These provisions are as under:

(i) The limiting velocities for existing conditions should be determined and gradients decided accordingly. Normally a minimum velocity of 1 m/s and maximum velocity 2 m/s are allowed.

(ii) Self-cleansing Velocity: It is necessary to maintain a minimum velocity or self-cleansing velocity in a sewer to ensure that suspended solids do not deposit and cause blockage. A Minimum velocity of 0.8 m/s at design peak flow in the sanitary sewers is recommended subject to a minimum velocity of 0.6 m/s for present peak flow.

(iii) Velocity at minimum flow: To avoid steeper gradients which will require deeper excavations, it is a practice to design sewers for the self-cleansing velocity at ultimate peak flow. This is done on the assumption that although silting might occur at minimum flow, the silt would be flushed out during the peak flows.

## 4. Design of a typical Yard Drainage System

Based on the provisions of various standards as mentioned in Para-3 above, and other relevant factors, the longitudinal drain, chambers and cross drains were designed as follows:

### 4.1 Type of longitudinal drains

(i) In station yards it is difficult to cast the drains in-situ with required quality. Hence, the drains have been kept as pre-cast RCC Drains. The drains can be cast in elements of suitable lengths (with typical segment length of 1m or 0.5m, depending upon the method of handling proposed i.e. manually or mechanically), at a suitable location near the station yard and then pre-cast elements can be laid at site. This will also reduce the duration of open excavation on the side of running tracks, which is required to be kept minimum from safety point of view.

(ii) For the ease of casting and laying, the longitudinal drains have been kept rectangular in shape, with vertical slits on both the vertical walls. The dimensions and location of the vertical slits has been worked out in subsequent paras.

### 4.2 Bed Gradient of Longitudinal Drain

(i) The bed gradient of longitudinal drain is kept as 1 in 350 or steeper, to get required self-cleansing velocity of flow and to ensure sub-critical flow conditions. Actual velocity of flow and Froude Number has been calculated and verified subsequently.

(ii) To minimise excavation for drains, the gradient of longitudinal drain shall be same as gradient of track/formation. As per Schedule of Dimensions (IRSOD), the Steepest Gradient in yards can vary from 1 in 260 to Level (generally being 1 in 1200 for new yards). Therefore, in cases where the gradient of yard/formation is 1 in 350 or steeper, the longitudinal drain shall have same gradient as that of yard/formation. However, in cases where gradient of yard/formation is flatter than 1 in 350, the longitudinal drain shall have gradient of 1 in 350.

(iii) In cases where bed gradient of longitudinal drain is 1 in 350 and yard/formation gradient is flatter than this, the depth of drain will increase along its' length in the direction of falling gradient.

### 4.3 Size of longitudinal drains

(i) The width of longitudinal drains has been kept as 450mm, to facilitate their cleaning during service life.

(ii) The depth of longitudinal drains is decided based on following three considerations:

(a) The ballast profile side slope line shall cut the drain below its' top, to avoid ballast falling in drain;
(b) The bottom of vertical slit should be at the level of top of formation profile level, to avoid washing away of formation soil in the drain;
(c) Drain depth of 150mm is provided below the vertical slit to avoid the slits getting chocked due to siltation in drain when flow is low; and
(d) To avoid deep excavation on the side of running track, the maximum depth of longitudinal drains has been restricted to a value of 1200mm.

(iii) As per Schedule of Dimensions (IRSOD), the minimum distance between track centres in yards is 4265mm for existing yard and 5300mm for all new yards. Thus, the drain depth has to be decided for both these track centre distances, out of which the lower track centre (4265mm) will require deeper drain to ensure that the ballast profile side slope line cuts the drain below its' top.

(iv) With the above factors in view, the depth of drain has been decided as under:

(a) For Track Centres at 5300mm
Total depth of drain is 450mm (minimum) at the starting point and when the depth reaches 1200mm, a chamber will be provided and the drain will be continued on other side of chamber starting with a minimum depth of 450mm again.

(b) For Track Centres at 4265mm
Total depth of drain is 750mm (minimum) at the starting point and when the depth reaches 1200mm, a chamber will be provided and the drain will be continued on other side of chamber starting with a minimum depth of 750mm again.

(v) The longitudinal drains are normally open. However, in yards where there is likelihood of drains getting blocked due to garbage etc. or movement of maintenance staff is required on longitudinal drains, grated covers can be provided on top.

Relevant details of longitudinal drains, for track centre distances of 4265mm and 5300mm have been shown in Fig. 2A and Fig. 2B respectively.

(vi) If the maximum depth of the longitudinal drain has to be kept less than 1200mm, then a maximum depth of 1000mm or so can also be adopted. This will increase the number of chambers and cross drains. The typical spacing for chambers/cross drains, with Yard/Formation gradient of 1 in 1200 and longitudinal bed gradient of 1 in 350, for different values of maximum depth of longitudinal drain will be as following:

| **Track Centre Distance** | **Maximum Depth of Longitudinal Drain** | **Spacing of Chambers/Cross Drains** |
|---|---|---|
| 4265 mm | 1200 mm | 222.3 m |
| | 1000 mm | 123.5 m |
| 5300 mm | 1200 mm | 370.5 m |
| | 1000 mm | 271.7 m |

(vii) Weight of each pre-cast segment of longitudinal drain, which will be useful in deciding the suitable means for handling them, will be as under:

| **Depth of Longitudinal Drain** | **Weight of each Segment** | |
|---|---|---|
| | **With segment length 1.0m** | **With segment length 0.5m** |
| 450 mm | 388 kg | 194 kg |
| 750 mm | 538 kg | 269 kg |
| 1000 mm | 662 kg | 331 kg |
| 1200 mm | 762 kg | 381 kg |

4.4 Size of chambers
The chamber size has been kept as 0.9m x 1.2m. The arrangement at chambers, with cross drains, has been shown in Fig. 3.

4.5 Type, Size and Bed Gradient of Cross Drain

(i) The cross drains have been kept as perforated pipes, 300mm diameter, with wrapping of non-woven geotextiles.

(ii) The bed gradient of cross drains shall be 1 in 350 or steeper to achieve self-cleansing velocity of flow in them.

## 5. Checking of longitudinal drains

5.1 Check for various hydraulic parameters
As mentioned in Para.4 above, the bed gradient for longitudinal drains will vary from 1 in 260 to 1 in 350 and the depth of drain will vary from 450mm (or 750mm) to 1200mm. Therefore, the relevant hydraulic parameters of longitudinal drains were checked for different combinations. The details of checking are attached as Annexure-1, 2, 3 and 4. The relevant details of checking are summarised as under:

(A) For Track centres at 4265mm

| **Depth of Drain (in mm)** | **Bed Gradient** | **Discharge (in lit/s)** | | **Velocity (in m/s)** | | **Froude Number** | |
|---|---|---|---|---|---|---|---|
| | | **With Peak Flow** | **With Optimum Flow (*)** | **With Peak Flow** | **With Optimum Flow (*)** | **With Peak Flow** | **With Optimum Flow (*)** |
| 750 | 1 in 260 | 433 | 359 | 1.284 | 1.250 | 0.473 | 0.500 |
| | 1 in 350 | 374 | 309 | 1.107 | 1.078 | 0.408 | 0.431 |
| 1200 | 1 in 260 | 737 | 615 | 1.364 | 1.339 | 0.398 | 0.423 |
| | 1 in 350 | 635 | 530 | 1.176 | 1.154 | 0.343 | 0.365 |

(*) when Free Board is equal to 15% of total drain depth

(B) For Track centres at 5300mm

| Depth of Drain (in mm) | Bed Gradient | Discharge (in lit/s) | | Velocity (in m/s) | | Froude Number | |
|---|---|---|---|---|---|---|---|
| | | With Peak Flow | With Optimum Flow (*) | With Peak Flow | With Optimum Flow (*) | With Peak Flow | With Optimum Flow (*) |
| 450 | 1 in 260 | 236 | 193 | 1.167 | 1.124 | 0.556 | 0.580 |
| | 1 in 350 | 204 | 167 | 1.006 | 0.968 | 0.479 | 0.500 |
| 1200 | 1 in 260 | 737 | 615 | 1.364 | 1.339 | 0.398 | 0.423 |
| | 1 in 350 | 635 | 530 | 1.176 | 1.154 | 0.343 | 0.365 |

(*) when Free Board is equal to 15% of total drain depth

5.2 Check for Clearances

(A) Horizontal Clearances

(i) For working of BCM in yards, a clear total width of 4280mm is required i.e. 2140mm on one side from centre of track.

In the yards, with track centre distance of 4265mm, the horizontal clearances between the track centre and outside of longitudinal drain will be 1807mm. Thus, the BCM will not be able to work in these yards. However, it is relevant to note that in yards lines, with platforms, the BCM is not able to work even without drains also.

To enable BCM working in yards with longitudinal drains, a minimum track centre distance of 4930mm will be required. All new yards are constructed with minimum track centre distance of 5300mm. Therefore, for all new yards and all existing yards with track centre distance of 4930mm or above, the BCM will be able to work with longitudinal drains.

(ii) As mentioned in Para 3.1(ii) above, a horizontal distance of 1750mm is desirable from the centre of drain to the nearest gauge face of the track.

In the yards, with track centre distance of 4265mm, the horizontal distance from the centre of drain to the nearest gauge face of the track will be 970mm. Thus, this requirement will not be fulfilled in these yards. But, this is unavoidable in yards with track centre distance of 4265mm.

To enable fulfilment of this requirement, a minimum track centre distance of 5176mm will be required. All new yards are constructed with minimum track centre distance of 5300mm. Therefore, for all new yards and all existing yards with track centre distance of 5176mm or above, this condition will be fulfilled.

(B) Vertical Clearances

As mentioned in Para 3.1(ii) above, minimum depth of drain invert level, from rail level, shall be 850mm. In yards with track centre distance of 4265mm, this vertical clearance varies from 861mm to 1361mm and in yards with track centre distance of 5300mm, this vertical clearance varies from 874mm to 1674mm. Therefore, this condition is fulfilled in all cases.

5.3 From the details in Para 5.1 and 5.2 above, it is observed that:

(i) The flow velocity achieved, when flowing at peak and optimum capacity (i.e. free board equal to 15% of drain depth) is about or more than 1 m/s and less than 2 m/s. Hence, the requirement of minimum velocity for self-cleansing and maximum velocity to avoid scouring is fulfilled.

(ii) The Froude Number, when flowing at peak and optimum capacity (i.e. free board equal to 15% of drain depth) is less than 0.8. Hence, the requirement of sub-critical flow is fulfilled.

(iii) The BCM will not be able to work in existing yard with track centre distances of 4265mm. But all in existing yards with track centre distance of 4930mm or above and all new yards (wherein track centre distance is 5300mm minimum), the BCM will be able to work without any hindrance.

(iv) The desirable horizontal distance of 1750mm, between centre of drain to nearest gauge face is not available in existing yards with track centre distances of 4265mm. But, this is unavoidable in yards with track centre distance of 4265mm. But in all existing yards with track centre distance of 5176mm or above and all new yards (wherein track centre distance is 5300mm minimum), the desirable horizontal clearance will be available.

(v) The depth of invert of drain from rail level is more than 850mm.

In view of above the design of drainage system is considered satisfactory.

## 6. Conclusion

It is expected that a yard drainage system, designed and constructed taking into account the relevant technical parameters detailed in the above, will be effective in discharging the water away from the track formation. This will not only improve the reliability of assets but will also ensure fruitful utilisation of the money spent in the yard drainage system.

## References


(i) Australian Rail Track Corporation Ltd. (ARTC): Engineering Practices Manual: Civil Engineering – RTS 3432: Track Drainage – Inspection and Maintenance (March'2006).

(ii) Australian Rail Track Corporation Ltd. (ARTC): Engineering Practices Manual: Civil Engineering – RTS 3433: Track Drainage – Design and Construction (June'2013).

(iii) IS:1724-1983 Indian Standard Code of Practice for Building Drainage.

(iv) Indian Railways Way and Works Manual.

(v) Public Utilities Board(PUB) Singapore: Code of Practice on Surface Water Drainage (Dec'2011).

(vi) Joint Feasibility Study for Mumbai – Ahmedabad High Speed Rail Corridor: Fianl Report (July'2015).

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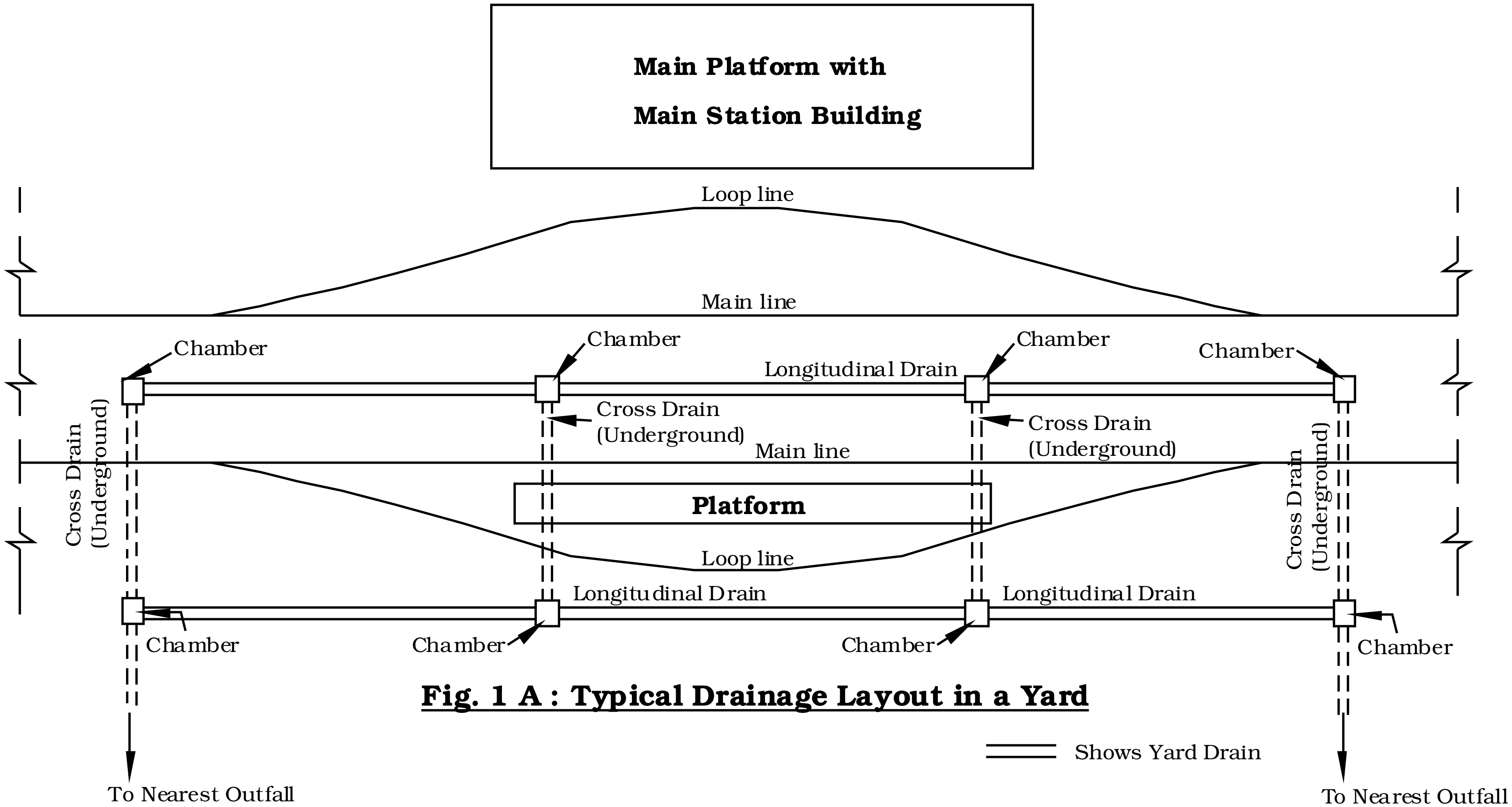


**Fig. 1 A : Typical Drainage Layout in a Yard**

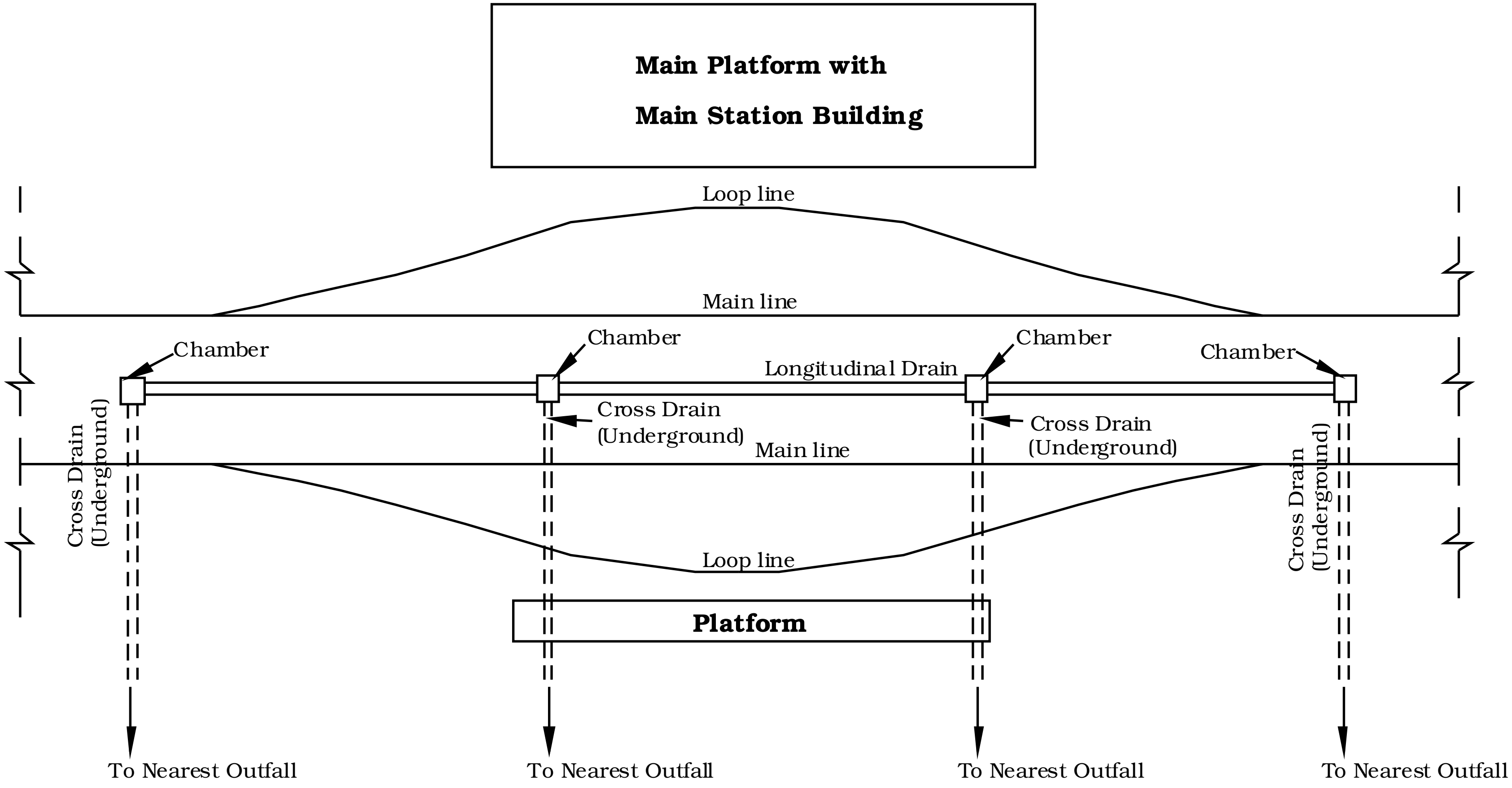


**Fig. 1 B : Typical Drainage Layout in a Yard**

Shows Yard Drain

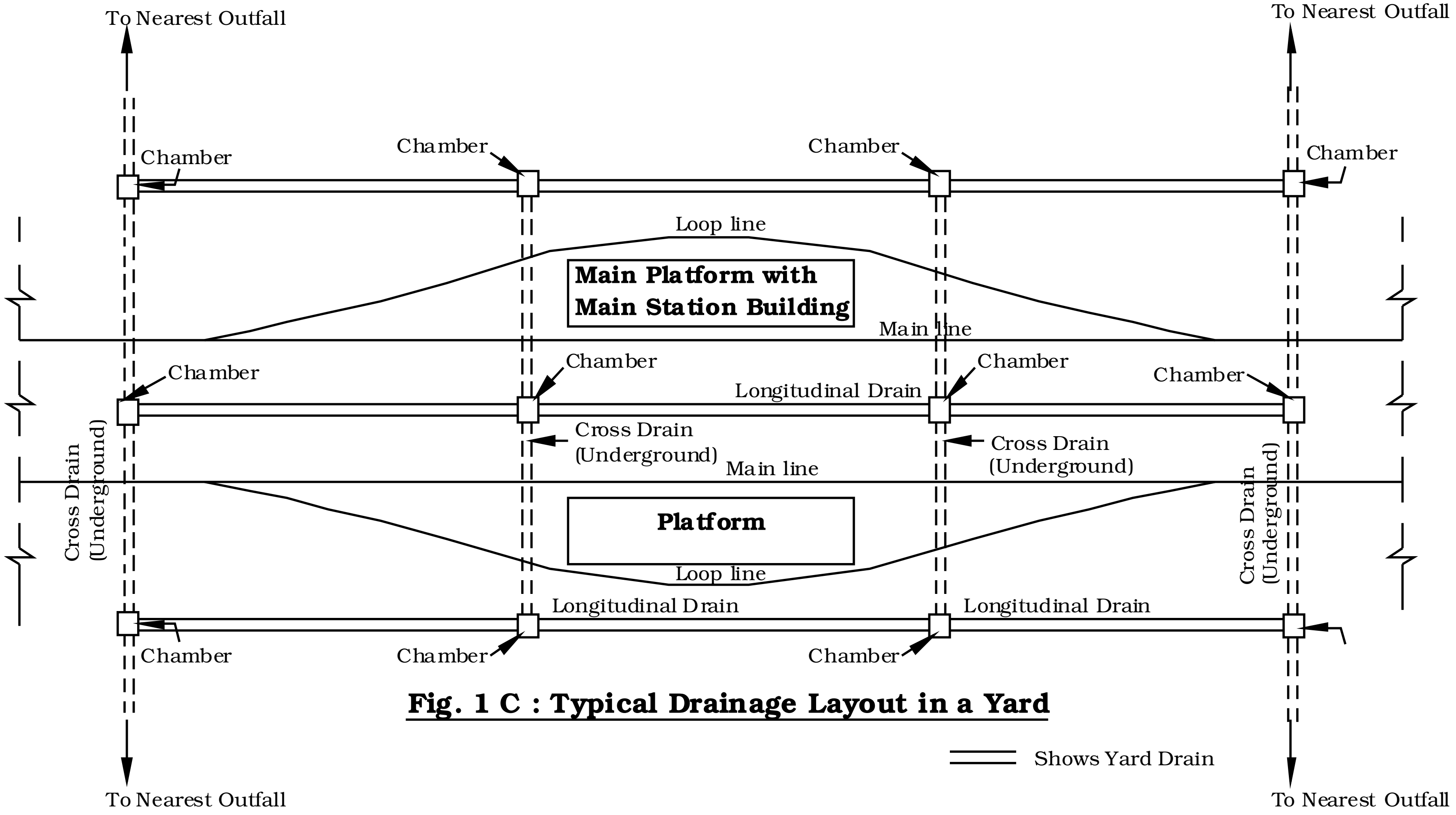


**Fig. 1 C : Typical Drainage Layout in a Yard**

## Notes for Fig.1A, Fig.1 B and Fig.1C

(i) The longitudinal drain is made of Pre-cast RCC segments, laid on 150mm thick lean concrete. The section of longitudinal drain shall be as given in Fig. 2A or Fig. 2B. The joint/junction between the two pre-cast elements of longitudinal drain shall be sealed with Cement Mortar or any other suitable sealing material.

(ii) To minimise excavation for drains, the gradient of longitudinal drain shall be same as gradient of track/formation. For self-cleansing velocity in the longitudinal drain, bed gradient of 1 in 350 is desirable. Therefore, in cases where the gradient of yard/formation is 1 in 350 or steeper, the longitudinal drain shall have same gradient as that of yard/formation. However, in cases where gradient of yard/formation is flatter than 1 in 350, the longitudinal drain shall have gradient of 1 in 350.

(iii) The top of the longitudinal drain shall be kept parallel to the track/formation profile in the yards. In cases where bed gradient of longitudinal drain is 1 in 350 and yard/formation gradient is flatter than this, the depth of drain will increase along its' length in the direction of falling gradient. The maximum depth of drain shall be 1200mm and wherever the depth of longitudinal drain reaches 1200mm, a chamber should be provided as shown in Fig. 3, with cross drainage. The invert level of the longitudinal drain will change at the chamber location. After chamber, the longitudinal drain shall continue with depth of 450mm/750mm at beginning. If the site conditions do not permit a maximum drain depth of 1200mm, a maximum depth of 1000mm can also be adopted, but this will increase the number of chambers and cross drains.

(iv) On the side walls of the longitudinal drain, vertical slits of width 40mm are provided at a spacing of 250mm c/c. The top of slits is 150mm below the top of drain and the bottom of slits is at the formation level. The depth of slits will remain constant. Details of slits are shown in Fig. 2A and Fig. 2B.

(v) The longitudinal drains are normally open. However, in yards where there is likelihood of drains getting blocked due to garbage etc. or movement of maintenance staff is required on longitudinal drains, grated covers can be provided on top.

(vi) The cross drains shall be perforated pipes, 300mm diameter, with wrapping of non-woven geotextiles, preferably of a type which can be pushed across the platform and track. However, if discharge is more, this can be increased to take care of the anticipated discharge.

(vii) The cross drain shall cross the track(s) and platform, as needed as per site conditions.

(viii) In case the longitudinal drain meets any culvert in the yard, it shall connect to and discharge in the culvert subject to invert level and discharge capacity of the culvert permitting it.

(ix) The gradient of the cross drain shall be 1 in 350 or steeper.

(x) The chamber size shall be 0.9m x 1.2m. The arrangement at chambers is shown in Fig. 3.

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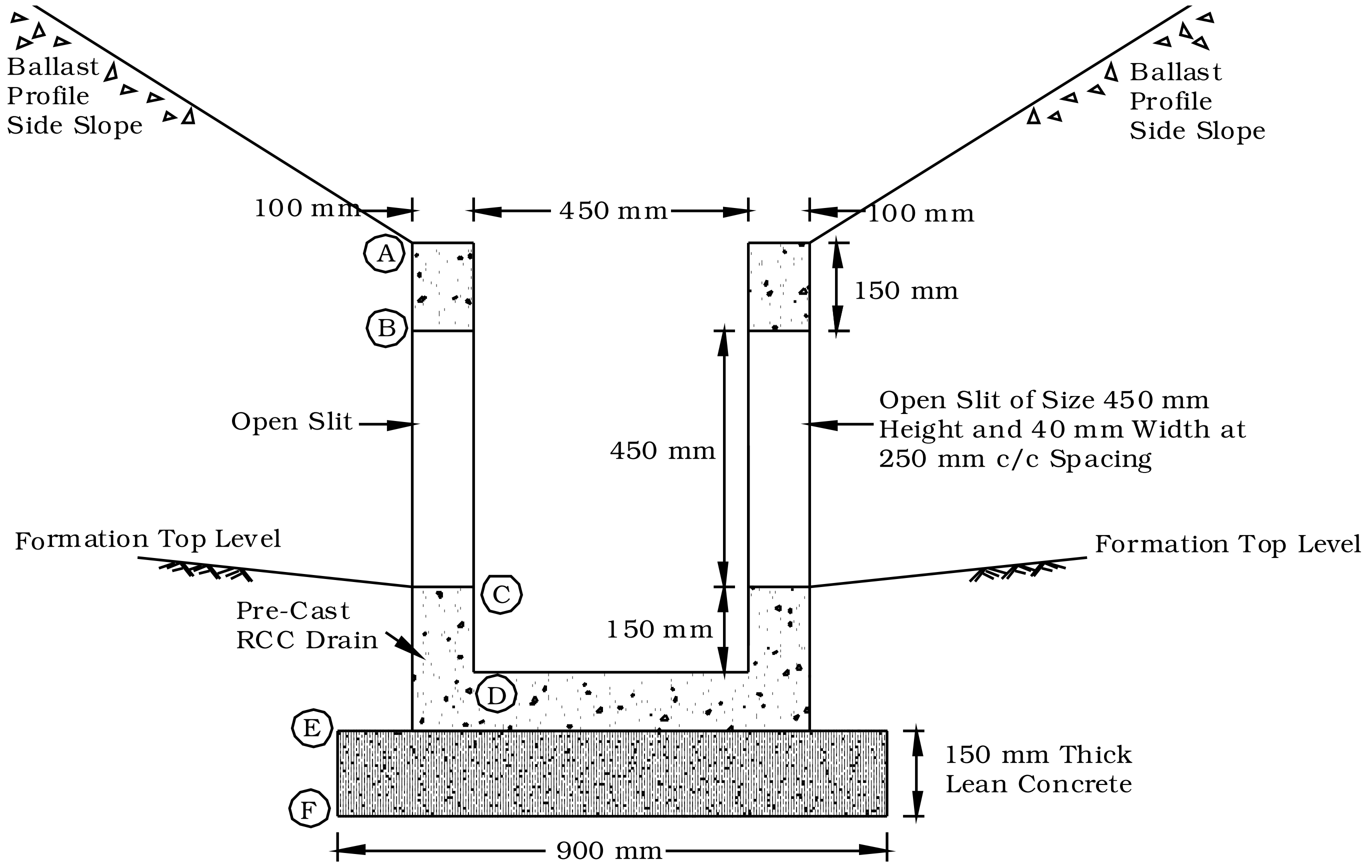


**Fig. 2 A/1: Details of Longitudinal Drain**
**(For Track Centre 4265 mm)**

| Location | | Levels For Drain depth 750mm | Levels For Drain depth 1200mm |
|---|---|---|---|
| Rail Level | | L m | L m |
| Platform Level | | L + 840 m For High level<br>L + 760 m For Middle level<br>L + 455 m For Low level | L + 840 m For High level<br>L + 760 m For Middle level<br>L + 455 m For Low level |
| Top of Drain | (A) | L – 0.111 m | L – 0.111 m |
| Top of Slit | (B) | L – 0.261 m | L – 0.261 m |
| Bottom of Slit / Formation level | (C) | F= (L – 0.711 m) | F = (L – 0.711m) |
| Invert Level of Drain | (D) | F – 0.150 m<br>(L – 0.861 m) | F – 0.600 m<br>(L – 1.311 m) |
| Bottom of Drain / top of Footing | (E) | F – 0.250 m<br>(L – 0.961 m) | F – 0.700 m<br>(L – 1.411 m) |
| Bottom Of Footing | (F) | F – 400 m<br>(L – 1.111 m) | F – 0.850 m<br>(L – 1.561 m) |

## Levels Table

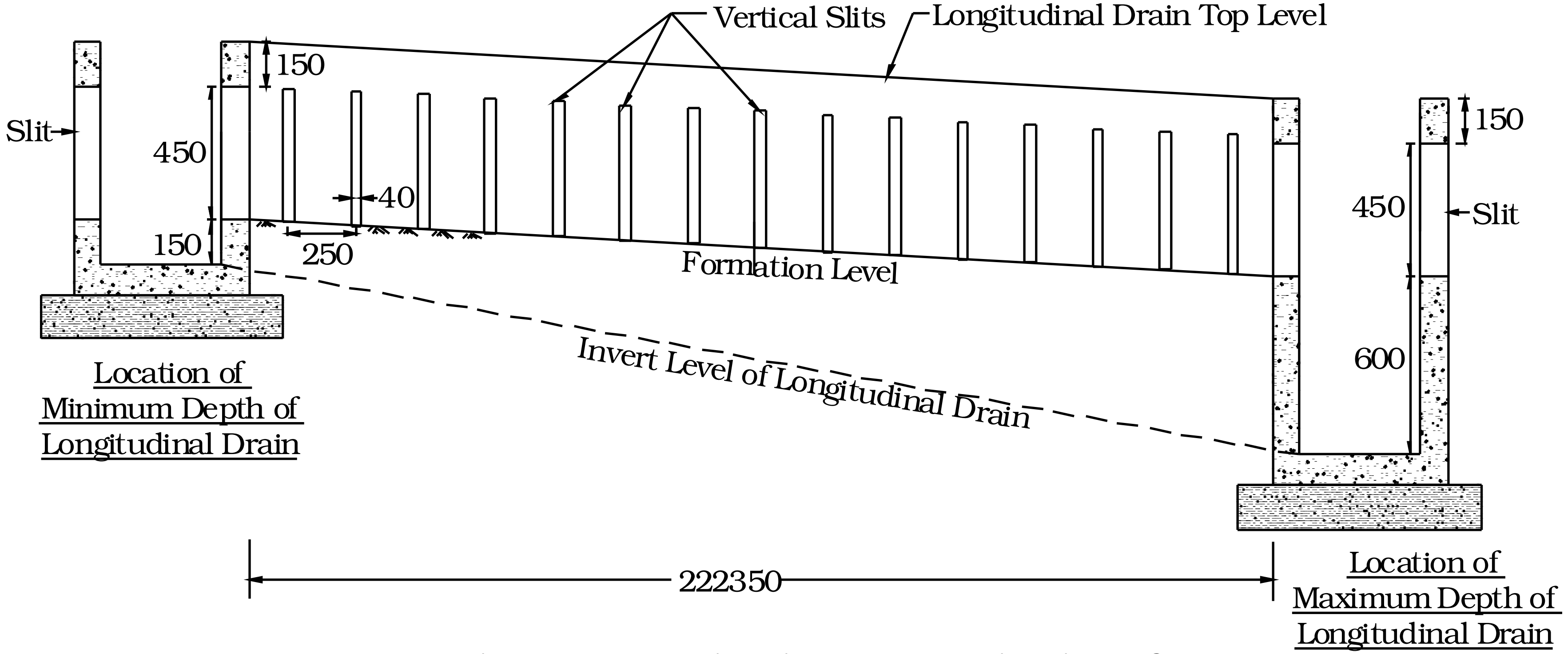


**Fig. 2A/2: Longitudinal Schematic View of The Longitudinal Drain(For Track Centre 4265 mm)**

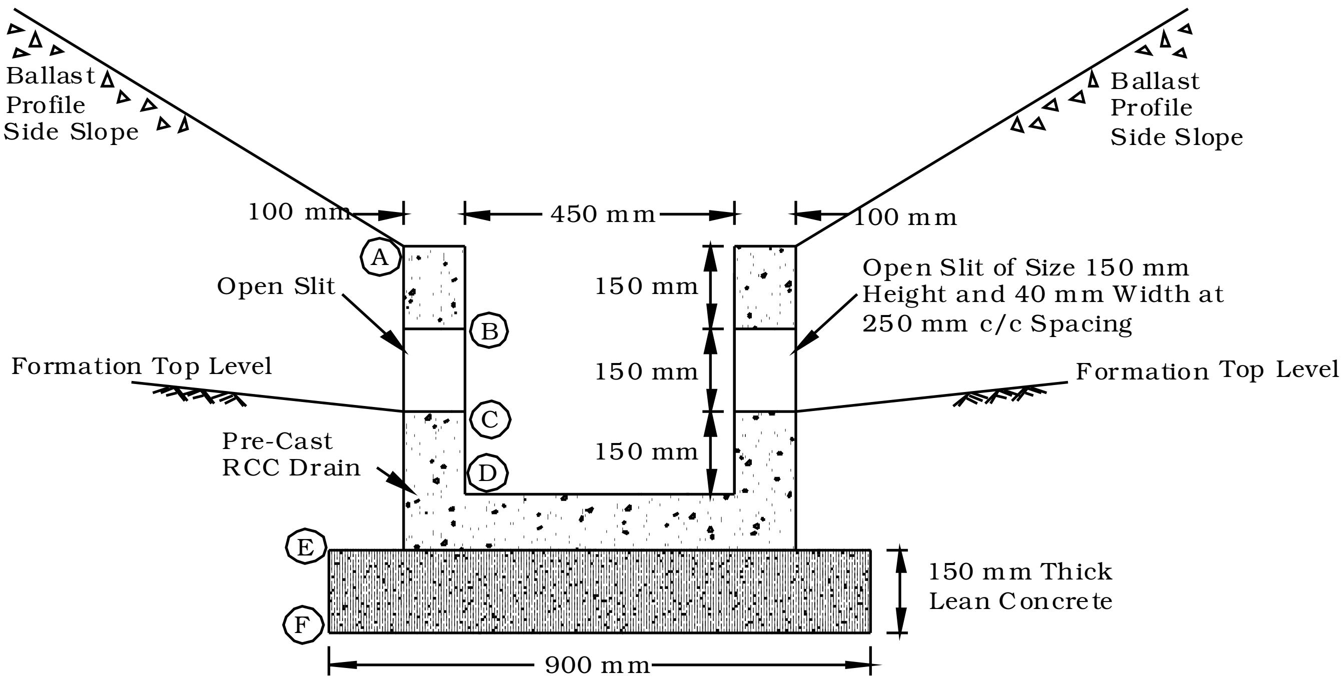


**Fig. 2 B/1: Details of Longitudinal Drain**
**(For Track Centre 5300 mm)**

| Location | Levels For drain depth 450mm | Levels For Drain depth 1200mm |
|---|---|---|
| Rail Level | L m | L m |
| Platform Level | L + 840 m For High level<br>L + 760 m For Middle level<br>L + 455 m For Low level | L+ 840 m For High level<br>L + 760 m For Middle level<br>L+ 455 m For Low level |
| Top of Drain (A) | L – 0.424 m | L – 0.424 m |
| Top Of Slit (B) | L – 0.574 m | L – 0.574 m |
| Bottom Of Slit / Formation Level (C) | F = (L – 0.724 m) | F = (L – 0.724 m) |
| Invert Level of Drain (D) | F – 0.150 m<br>(L – 0.874 m) | F – 0.900 m<br>(L – 1.624 m) |
| Bottom of Drain / Top of Footing (E) | F – 0.250 m<br>(L – 0.974 m) | F – 1.000 m<br>(L – 1.724 m) |
| Bottom Of Footing (F) | F – 0.400 m<br>(L – 1.124 m) | F – 1.150 m<br>(L – 1.874 m) |

## Levels Table

**Page 1/2**

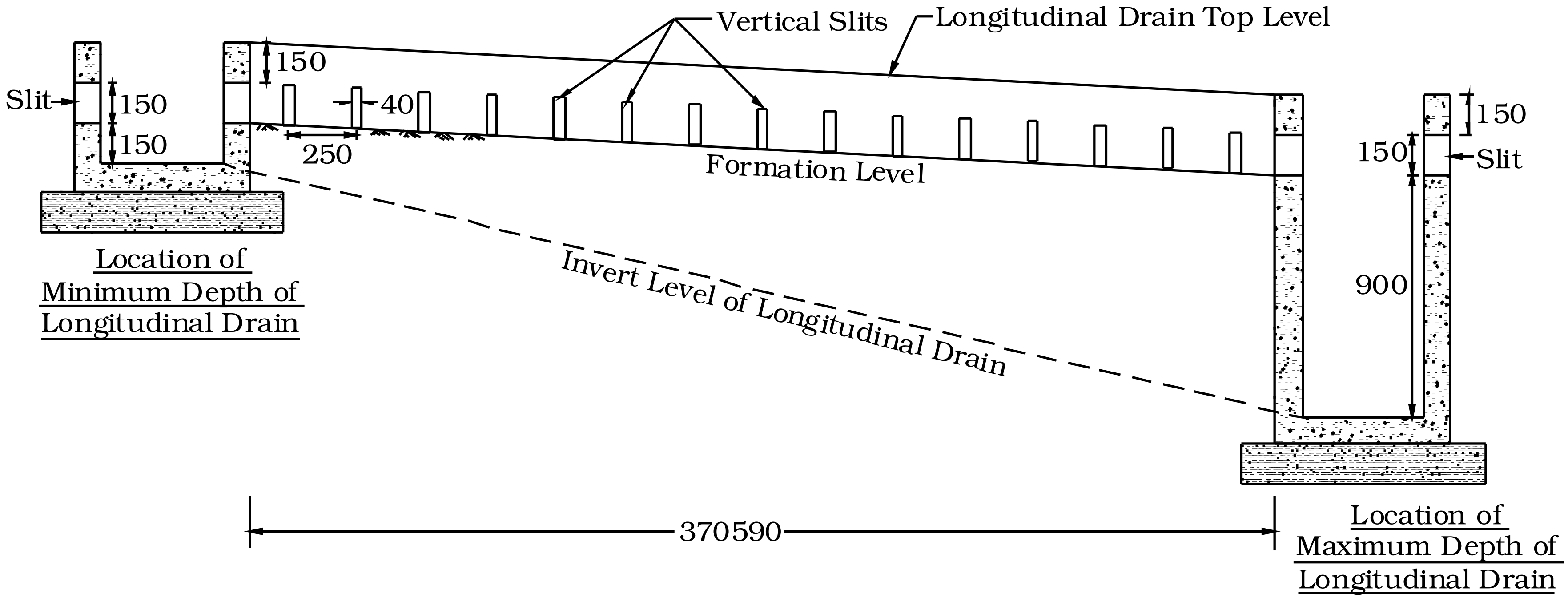


**Fig. 2 B/2: Longitudinal Schematic View of The Longitudinal Drain (For Track Centre 5300 mm)**

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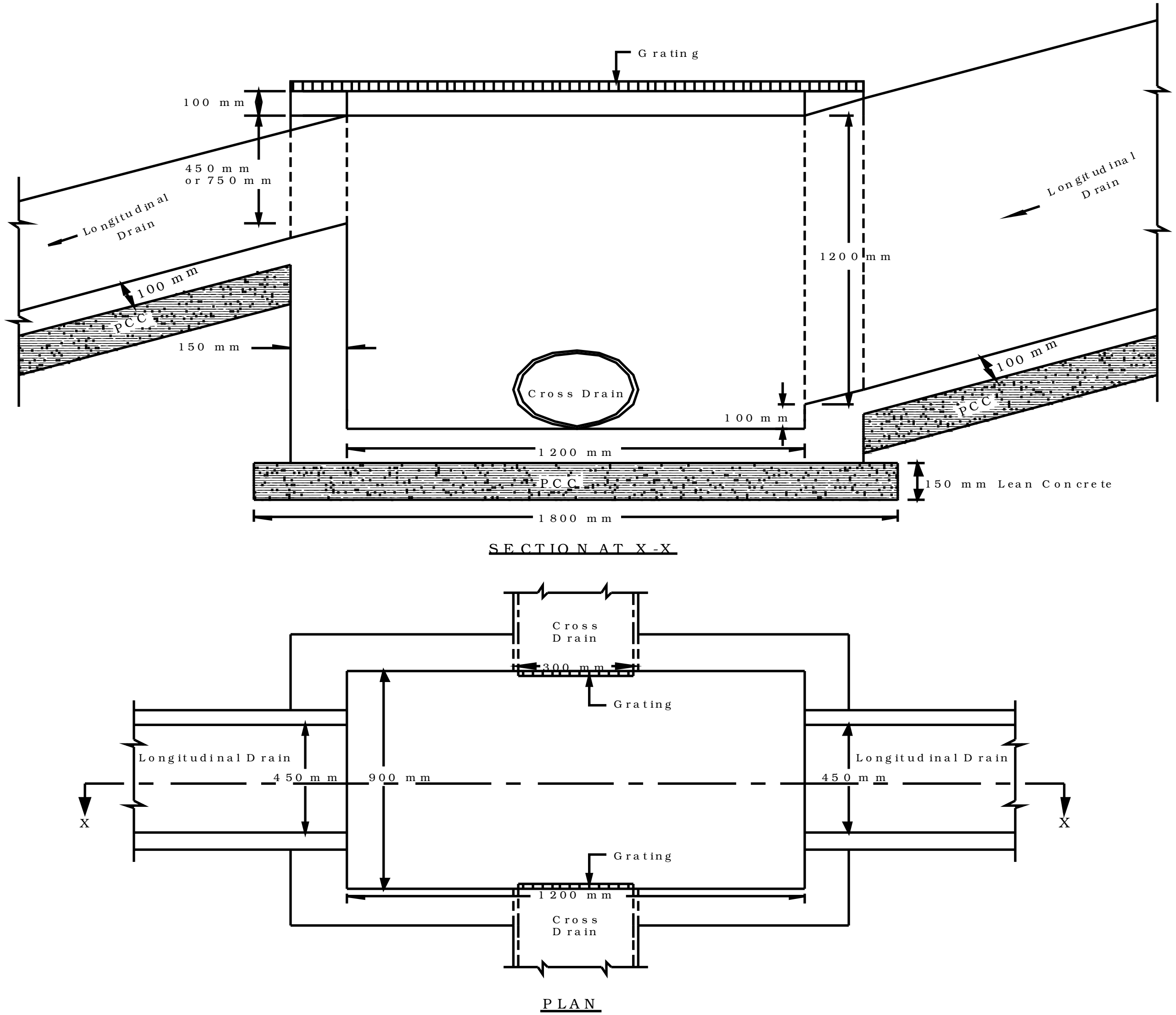


**Fig. 3 Details of Sump With Cross Drain**

ANNEXURE - 1

Case -1 (With Track Centres at 4265 mm, for Minimum Depth of Drain i.e. 750 mm)

Bed Gradient = 1 in 260 = 0.003846 Width of Drain W (in m)= 0.45

| Depth of flow (in m) | Area of Flow (in Sq.m.) | Wetted Perimeter (in m) | Hydraulic Radius (in m) | Velocity (in m/s) | Discharge (in lit/s) | Froude Number | Remarks |
|---|---|---|---|---|---|---|---|
| (D) | (A) = WxD | (P) = W+2D | (R) = A/P | (V) | (Q) = VxA | (N) | |
| 0.750 | 0.338 | 1.950 | 0.173 | 1.284 | 433 | 0.473 | |
| 0.700 | 0.315 | 1.850 | 0.170 | 1.270 | 400 | 0.485 | |
| 0.638 | 0.287 | 1.725 | 0.166 | 1.250 | 359 | 0.500 | Free Board= 15% of Drain depth |
| 0.600 | 0.270 | 1.650 | 0.164 | 1.237 | 334 | 0.510 | |
| 0.500 | 0.225 | 1.450 | 0.155 | 1.194 | 269 | 0.539 | |
| 0.400 | 0.180 | 1.250 | 0.144 | 1.136 | 204 | 0.573 | |
| 0.300 | 0.135 | 1.050 | 0.129 | 1.053 | 142 | 0.614 | |
| 0.200 | 0.090 | 0.850 | 0.106 | 0.925 | 83 | 0.661 | |
| 0.100 | 0.045 | 0.650 | 0.069 | 0.697 | 31 | 0.704 | |

Case -2 (With Track Centres at 4265 mm, for Minimum Depth of Drain i.e. 750 mm)

Bed Gradient = 1 in 350 = 0.002857 Width of Drain W (in m)= 0.45

| Depth of flow (in m) | Area of Flow (in Sq.m.) | Wetted Perimeter (in m) | Hydraulic Radius (in m) | Velocity (in m/s) | Discharge (in lit/s) | Froude Number | Remarks |
|---|---|---|---|---|---|---|---|
| (D) | (A) = WxD | (P) = W+2D | (R) = A/P | (V) | (Q) = VxA | (N) | |
| 0.750 | 0.338 | 1.950 | 0.173 | 1.107 | 374 | 0.408 | |
| 0.700 | 0.315 | 1.850 | 0.170 | 1.095 | 345 | 0.418 | |
| 0.638 | 0.287 | 1.725 | 0.166 | 1.078 | 309 | 0.431 | Free Board= 15% of Drain depth |
| 0.600 | 0.270 | 1.650 | 0.164 | 1.066 | 288 | 0.439 | |
| 0.500 | 0.225 | 1.450 | 0.155 | 1.029 | 232 | 0.465 | |
| 0.400 | 0.180 | 1.250 | 0.144 | 0.979 | 176 | 0.494 | |
| 0.300 | 0.135 | 1.050 | 0.129 | 0.908 | 123 | 0.529 | |
| 0.200 | 0.090 | 0.850 | 0.106 | 0.798 | 72 | 0.569 | |
| 0.100 | 0.045 | 0.650 | 0.069 | 0.601 | 27 | 0.607 | |

ANNEXURE - 2

Case -3 (With Track Centres at 4265 mm. for Maximum Depth of Drain i.e. 1200 mm)

Bed Gradient = 1 in 260 = 0.003846 Width of Drain W (in m)= 0.45

| Depth of flow (in m) | Area of Flow (in Sq.m.) | Wetted Perimeter (in m) | Hydraulic Radius (in m) | Velocity (in m/s) | Discharge (in lit/s) | Froude Number | Remarks |
|---|---|---|---|---|---|---|---|
| (D) | (A) = WxD | (P) = W+2D | (R) = A/P | (V) | (Q) = VxA | (N) | |
| 1.200 | 0.540 | 2.850 | 0.189 | 1.364 | 737 | 0.398 | |
| 1.100 | 0.495 | 2.650 | 0.187 | 1.351 | 669 | 0.411 | |
| 1.020 | 0.459 | 2.490 | 0.184 | 1.339 | 615 | 0.423 | Free Board= 15% of Drain depth |
| 1.000 | 0.450 | 2.450 | 0.184 | 1.336 | 601 | 0.427 | |
| 0.900 | 0.405 | 2.250 | 0.180 | 1.318 | 534 | 0.444 | |
| 0.800 | 0.360 | 2.050 | 0.176 | 1.297 | 467 | 0.463 | |
| 0.700 | 0.315 | 1.850 | 0.170 | 1.270 | 400 | 0.485 | |
| 0.600 | 0.270 | 1.650 | 0.164 | 1.237 | 334 | 0.510 | |
| 0.500 | 0.225 | 1.450 | 0.155 | 1.194 | 269 | 0.539 | |
| 0.400 | 0.180 | 1.250 | 0.144 | 1.136 | 204 | 0.573 | |
| 0.300 | 0.135 | 1.050 | 0.129 | 1.053 | 142 | 0.614 | |
| 0.200 | 0.090 | 0.850 | 0.106 | 0.925 | 83 | 0.661 | |
| 0.100 | 0.045 | 0.650 | 0.069 | 0.697 | 31 | 0.704 | |

Case - 4 (With Track Centres at 4265 mm. for Maximum Depth of Drain i.e. 1200 mm)

Bed Gradient = 1 in 350 = 0.002857 Width of Drain W (in m)= 0.45

| Depth of flow (in m) | Area of Flow (in Sq.m.) | Wetted Perimeter (in m) | Hydraulic Radius (in m) | Velocity (in m/s) | Discharge (in lit/s) | Froude Number | Remarks |
|---|---|---|---|---|---|---|---|
| (D) | (A) = WxD | (P) = W+2D | (R) = A/P | (V) | (Q) = VxA | (N) | |
| 1.200 | 0.540 | 2.850 | 0.189 | 1.176 | 635 | 0.343 | |
| 1.100 | 0.495 | 2.650 | 0.187 | 1.164 | 576 | 0.354 | |
| 1.020 | 0.459 | 2.490 | 0.184 | 1.154 | 530 | 0.365 | Free Board= 15% of Drain depth |
| 1.000 | 0.450 | 2.450 | 0.184 | 1.151 | 518 | 0.368 | |
| 0.900 | 0.405 | 2.250 | 0.180 | 1.136 | 460 | 0.382 | |
| 0.800 | 0.360 | 2.050 | 0.176 | 1.117 | 402 | 0.399 | |
| 0.700 | 0.315 | 1.850 | 0.170 | 1.095 | 345 | 0.418 | |
| 0.600 | 0.270 | 1.650 | 0.164 | 1.066 | 288 | 0.439 | |
| 0.500 | 0.225 | 1.450 | 0.155 | 1.029 | 232 | 0.465 | |
| 0.400 | 0.180 | 1.250 | 0.144 | 0.979 | 176 | 0.494 | |
| 0.300 | 0.135 | 1.050 | 0.129 | 0.908 | 123 | 0.529 | |
| 0.200 | 0.090 | 0.850 | 0.106 | 0.798 | 72 | 0.569 | |
| 0.100 | 0.045 | 0.650 | 0.069 | 0.601 | 27 | 0.607 | |

ANNEXURE - 3

Case -5 (With Track Centres at 5300 mm, for Minimum Depth of Drain i.e. 450 mm)

Bed Gradient = 1 in 260 = 0.003846 Width of Drain W (in m)= 0.45

| Depth of flow (in m) | Area of Flow (in Sq.m.) | Wetted Perimeter (in m) | Hydraulic Radius (in m) | Velocity (in m/s) | Discharge (in lits) | Froude Number | Remarks |
|---|---|---|---|---|---|---|---|
| (D) | (A) = WxD | (P) = W+2D | (R) = A/P | (V) | (Q) = VxA | (N) | |
| 0.450 | 0.203 | 1.350 | 0.150 | 1.167 | 236 | 0.556 | |
| 0.400 | 0.180 | 1.250 | 0.144 | 1.136 | 204 | 0.573 | |
| 0.350 | 0.158 | 1.150 | 0.137 | 1.099 | 173 | 0.593 | |
| 0.383 | 0.172 | 1.215 | 0.142 | 1.124 | 193 | 0.580 | Free Board= 15% of Drain depth |
| 0.300 | 0.135 | 1.050 | 0.129 | 1.053 | 142 | 0.614 | |
| 0.250 | 0.113 | 0.950 | 0.118 | 0.997 | 112 | 0.637 | |
| 0.200 | 0.090 | 0.850 | 0.106 | 0.925 | 83 | 0.661 | |
| 0.150 | 0.068 | 0.750 | 0.090 | 0.830 | 56 | 0.684 | |
| 0.100 | 0.045 | 0.650 | 0.069 | 0.697 | 31 | 0.704 | |

Case -6 (With Track Centres at 5300 mm, for Minimum Depth of Drain i.e. 450 mm)

Bed Gradient = 1 in 350 = 0.002857 Width of Drain W (in m)= 0.45

| Depth of flow (in m) | Area of Flow (in Sq.m.) | Wetted Perimeter (in m) | Hydraulic Radius (in m) | Velocity (in m/s) | Discharge (in lit/s) | Froude Number | Remarks |
|---|---|---|---|---|---|---|---|
| (D) | (A) = WxD | (P) = W+2D | (R) = A/P | (V) | (Q) = VxA | (N) | |
| 0.450 | 0.203 | 1.350 | 0.150 | 1.006 | 204 | 0.479 | |
| 0.400 | 0.180 | 1.250 | 0.144 | 0.979 | 176 | 0.494 | |
| 0.383 | 0.172 | 1.215 | 0.142 | 0.968 | 167 | 0.500 | Free Board= 15% of Drain depth |
| 0.350 | 0.158 | 1.150 | 0.137 | 0.947 | 149 | 0.511 | |
| 0.300 | 0.135 | 1.050 | 0.129 | 0.908 | 123 | 0.529 | |
| 0.250 | 0.113 | 0.950 | | | 0 | | |
| 0.200 | 0.090 | 0.850 | 0.106 | 0.798 | 72 | 0.569 | |
| 0.150 | 0.068 | 0.750 | 0.090 | 0.716 | 48 | 0.590 | |
| 0.100 | 0.045 | 0.650 | 0.069 | 0.601 | 27 | 0.607 | |

ANNEXURE - 4

Case -7 (With Track Centres at 5300 mm. for Maximum Depth of Drain i.e. 1200 mm)

Bed Gradient = 1 in 260 = 0.003846 Width of Drain W (in m)= 0.45

| Depth of flow (in m) | Area of Flow (in Sq.m.) | Wetted Perimeter (in m) | Hydraulic Radius (in m) | Velocity (in m/s) | Discharge (in lit/s) | Froude Number | Remarks |
|---|---|---|---|---|---|---|---|
| (D) | (A) = WxD | (P) = W+2D | (R) = A/P | (V) | (Q) = VxA | (N) | |
| 1.200 | 0.540 | 2.850 | 0.189 | 1.364 | 737 | 0.398 | |
| 1.100 | 0.495 | 2.650 | 0.187 | 1.351 | 669 | 0.411 | |
| 1.020 | 0.459 | 2.490 | 0.184 | 1.339 | 615 | 0.423 | Free Board= 15% of Drain depth |
| 1.000 | 0.450 | 2.450 | 0.184 | 1.336 | 601 | 0.427 | |
| 0.900 | 0.405 | 2.250 | 0.180 | 1.318 | 534 | 0.444 | |
| 0.800 | 0.360 | 2.050 | 0.176 | 1.297 | 467 | 0.463 | |
| 0.700 | 0.315 | 1.850 | 0.170 | 1.270 | 400 | 0.485 | |
| 0.600 | 0.270 | 1.650 | 0.164 | 1.237 | 334 | 0.510 | |
| 0.500 | 0.225 | 1.450 | 0.155 | 1.194 | 269 | 0.539 | |
| 0.400 | 0.180 | 1.250 | 0.144 | 1.136 | 204 | 0.573 | |
| 0.300 | 0.135 | 1.050 | 0.129 | 1.053 | 142 | 0.614 | |
| 0.200 | 0.090 | 0.850 | 0.106 | 0.925 | 83 | 0.661 | |
| 0.100 | 0.045 | 0.650 | 0.069 | 0.697 | 31 | 0.704 | |

Case - 8 (With Track Centres at 5300 mm. for Maximum Depth of Drain i.e. 1200 mm)

Bed Gradient = 1 in 350 = 0.002857 Width of Drain W (in m)= 0.45

| Depth of flow (in m) | Area of Flow (in Sq.m.) | Wetted Perimeter (in m) | Hydraulic Radius (in m) | Velocity (in m/s) | Discharge (in lit/s) | Froude Number | Remarks |
|---|---|---|---|---|---|---|---|
| (D) | (A) = WxD | (P) = W+2D | (R) = A/P | (V) | (Q) = VxA | (N) | |
| 1.200 | 0.540 | 2.850 | 0.189 | 1.176 | 635 | 0.343 | |
| 1.100 | 0.495 | 2.650 | 0.187 | 1.164 | 576 | 0.354 | |
| 1.020 | 0.459 | 2.490 | 0.184 | 1.154 | 530 | 0.365 | Free Board= 15% of Drain depth |
| 1.000 | 0.450 | 2.450 | 0.184 | 1.151 | 518 | 0.368 | |
| 0.900 | 0.405 | 2.250 | 0.180 | 1.136 | 460 | 0.382 | |
| 0.800 | 0.360 | 2.050 | 0.176 | 1.117 | 402 | 0.399 | |
| 0.700 | 0.315 | 1.850 | 0.170 | 1.095 | 345 | 0.418 | |
| 0.600 | 0.270 | 1.650 | 0.164 | 1.066 | 288 | 0.439 | |
| 0.500 | 0.225 | 1.450 | 0.155 | 1.029 | 232 | 0.465 | |
| 0.400 | 0.180 | 1.250 | 0.144 | 0.979 | 176 | 0.494 | |
| 0.300 | 0.135 | 1.050 | 0.129 | 0.908 | 123 | 0.529 | |
| 0.200 | 0.090 | 0.850 | 0.106 | 0.798 | 72 | 0.569 | |
| 0.100 | 0.045 | 0.650 | 0.069 | 0.601 | 27 | 0.607 | |