Chapter 8

Ballast, Formation and Drainage
Part I

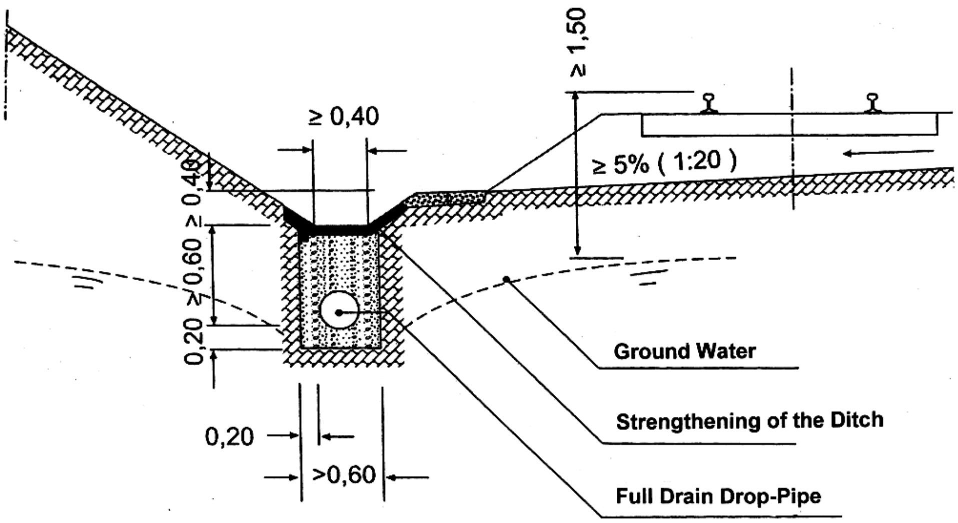
with the Amendment:

Water the Enemy of the Rail Track
Part II

Elaborated by Dr. F.A. Wingler, September 2016

Chapter 8

Ballast, Formation and Drainage; Part I



Dimensions for Sub-Soil Drainage System
(Graph from B. Lichtberger, Track Compendium)

Fundamentals of Rail Road Engineering

By F. Wingler

Water is the Enemy of the Rail Track and Rail Road; proper Drainage is essential. Ballast is the Blood of the Rail Track; Ballast has to be kept clean from impurities otherwise it loses its elasticity; proper Ballast Management is essential.
Track Quality is no Luxury.
A lower Quality Track deteriorates faster than a high Quality Track.
A Measure for Track Quality is the Deterioration-Rate – the Loss of Alignment Parameters over the Time under given Traffic Load.
Capital and Engineering Investments in initial High Track Quality pay off by low overall Life Cycle Costs.
The Track interacting Constituents have to be treated in their Entirety rather by only the individual and particular Constituents.
Without a well bearing and well drained Blanket, Sub-Soil, Sub-Grade and Formation there will be no stable Rail Road.
A Blanked develops its Benefits only if it is kept dry. A wet Blanked exacerbates the situation creating Memory Effects for Misalignments.
The Stability and Longevity depends in a high extent if the Water can be taken out and kept away from the Track-Bed.
Cuttings disturb the natural Waterflow and are an Injury to the Nature; if not adequately secured Nature will take Revenge with Hill-, Mud-, Earth- or Rock-Slides, which can lead to nasty Railway Accidents.
One has to manage effectively the all-important Wheel-Rail Interface.
Political Interference and Corruption may wreck Quality.

Revised by Dr. Frank Wingler, JANUARY, 2016

Chapter 8

Ballast, Formation and Drainage

8.1 LOAD TRANSFER IN TRACK

The track has the purpose to transfer in a satisfactory manner the train load to the formation. During this transfer it has to be ensured that the track components are not subjected to loads beyond their bearing capacity. The conventional track consists of rails, sleepers and ballast bed. Load transfer works on the principle of stress reduction layer by layer, as depicted schematically in **Fig. 8.1**:

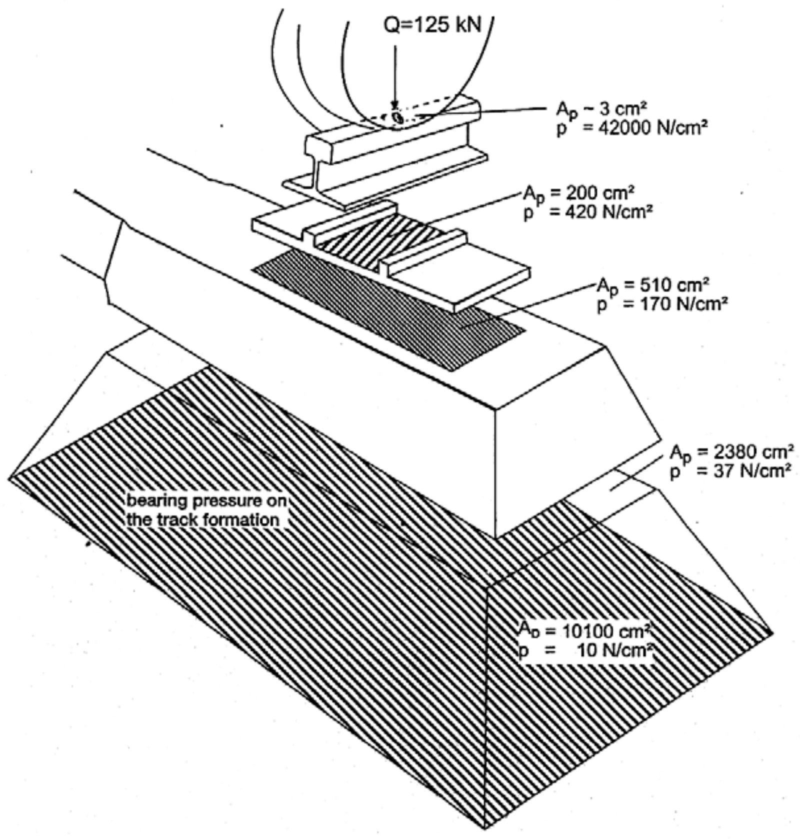


Fig. 8.1: Principle of Load Distribution of the Wheel Force Q through the individual System Components of the Track

The greatest stress occurs between wheel and rail. The stress is in the order of 42 kN/cm^2.It has to be gradually brought down to about 10 N/cm^2 at the formation level. Ballast in railway track performs an important function in order to bring down the stress to a level, which the formation can safely bear without any undue settlement.

8.2 STANDARD TRACK NOMENCLATUR

Below is a set of terms defined and used for ballast and formation illustrated in **Fig. 8.2**, which shows a plan and a cross-section for a railway track.

1. **Track-Structure:** Rails, sleepers, their fastenings and ballast constitute the track structure.

2. **Track-Foundation:** The blanket and other constituents placed between track structure and the sub-grade to avoid failure of sub-grade below constitute the track foundation.
3. **Ballast:** It is a high quality crushed stone with desired specifications placed immediately beneath the sleeper.
4. **Ballast-Section**: A section of the ballast, taken perpendicularly across the track in between the sleepers brings out the ballast section.
5. **Ballast-Profile:** The diagram indicating the ballast position with respect to the formation and the track component is called the ***"Ballast Profile"***.
6. **Ballast-Cushion:** The depth of ballast below the bottom of the sleepers, normally measured under the rail seat, is termed as the ballast-cushion (**d** in **Fig. 8.2**).
7. **Cess:** It is that part of the formation, which lies between the toe of the ballast and the edge of the formation.
8. **Crib-Ballast:** Ballast provided in between sleepers, i.e. in the sleeper cribs, is called ***"Crib Ballast"*** (**Cb** in **Fig. 8.2**).
9. **Formation**: It is the surface on which the ballast is laid. It is also known as the roadbed.
10. **Formation-Level:** It is the level of the prepared surface on its centre line, including the blanketing material, if any.
11. **Formation-Width:** It is the distance between the edges of the prepared surface.
12. **Shoulder-Ballast:** Ballast provided beyond the sleeper edge is called ***"Shoulder-Ballast"***. The distance by which the ballast top line projects beyond the edge of sleeper is called ***"Shoulder Width of Ballast"***.
13. **Side-Slope:** It is the inclined surface of an embankment on cutting.
14. **Side-Slope of Ballast:** The slope at which the ballast top line at the shoulders meets the formation line is termed as side slope of the ballast. It is usually kept as 1.5:1.
15. **Sub-Grade:** It is the part of embankment cutting on which track and its foundations are supported, and it is made of the same material as that of the embankment or the sub-soil in cutting.
16. **Sub-Soil:** It is the soil immediately under the natural ground level.

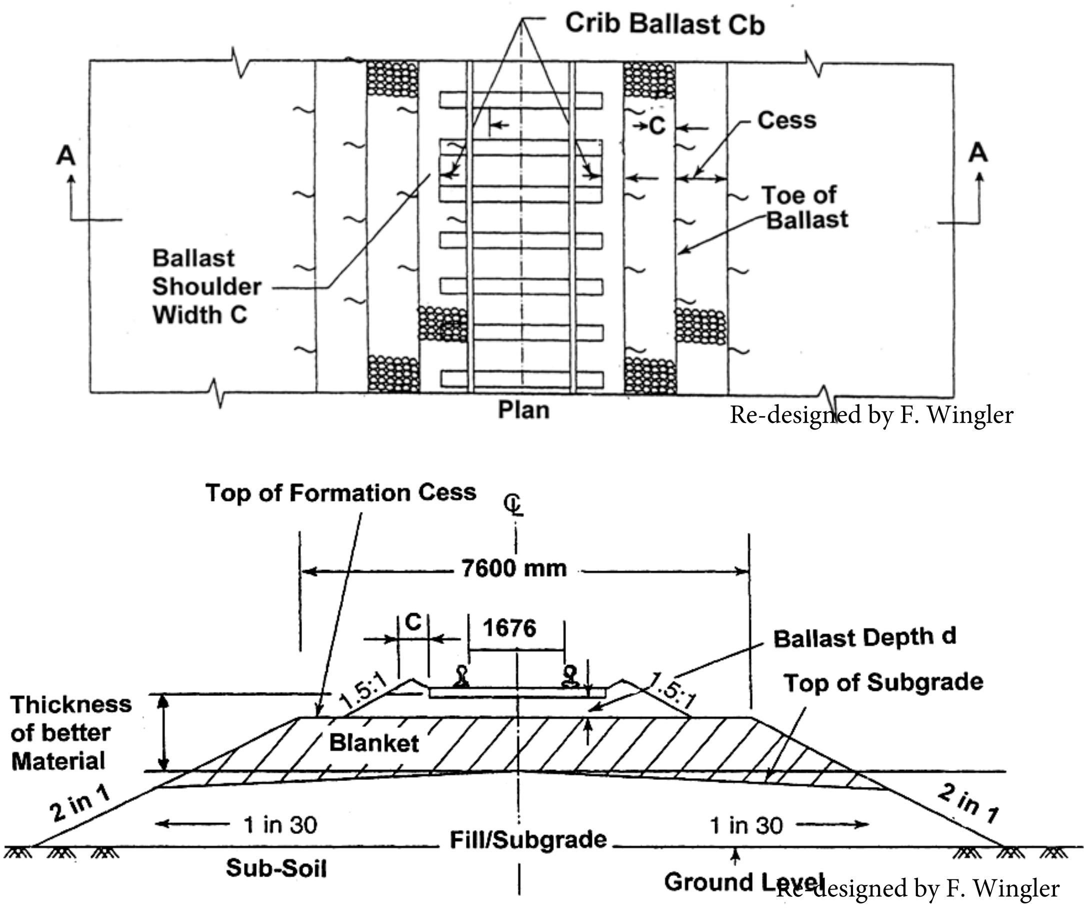


Fig. 8.2: Plan and Cross-Section of a Railway Track

8.3 BALLAST

Ballast is an important constituent of conventional track structure. It is the granular material consisting usually of broken stones or bricks, shingles or kankar, gravel or sand placed and packed below and around the sleepers to transmit load from sleepers to the formation and at the same time allowing drainage of the track. It provides a suitable foundation for the sleepers and also holds the sleepers in their correct level and position, preventing their displacement by lateral or longitudinal thrusts.

Granite, quartz, trap, sandstone, limestone etc. have been used as stone ballast in India. The shape of the ballast should be cubic and/or angular. This will be automatically achieved, if the parent rock material is non-stratified and has a good compressive strength.

Even earth and ashes are used as packing material on some unimportant lines and sidings; however, these are not relevant to a normal track structure.

Ballast performs the following important functions in a track:

1. Carries the load and distributes it safety on to the formation.
2. Provides a firm, level and resilient bed for the sleeper.
3. Facilitates easy drainage.
4. Fills inequalities on the formation.
5. Provides lateral and longitudinal stability to track.
6. Protects formation against rains and winds.
7. Protects the sleepers from capillary moisture of formation.
8. Does not allow free vegetation growth.
9. Provides a medium for energy absorption of all impact forces coming from rolling stocks by undergoing a temporary change in composite contact relationship among the ballast particle. The ballast particles can be lifted back to their normal level by manual packing or mechanical tamping. This is one of the most vital functions that the ballast performs in the track.

8.4 STRESS IN BALLAST

The transmission of the pressure from the sleepers to the ballast depends upon the elastic properties of the sleepers, the degree of compaction and the nature of the ballast bed. Bigger cess and a greater section of sleeper with longer sleeper length will result in decreased pressure on ballast and formation. **Fig 8.3** shows the typical pressure distribution in ballast section.

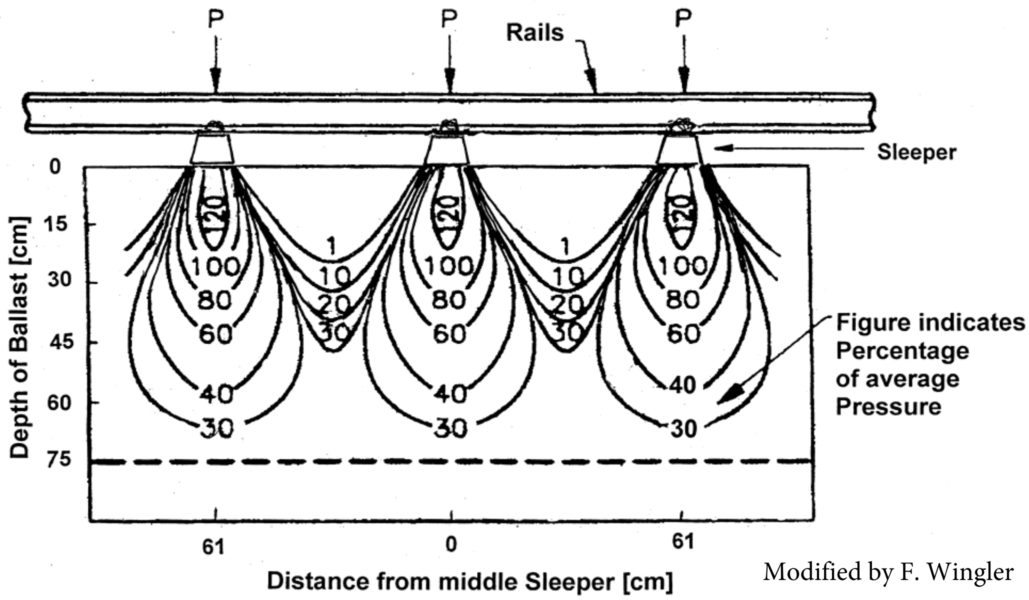


Fig. 8.3: Distribution of Pressure in Ballast Section

8.5 BALLAST SPECIFICATION ON INDIAN RAILWAYS

8.5.1 General

1. **Basic Quality:** Ballast should be hard durable and as far as possible angular along edges/corners, free from weathered portions of parent rock, organic impurities and inorganic residues.
2. **Particle Shape:** Ballast should be cubical in shape as far as possible. Individual pieces should not be flaky and should have generally flat faces with not more than two rounded/sub rounded faces.
3. **Mode of Manufacture:** Ballast for all BG main lines and running lines, except on 'E' routes but including 'E' special routes, shall be machine crushed. For other BG lines and MG/NG routes planned/sanctioned for conversion, the ballast shall preferably be machine crushed. Hand broken ballast can be used in exceptional cases with prior approval of Chief Track Engineer/CAO/C. Such approval shall be obtained prior to invitation of tenders.
4. **On other MG and NG** routes not planned/sanctioned for conversion hand broken ballast can be used for which no approval shall be required.

8.5.2 Physical Properties

Ballast samples should satisfy the following physical properties in accordance with IS: 2386 Pt.IV-1963 when tested as per the procedure laid down in **Table 8.1a**:

Table 8.1a: Physical Properties of Ballast

	BG, MG and NG (planned/sanctioned for Conversion)	NG and MG (other than those planned/sanctioned for Conversion)
Aggregate Abrasion Value:	30% max.*	35% max.
Aggregate Impact Value:	20% max.*	30% max.

*) In exceptional cases, on technical and/or economic grounds, relaxable up to 35% and 25% respectively by CTE in open line and CAO/C for construction projects. The relaxation in Abrasion and Impact Values shall be given prior to invitation of tender and should be incorporated in the tender document.

The **'Water Absorption'** tested as per IS 2386 Pt.III-1963 should indicate not more than 1%. This test is to be prescribed at the discretion of CE/CTE for open lines and CAO/Con. for construction projects.

8.5.3 Size and Gradation

- **Ballast should satisfy the following Size and Gradation:**
  1. Retained on 65 mm square mesh sieve 5% maximum.
  2. Retained on 40 mm square mesh sieve* 40%-60%.
  3. Retained on 20 mm square mesh sieve not less than 98% for machine crushed and not less than 95% for hand broken.

     *) For machine crushed ballast only.
- **Oversize Ballast:**
  1. Retention on 65mm square mesh sieve: A maximum of 5% ballast retained on 65mm sieve shall be allowed without deduction in payment. In case ballast retained on 65mm sieve exceeds 5% but does not exceed 10%, payment at 5% reduction in contracted rate shall be made for the full stack. Stacks having more than 10% retention of ballast on 65mm sieve shall be rejected.
  2. In case ballast retained on 40 mm square mesh sieve (machine crushed case only) exceeds 60% limit prescribed above, payment at the following reduced rates shall be made for the full stack in addition to the reduction worked out at 1. above:

3. In case retention on 40 mm square mesh sieve exceeds 70%, the stack shall be rejected.
4. In case of hand broken ballast supply, 40 mm sieve analysis may not be carried out. The executive may however ensure that the ballast is well graded between 65 mm and 20 mm size.

- **Under Size Ballast:**

  The Ballast shall be treated as undersize and shall be rejected if:

  (a) Retention on 40 mm square mesh sieve is less than 40%.

  (b) Retention on 20 mm square mesh sieve is less than 98% (for machine crushed) or 95% (for hand broken).

- **Method of Sieve Analysis:**

1. Sieve sizes mentioned in this specification are nominal sizes. The following tolerances in the size of holes for 65, 40 and 20 mm nominal sieves sizes shall be permitted:
   (a) 65 mm square mesh sieve plus minus 1.5 mm,
   (b) 40 mm square mesh sieve plus minus 1.5 mm and
   (c) 20 mm square mesh sieve plus minus 1.0 mm.
2. Mesh sizes of the sieves should be checked before actual measurement. The screen for sieving the ballast shall be of square mesh and shall not be less than 100 cm in length, 70 cm in width and 10 cm in height on sides.
3. While carrying out sieve analysis, the screen shall not be kept inclined, but held horizontally and shaken vigorously. The pieces of ballast retained on the screen can be turned with hand, to see if they pass through, but should not be pushed through the sieve.
4. The percentage passing through or retained on the sieve shall be determined by weight.

8.6 BALLAST PROFILES, SECTIONS AND DEPTH OF BALLAST-CUSHION

8.6.1 Depth of Ballast-Cushion

One of the important functions of the ballast is to distribute the load coming onto the sleeper safely into the formation. The pressure from the sleeper spreads through the body of the ballast. For coarse, rough, dry and clean ballast this angle is about 45°, but becomes smaller for moist and dirty ballast. This brings out distinctly the advantage of clean ballast-cushion in reducing the formation pressures.

To obtain wider distribution of the wheel loads upon the formation, it is advantageous to have the longest and the broadest sleeper possible. The quality of the ballast should be such as to provide the widest possible angle of pressure spread and deep enough to distribute the oncoming loads to the maximum area at the level of the formation.

Although the lines of equal pressure in ballast brought in by the wheel loads are in the shape of a 'bulb' (refer to **Fig. 8.3**) yet for simplicity purpose the load dispersion can be assumed at 45º to the vertical. For uniform distribution of load on the formation the depth of ballast should be such that the dispersion lines do not overlap each other. From simple geometry of **Fig. 8.4** the depth of ballast can be calculated as below:

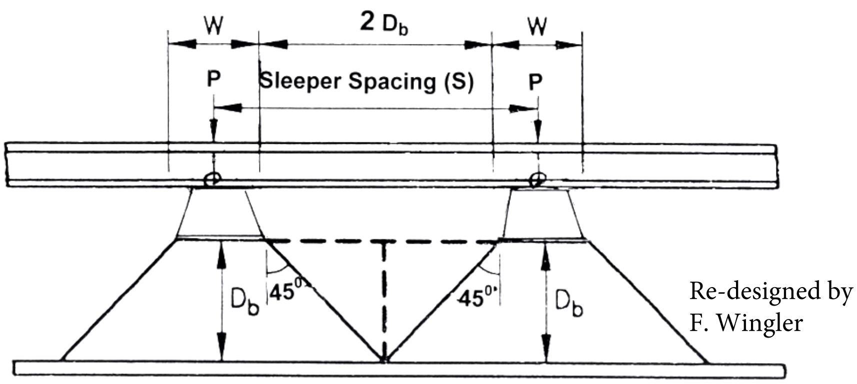


Fig. 8.4: Minimum Depth of Ballast

Sleeper Spacing (S) – Width of Sleeper Density (W) + 2 x Depth of the ballast (Db) or S = W + 2 x Db.

$$Db = \frac{S - W}{2} = \text{minimum Depth of ballast}$$

For example, with a sleeper density as (n+7) ,a sleeper spacing of 65 cm and a width of sleeper of 25 cm the minimum depth of ballast from the above formula works out to be 20 cm, which is minimum depth of ballast generally prescribed on Indian Railways.

The depth of ballast-cushion as prescribed for various groups of tracks on Indian Railways is given in **Table 8.1b:**

Table 8.1b: Depth of Ballast-Cushion

Group	Recommended Depth
BG Group 'A'	300 mm
BG Group 'B' and 'C'	250 mm
BG Group 'D'	200 mm
BG Group 'E'	150 mm
MG 'Q' routes	250 mm (300 mm when speed is 100 kmph)
MG 'R'-1 routes	250 mm
MG 'R'-2/'R'-3 routes	200 mm
MG 'S' routes	150 mm
NG	150 mm

Note:

(a) In case of SWR the recommended depth is 200 mm.

(b) Whenever primary renewals are carried out even on 'E' routes, the minimum depth of ballast of 200 mm shall be provided.

(c) Minimum depth of ballast under the rail seat of the sleepers shall be 150 mm except under PRC sleepers, where it shall be 250 mm.

(d) Wherever 22.1 t axle-load rolling stocks are nominated to run, the minimum depth of ballast shall be 350 mm.

8.6.2 Ballast Profile

It is mainly determined by (a) Ballast-Cushion, (b) Shoulder-Ballast, (c) Crib-Ballast and (d) Side- Slope of Ballast. Deeper ballast-cushion ensures better distribution of load onto the formation.

The main purpose of shoulder ballast is to retain the lateral movement of track. Crib ballast gives resistance to the longitudinal movement of track. To retain the ballast to a certain section, it is essential to provide some stable side slopes. Years of experience of track maintenance and the results obtained from research and experiments have helped the railways to arrive at the optimum ballast profiles for various track gauges and the types of sleepers.

On curves, extra ballast on the outer shoulder helps the track structure to cope with the centrifugal forces generated by the moving vehicles. In LWR, ballast plays a vital role in lending longitudinal and lateral stability to track under locked-up compressive and tensile forces. To meet this situation, curves and LWR tracks are heaped up with extra ballast.

Ballast profiles recommended for adoption for various groups of BG and MG (other than LWR/CWR) are given in **Fig. 8.5/Table 8.2** and **Fig. 8.6/Table 8.3**.

Ballast profiles recommended for adoption on LWR/CWR tracks are given in **Chapter10**.

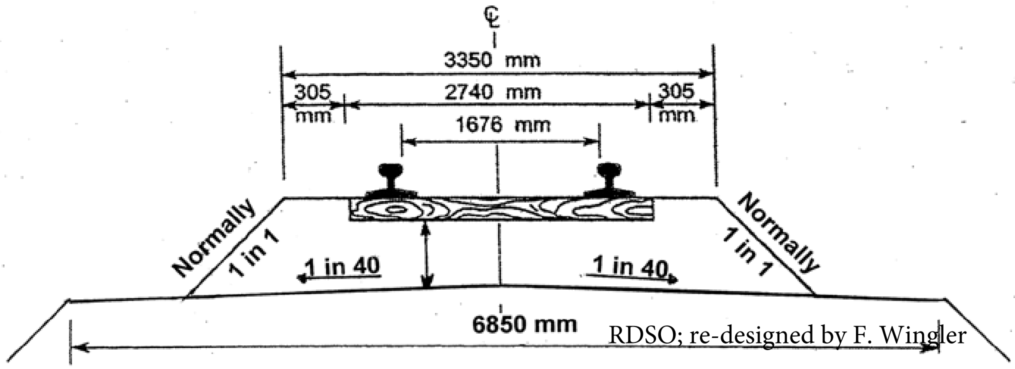


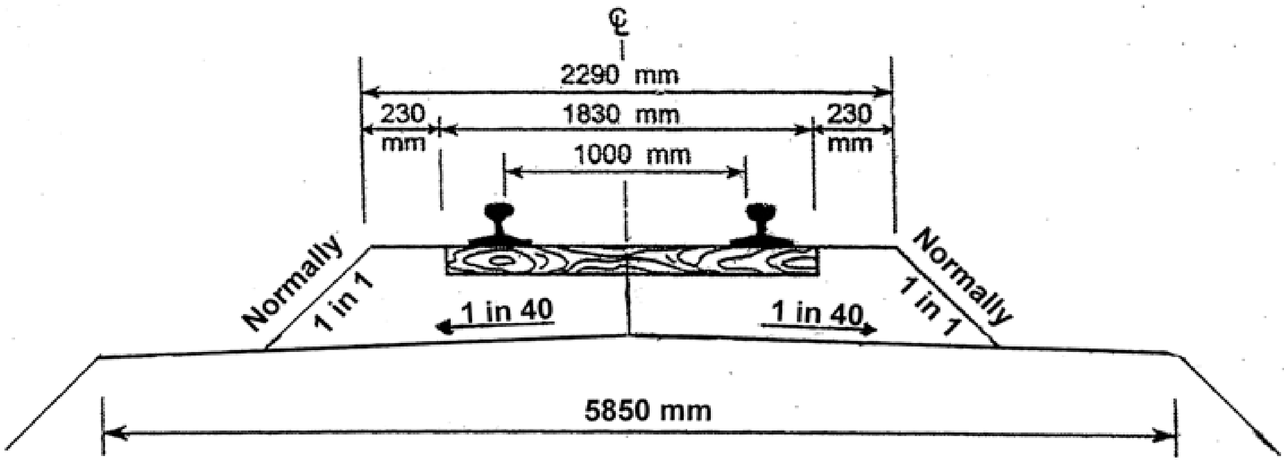
Fig. 8.5: Standard Ballast Profile for BG Track: other than LWR/CWR

Table 8.2: Requirements of Ballast Depth/Quantity for BG Fish-plated Track; other than LWR/CWR

Group	Recommended Depth of Ballast Cushion [mm]:	Quantity of Ballast [m^3] required per Meter Track	
		on Straight and Curves of Radius flatter than 600 m:	on Curves of Radius tighter than 600 m:
'A'	300	1.586	1.634
'B' and' 'C'	250	1.375	1.416
'D'	200	1.167	1.202
'E'	150	0.964	0.996

Note:

1. On ordinary fish-plated tracks: To be increased to 400 mm outside of curves tighter than 600 m.
2. On short welded panel tracks: To be increased to 400 mm outside of all curves flatter than 875 m and to 450 mm on curves tighter than 875 m.
3. On turnouts in passenger yards: To be increased to 550 mm on the outside of the turn in curves.
4. On SWR the minimum of ballast-cushion should be 200 mm.



RDSO; re-designed by F. Wingler

Fig. 8.6: Standard Ballast Profile for MG; other than LWR/CWR

Table 8.3: Requirements of Ballast-Depth/Quantity for MG Fish-plated Track; other than LWR/CWR

Routes	Recommended Depth of Ballast Cushion [mm]:	Quantity of Ballast [m³] required per Meter Track on Straight and Curves of Radius flatter than 600 m:	on Curves of Radius tighter than 600 m:
'Q' Routes, 100 kmph:	300	1.170	1.145
'Q' Routes, < 100kmph:	250	0.965	1.033
'R'-1 Routes:	250	0.965	1.033
'R'-2 Routes, where LWR is contemplated:	250	0.965	1.033
'R'-2 Routes, where LWR is not contemplated:	200	0.817	0.905
'R'-3 Routes:	200	0.817	0.905
'S' Routes:	150	0.673	0.725

Note:
1. On fish-plated tracks: To be increased to 400 mm outside of curves tighter than 600 m.
2. On short-welded panels: To be increased to 330 mm on all curves flatter than 600 mm.
3. On junction turnouts of passenger yards: To be increased to 550 mm on the curve-outsides.
4. On SWR tracks the minimum cushion-depth shall be 200 mm.

8.7 FORMATION

8.7.1 Purpose of Formation

The formation is required to serve the following purposes:
1. To provide support for a stable track structure, i.e. cumulative settlements under repeated loadings should be as uniform as possible and within acceptable limits.
2. To provide desired line and level for track.
3. To provide a smooth and regular surface on which ballast and track can be laid.

8.7.2 Definition

1. **Track Foundation:** Constitutes blanket and sub-grade, which is placed/exist below track structure to transmit load to sub-soil.
2. **Ballast:** Crushed stones with desired specifications placed directly below the sleepers.
3. **Sub-Ballast:** Sub-ballast is a layer of coarse-grained material provided between blanket/sub-grade and ballast and confined to width of ballast section only. Sub-ballast is not in vogue on Indian Railways.
4. **Blanket:** Blanket is a layer of specified coarse, granular material of designed thickness provided over full width of formation between sub-grade and ballast.
5. **Sub-Grade:** It is part of embankment/cutting provided above sub-soil by borrowed soil of suitable quality up to bottom of blanket/ballast.
6. **Cohesive Sub-Grade:** Sub-grade constructed with soils having cohesive i.e., shear strength is predominantly derived from cohesion of the soil and is termed as cohesive sub-grade. Normally, soils having particles finer than 75 micron exceeding 12% exhibit cohesive behavior. As per IS classification, all fine-grained soils and GM, GM-GC, GC, SM, SM-SC & SC types of soils exhibit cohesive behaviour. Brief details of soil classification as per IS: 1498, are given at **Annexure-I**.
7. **Cohesion-less Sub-Grade**: In sub-grades constructed with cohesion-less or coarse-grained soils i.e. the shear strength is predominantly derived from internal friction of the soil. This is termed as cohesion-less sub-grade. Soils having normally less than 5% particles finer than 75 micron exhibit cohesion-less behaviour. As per IS Classification, GW, GP, SW & SP types of soils fall in this category.

8. **Other Types of Soils,** which have soil particles finer than 75 micron between 5 to 12%, need detailed study for ascertaining their behaviour.
9. **Dispersive Soil:** Dispersive clayey soils are those, which normally deflocculated when exposed to water of low salt content. Dispersive clayey soils are generally highly erosive and have high shrink and swell potential. These soils can be identified by Crumb, Double Hydrometer, Pin Hole and Chemical Tests.
10. **Formation Top:** Boundary between ballast and top of blanket or sub-grade (where blanket layer is not provided).
11. **Cess:** It is part of the top of formation from toe of ballast to edge of formation.
12. **Formation**: It is a general term referring to the whole of blanket, sub-grade and sub-soil.
13. **Sub-Soil:** Soil of natural ground below sub-grade.
14. **Unstable Formation:** It is yielding formation with non-terminating settlement including slope failure, which requires excessive maintenance efforts.

8.7.3 Earthworks for Formation

To keep the permitted gradients and to avoid too frequent changes of gradient, it is usually necessary in different places for the level of formation to be below or above the natural ground level.

The natural ground is lowered, where it is high. Where the natural ground is low an embankment is made. In extreme cases, where the depth of cutting would be excessive, tunnels are made through the ground. And where an embankment is not possible, the track is supported on bridges or viaducts.

When a new railway line is planned, soil surveys and exploration must be undertaken. An effort is made to locate it in such a manner that the amount of material excavated from the cuttings is sufficient to form the necessary embankments. If this can be done, the expense of disposing of surplus excavated material or of obtaining material for embankments from other sources will be avoided.

If the material from excavation is not sufficient to form the necessary embankment, the required material will generally be obtained from borrow pits located close to the railway alignment. In low lying flood prone country, the formation level is kept well above the highest known flood level of the site by forming an embankment with material obtained by excavating borrow pits on either sides of the railway line.

The land purchased for the construction of the railway line is generally enough to accommodate the slopes, the borrow pits and the spoil banks and for some margin between the toe of the bank and the borrow pits/spoil banks; **Fig. 8.7a** and **Fig. 8.7b:**

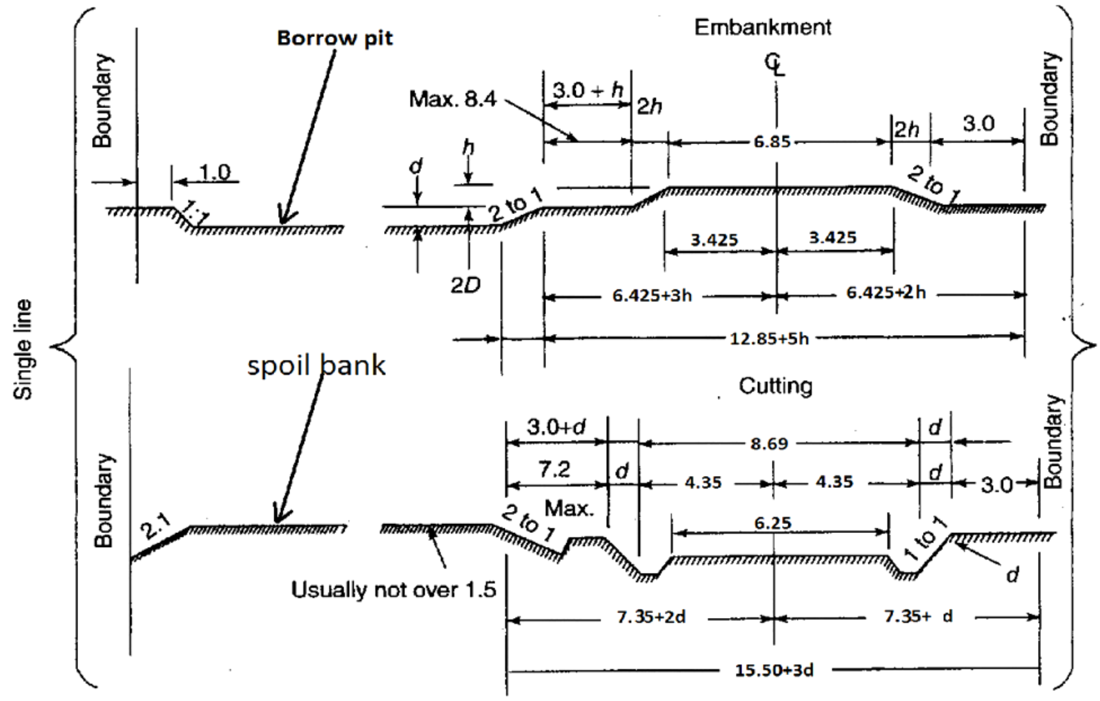
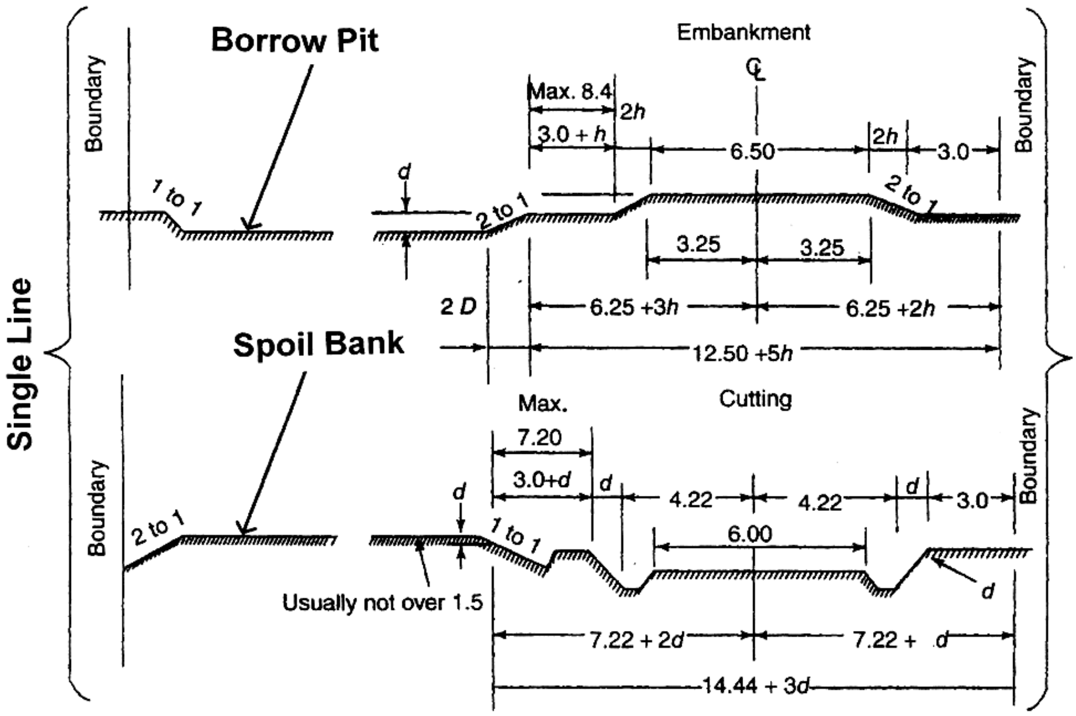


Fig. 8.7a: General Cross-Sections showing Width of Land to be taken-up for BG; Length Dimensions in [m]



Note: All dimensions are in metres

Fig. 8.7b: General Cross-Sections showing Width of Land to be taken up for MG; Length Dimensions in [m]

8.7.4 Soil Exploration and Survey

Objectives of constructing a stable formation can only be achieved, if soil exploration is undertaken in right earnest, and precautions are taken to design bank and cutting against likely causes, which could render troublesome during service.

Objectives of Soil Exploration

Main objectives of soil survey and exploration work are:

1. To determine soil type with a view to identify their suitability for earthwork in formation and to design the foundation for other structures.
2. To avoid known troublesome spots, unstable hill sides, swampy areas, soft rock areas and peat lands etc..
3. To determine method of handling and compaction of sub-grade.
4. To identify suitable alignment for embankment and cutting from stability, safety and economy in construction and maintenance considerations.
5. To identify suitable borrow areas for desired quality and quantity of sub-grade and blanket material.
6. To determine depth of various strata of soil and bed rock level.
7. To determine ground water table position and its seasonal variation and general hydrology of the area such as flood plains and river streams etc..
8. To determine behaviours of existing track or road structure natures and causes of geo-technical problems in them, if any.

8.7.5 Design of Railway Formation

In order to construct a formation, that gives trouble free service under the most adverse conditions of loading, maintenance and weather, it is necessary that sub-grade in bank or cutting is structurally sound so as not to fail in shear strength under its own load and live loads, and secondly any settlement due to compaction and consolidation in sub-grade and sub-soil should be within the permissible limits.

- **Various Aspects of Designing a Sub-Grade and Sub-Soil:**
  Sub-grade should be designed to be safe against shear failure and large deformations. Adequacy of sub-soil against shear strength and settlement should also be examined.
- **Deficient Shear Strength of Sub-Grade and/or Sub-Soil leads to**:
  1. Bearing capacity failure of sub-grade, resulting into cess and crib heave. Deep ballast pockets are formed as a result of such failures. Inadequate cess width is also responsible for initiation and enhancement of bearing capacity failure of sub grade.
  2. Interpenetration failure or mud pumping failure, resulting into vitiation of clean ballast-cushion, and
  3. Slope failure, if factor of safety against slope stability is not adequate. Therefore, sub-grade/sub-soil should be designed to ensure not to allow any shear failure.
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  3. Slope failure, if factor of safety against slope stability is not adequate. Therefore, sub-grade/sub-soil should be designed to ensure not to allow any shear failure.
- **Large Deformation without Shear Strength Failures of Soil can be due to:**
  1. Poor compaction during construction and consolidation (primary and secondary) of sub-grade and/or sub-soil.
  2. Settlement and heave due to shrinking and swelling characteristics of sub-grade and/or sub-soil. The swelling and shrinkage characteristics of sub-soil shall be significant in cases where bank height is less than 1 m or it is in cutting.

These aspects should be taken into account at the time of construction to avoid large settlements causing maintenance problems and leading to formation failure.

8.7.6 Top Width of Formation

1. It should be adequate enough to accommodate track laid with concrete sleepers and standard ballast section and have minimum 900 mm cess width on either side. Formation widths adopted in the Indian Railways are given in **Fig. 8.8 and Table 8.4:**

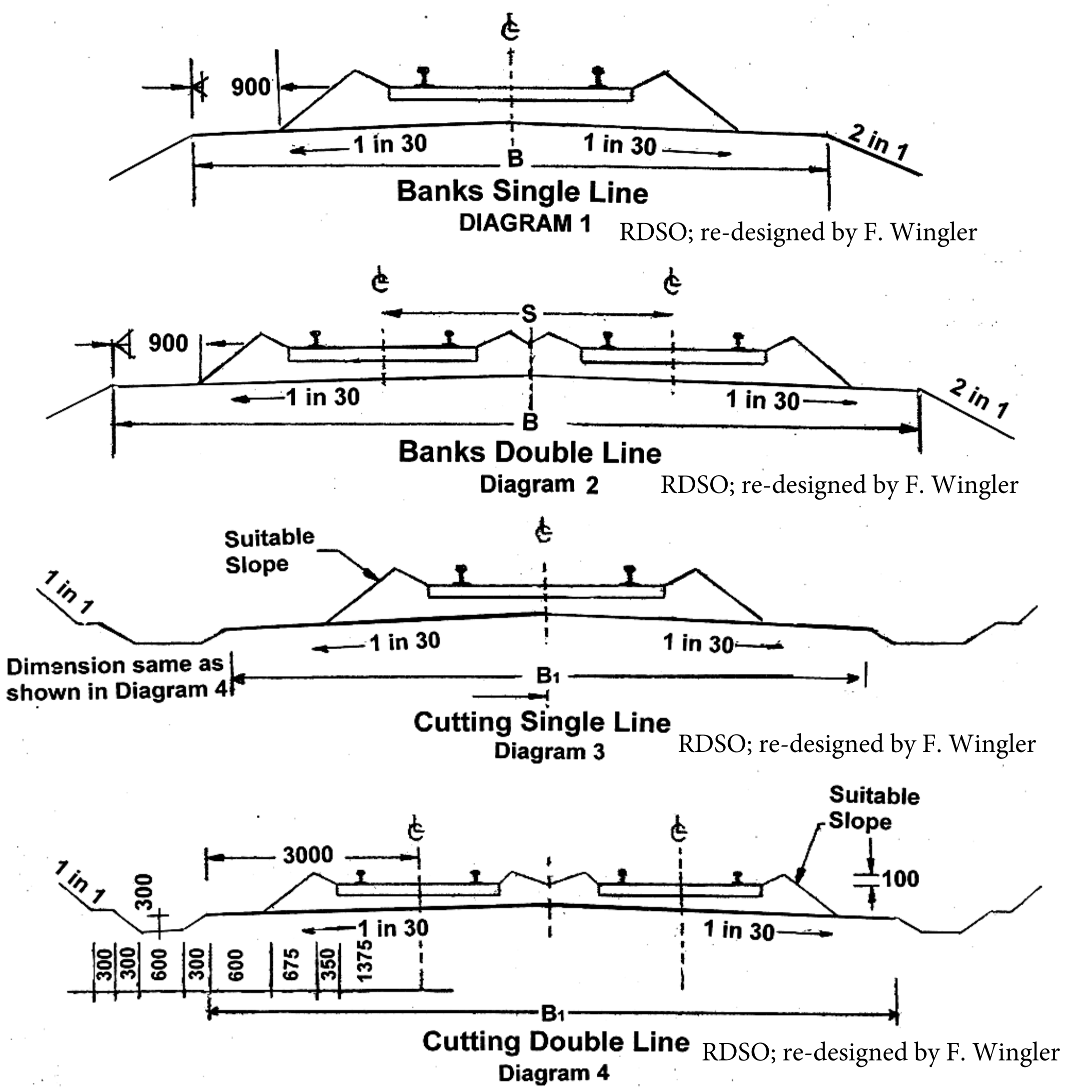

Fig. 8.8: Minimum Formation Widths for Bank/Cuttings for Concrete Sleeper Tracks: Dimensions in [mm]

Table 8.4: Minimum recommended Formation Width [m] for Concrete Sleeper Tracks

Gauge [mm]	in Banks (B) Single Line	in Banks (B) Double Line	in Cuttings (B1) Single Line	in Cuttings (B1) Double Line
BG: 1676	6.85	12.16	6.25	11.55
MG: 1000	5.85	9.81	5.25	9.21

Notes:

1. All dimensions in the diagrams of **Fig. 8.8** are in [mm].
2. On BG and MG double lines the minimum formation width is based on the distance [S] between track centres of 5.30 m and 4.96 m respectively.
3. In flat terrains the height of the bank/depth of cuttings should preferably be not less than 1 m to ensure good drainage, formation stability and to avoid trespassing.
4. These dimensions are based on a ballast-cushion of 30 cm.

5. The dimensions are also applicable in case of all new lines in case of the later use of concrete sleepers.
6. On curves the formation width shall be increased as follows:
   (a) For extra ballast-cushion on outside of single line curves an 15 cm increase and a 30 cm increase on the outside of double line curves including 15 cm increase of track centre distance.
   (b) For extra clearance required for double lines due to super-elevation ect. as stipulated in the RDSO appendix to the schedule of dimensions for BG and MG.
7. The formation widths have been calculated according an assumed ballast side slope of 1 in 1.
8. Additional width of formation will have to be provided to cater for increase in extra ballast on the outside of curves.
9. Adequate drainage must be ensured for the worst in service conditions. The top of formation should have a cross slope of 1 in 30 from centre of track towards both sides.
10. The design should provide for a suitable and cost-effective erosion control system considering soil matrix, topography and hydrological conditions.
11. It will be necessary to keep borrow pits sufficiently away from the toe of the embankments to prevent base failures due to lateral escapement of the soil. The distance of borrow pit from the bank will have to be decided in each case on its merits. Existing borrow pits close to toe of bank may be filled or its depth should be taken into account in analysing slope stability of the bank.
12. In the case of embankments/cuttings in highly cohesive clayey soils, special treatment may be necessary to ensure a stable formation. Such measures will have to be determined after thorough investigation and study of the soil properties.
13. Special investigation will also be necessary in regard to high fill construction on swampy ground or marshy lands and deep cuttings.
14. In case of all new constructions minimum height of embankment should not be less than 1 metre to ensure proper drainage, avoid organic matters and trespassing.
15. Soils prone to liquefaction falling in gradation zone as per sketch at **Annexure-II** and having coefficient of uniformity Cu < 2 should be adequately designed to take care of this.

8.7.7 Design of Embankment Side Slopes

1. Slope stability analysis should be carried out to design stable slopes for the embankments. Usually slopes of 2 : 1 of embankment up to height of 6.0 m would be safe for most of the soils. However, this analysis has to be carried out in detail for any height of embankment in following situations:
   (a) When sub-soil is soft, compressible and of marshy type for any depth.
   (b) When sub-grade soil (fill material) has very low value of cohesion C such that $C/\gamma H$ (where H is the height of the embankment and γ is bulk density of soil) is negligible, i.e. in the range of 0.01 or so.
   (c) When highest water table is within 1.5 x H (H is the height of embankment) below ground level, then submerged unit weight of soil below water level should be taken.
2. In cutting slopes, softening of soil occurs with the passage of time, and therefore long term stability is most critical and should be taken into consideration while designing the cuttings.
3. Detailed slope stability analysis should be carried out as per procedure laid down for this purpose.

8.7.7 Materials for Construction

Construction of embankment is to be carried out normally with soil available in nearby area with proper design of slope and desired bearing capacity. However, there are some soils, which are not normally suitable to be used in construction of new lines as detailed below:

1. Organic clays, organic silts, peat, chalks, dispersive soils, poorly graded gravel and sand with uniformity coefficient less than 2.
2. Clays and silts of high plasticity (CH & MH) in top 3 m of embankment.

8.7.8 Execution of Formation and Earth Works

Execution of work has to be carried out in systematic manner so as to construct formations of satisfactory quality, which would give trouble free service. Important activities in the execution of earthwork are as follows:

1. Compaction of earth work.
2. Placement of back-fills on bridge approaches and similar Locations.
3. Drainage arrangement in banks and cuttings.
4. Erosion control of slopes on banks and cuttings.

8.7.8.1 Compaction of Earth Work

Performance of the embankment would depend to large extent on the quality of compaction done during execution. Need to ensure proper compaction and precautions/guidelines for this have been given as follows:

Advantage of Compaction: Compaction is the process of increasing the density of soil by mechanical means by packing the soil particles closer together with reduction of air voids and to obtain a homogeneous soil mass having improved soil properties. Compaction brings many desirable changes in the soil properties as follows:

1. Helps soils to acquire increase in strength in both bearing resistance and shear strength.
2. Reduces compressibility, thus minimizing uneven settlement during service.
3. Increases density and permeability, thereby reducing susceptibility to change in moisture content.
4. Reduces erosion.
5. Results in homogenous uniform soil mass of known properties.
6. Reduction in frost susceptibility in cold regions.
7. While compaction of earthwork is a necessary condition to achieve a stable formation, it does not help in checking against the following causes, which needs to be taken care during the design of bank or cutting:
    (a) Excessive creep or slipping of slopes.
    (b) Swelling and shrinkage characteristic of soils due to variation in moisture content because physical-chemical properties of a soil do not change on compaction.
    (c) Mud-pumping at ballast soil interface.
    (d) Settlements due to consolidation of bank and sub-soil, which can occur even few years after construction of the bank.

Methods of Compaction: The methods of compaction can be divided into three groups, viz.:

1. Suitable for sandy or silty soils with moderate cohesion; these soils on drying do not form hard lumps of soils, which could create difficulty in breaking under rollers.
2. Cohesive soils such a clayey sands (SC), clayey gravels (GC), silty sand mixture (SM), silty gravel mixture (GM) and other soils having predominantly clay fraction, which form hard lump of soil on drying and are difficult to break under rollers and
3. suitable for cohesion-less soils, which remain loose under dry and wet conditions.

The classification between the first and the second categories largely depends on the percentage of plastic fines and their properties.

Compaction of sandy or silty Soils with moderate Cohesion:

1. For soils with moderate cohesion, compaction in layers by rollers is most effective. Vibratory rollers have been found more effective than static rollers, and greater thickness of layers can be allowed.
2. Water content and densities obtained in the field trails should conform to IS: 2720 (Pt. VIII)-1983 to determine thickness of layers, dry densities to be achieved and the optimum moisture content. Densities should be around maximum dry densities obtained during these

tests and form the basis of specifications and control. The moisture content controls may not be specified, and 98% of such densities as achieved in field trails are only specified.

Compaction of Cohesive Soils (Clays):

1. The main objectives to compact predominantly clayey soils are, to achieve an uniform mass of soil with no voids between the chunks of clays, which are placed during the earthwork. Rollers will tend to sink into the soil if the moisture content is too high, while chunks will not yield to rolling by rollers if the moisture content is too low. Maximum dry densities and optimum moisture contents should be ascertained from laboratory tests for heavy compaction as specified in IS: 2720 (Pt. VIII)-1983. The laboratory results may only be used to determine those practically achievable values of densities and optimum moisture contents as obtained from the field trails as per IS: 10379-1982.
2. Sheep foot rollers are most effective in breaking the clods and in filling large spaces. The layer thickness should be equal to the depth of the feet of roller plus 50 mm.

Compaction of Cohesion-less Soils:

1. An effective method of compacting cohesion-less soils is to use vibratory compaction. Moisture content control being redundant is not necessary. However, the railway embankments may show small settlements during the initial stages of traffic after the line is opened. Moreover, introduction of new type of stock with different vibratory characteristics and axle-loads etc. may also result in small settlements due to the embankment soil undergoing further compaction. These settlements would be small and may not present much problem. As such, there does not appear to be much gain in compacting the whole embankment formed of purely cohesion-less soils except in the top 1 m layer.
2. Poorly graded sands and gravels with uniformity coefficient of less than 2.0 should not be used in earthwork for the banks to safeguard against liquefaction under moving loads or especially due to an earthquake tremor.
3. IS Code No. 2720 (Pt. XIV)-1983 should be followed for compaction in cohesion-less soils. Minimum 70% relative density must be achieved during compaction, which shall be done in layers of uniform thickness not exceeding 60 cm.

8.7.8.2 Placement of Back-Fills on Bridge Approaches and similar Locations

The back fills resting on natural ground may settle in spite of heavy compaction and may cause differential settlements, vis-à-vis abutments, which rest on comparatively much stiffer base. To avoid such differential settlements, while on one hand it is essential to compact the back fill in the properly laid layers of soil, on the other hand the back fill should be designed carefully to keep:

1. Settlements within tolerable limits.
2. Coefficient of sub-grade reaction should have gradual change from approach to the bridge.

Fill material being granular and of sandy type soil need to be therefore placed in 150 mm or lesser thick layers and compacted with vibratory plate compactors. When placing backfill material benching should be made in approach embankments to provided proper bonding.

8.7.8.3 Drainage Arrangement in Banks and Cuttings

Drainage is the most important factor in the stability of bank/cutting in railway construction. Effective drainage of the rainwater in the monsoon season is very important to safeguard bank/cutting from failures. Railway formation is designed for fully saturated condition of soil. Flow of water should not be allowed along the track as it not only contaminates ballast but also erodes formation. Stagnation of water for long time on formation is not desirable. Drainage systems should be therefore efficient enough to prevent stagnation and it should allow quick flow of water. Some guidelines on this aspect are as follows:

- **Drainage of Embankment:**

  Cross slope is provided in bank from center towards end to drain out surface water. Normally there is no need of side drains in case of embankment. There are however situations, where height of bank is such that blanket layer goes below normal ground level. Side drains may require to be constructed in such a case along the track at suitable distance so that track alignment does not become a channel for flow of ground surface water.

In case of double line construction, open central drains between the tracks should be avoided to a possible extent, even if it means to resort additional earthwork to facilitate the flow of water). It is not only difficult to construct Central drains, but it is also difficult to maintain them due to the continuous vibrations caused by the traffic and by problems of proper curing of concrete etc.. Only in very rare situations, when drainage of water is not possible without construction of a drain, suitable arrangements for construction of drains with pre-cast concrete channel/sub-soil drains along with a proper outfall should be made. If the distance between adjacent tracks is large enough, suitable slopes should be provided on ground to make rain water flow in the natural manner. Wherever there is a level difference between two adjacent tracks, suitable non-load bearing dwarf wall may be constructed to retain earth.

- **Drainage in Cuttings:**
  1. **Side Drains**: In case of cuttings, properly designed side drains of required water carrying capacity are to be provided. If height of the cutting is less (say 4 m), normally only side drains on both sides of the track are to be provided. In case of deep cuttings, catch-water drains of adequate water carrying capacity are also required along with side drains. It is to be noted that blanket material is to be placed like fill/embankment, and the top of side drains has to remain below the bottom of blanket material.
  2. **Catch-Water Drains**: Surface water flowing from top of hill slope towards the track in huge quantity needs to be controlled on safety considerations. It is also not possible to allow water from the hillside to flow into the side drains, which are not designed for carrying a huge quantity of water. It is therefore essential to intercept and divert the water accordingly coming from the hill slopes. Accordingly catch-water drains are provided running almost parallel to the track. It may be required to divert the water from the catch-water drains by sloping drains and to carry the water across the track by means of culverts depending on site conditions. In some situations depending on topography of the cutting top, there may be required to construct a net of small catch-water drains, which are subsequently connected to the main catch-water drain so that there is no possibility of water stagnation/ponding up to a distance of approximately three times depth of cutting from its edge. Catch-water drains should be pucca lined with impervious locally available flexible material.
  3. **Considerations when designing Catch-Water Drains**: These should be properly designed, lined and maintained. If catch-water drains are kuchha/broken pucca drains, water percolates down to the track through cracks, dissolving the cementing material resulting in instable cuttings. Catch-water drains should be located slightly away (as per site conditions) from the top edge of the cutting, and water flow should be led into the nearby culvert or natural low ground. Some additional salient features to be observed are as follows:
     - (a) Catch-water drains shall have an adequate slope of 1 in 200 to 1 in 300 to ensure development of self-cleaning velocity.
     - (b) Water drains shall not have any weep hole.
     - (c) The expansion joints, if provided, shall be sealed with bituminous concrete.
     - (d) Regular inspection and maintenance work, especially before onset of monsoon, should be carried out to plug seepage of water.
     - (e) Catch-water drains shall have well designed out-falls with protection against tail end erosion.

Though capacity and section will depend on terrain characteristics, rainfall etc. but following parameters are important for design of catch-water drains:

- (a) Intensity and duration of rain fall.
- (b) Catchment area-shape, size and rate of infiltration etc.
- (c) Velocity of flow which should satisfy the Manning’s formula.
- (d) Minimum gradient of drain should be in range of 1 in 400 to 1 in 700.
- (e) Normally catch-water drains should be of trapezoidal cross section.

(f) Catch-water drains should not be given gradient more than about 1 in 50 (but in no case more than 1 in 33) to avoid high water velocity and possibility of washout of lining material.

(g) Rugosity coefficient should be about 0.03.

Alignment plan, longitudinal section and soil survey records of catch-water drains should be updated from time to time as per development in the area of influence. Further details about track drainage along with the recommended cross-sections are given in **Paragraph 8.10.**

8.7.8.4 Erosion Control of Slopes on Banks and Cuttings

Exposed sloping surfaces of bank/cutting experience surface erosion. It is caused due to the action of exogenous wind and water, resulting into loss of soil. This further leads to development of cuts and rills/gullies, adversely affecting the cess-width. This also disturbs the soil matrix, steepening of slopes etc.. Its severity depends on the type of soil, climatic conditions, topography of area and length of slope etc..

Erosion control measures are commonly classified in following categories:

1. Conventional non-agronomical systems,
2. Bio-technical systems,
3. Engineering systems and
4. non-conventional hydro-seeding systems.

Most common methods used are the Bio-technical and Engineering System. Appropriate methods need however to be decided depending on site conditions.

8.8 PROVISION OF BLANKET LAYER

To avoid failure of track formation due to inadequate bearing capacity and to safeguard against swelling and shrinking, adequate blanket thickness must be provided in all cases at the time of construction of new lines, permanent diversions, raising of formation, in cuttings etc. or while rehabilitating a failing track formation.

8.8.1 Need for Provision of Blanket Layer and its Functions:

1. A blanket material develops its benefits only, if it is well drained and if the water can be kept away. A wet and badly drained Sub-Ballast (Blanket, Formation Protective Layer) may aggravate the situation. This can lead to “Memory Effects” for misalignments. When laying and compacting a blanket layer the water content should be around 7 % by weight.
2. It reduces traffic-induced stresses to a tolerable limit on the top of sub-grade, thereby prevents sub-grade failures under adverse critical conditions of rainfall, drainage, track maintenance and traffic loadings.
3. It prevents penetration of ballast into the sub-grade and also prevents upward migration of fine particles from sub-grade into the ballast under adverse critical conditions during service.
4. Its absence or inadequate thickness results in yielding formation and instability. This necessitates high maintenance inputs and leads to increased cost of maintenance. Moreover, crippling speed restrictions may have to be imposed, which adversely affect the throughput.
5. Its absence may result in bearing capacity as well as progressive shear failure of sub-grade soil, thereby endangering safety of running traffic.
6. It restricts plastic deformation of sub-grade caused due to cyclic stresses induced by moving loads.
7. It results in increased track modulus but only if well drained; wet sub-ballast has an adverse effect on track modulus/stiffness parameters. I dry blanket reduces track deformations. Consequently due to reduction in dynamic augment, stresses in rails as well as sleepers are reduced.
8. It facilitates drainage of surface water and reduces moisture variations in sub-grade, thereby reducing track maintenance problems.

9. It prevents mud pumping by separating the ballast and sub-grade soil. Thus accumulation of negative pore water pressure in the soil mass is avoided which is responsible for mud pumping.
10. It ensures that the induced stress in sub-grade is below the threshold stress of sub-grade soil.
11. It ensures dissipation of excess pore water pressure developed in sub-grade on account of cyclic loading and leads to increase in shear strength of sub-grade soil.
12. It obviates the need for formation rehabilitation work under running traffic at prohibitive cost.
13. It leads to enhanced performance of sub-grade as sub-grade can serve designed functions more efficiently and effectively.

The quality and depth of blanket material, which would carry out the above functions satisfactorily under Indian conditions, have been brought out in the following **Paragraphs**.

8.8.2 Depth of Blanket Layer

Depth of blanket layer of specified material depends primarily on type of sub-grade soil and axle-load of the traffic.

1. **Depth of Blanket** to be provided for axle-loads up to 22.5 t for different types of sub-grade soils (minimum top one meter thickness) is indicated in **Paragraph 18**. In case more than one type of soil exists in top one meter of formation, then soil requiring higher thickness of blanket will govern its depth.

   <u>Note:</u> Symbols used below for classification of soil at top of sub-grades for deciding blanket depth is as per IS Classification are given in IS: 1498. For details refer **Annexure - I**.

   Following soils shall not need blanket:
   (a) Rocky beds except those, which are very susceptible to weathering e.g. rocks consisting of shales and other soft rocks, which become muddy after coming into contact with water.
   (b) Well graded Gravel (GW).
   (c) Well graded Sand (SW).
   (d) Soils conforming to specifications of blanket material.

   <u>Note:</u> Soils having grain size curve lying on the right side of the enveloping curves for blanket material like cobbles and boulders may or may not need blanket. In such cases the need of blanket and its design should be done in consultation with RDSO.

   Following soils shall need minimum 45 cm thick blanket:
   (a) Poorly graded Gravel (GP) having Uniformity Coefficient more than 2.
   (b) Poorly grade Sand (SP) having Uniformity Coefficient more than 2.
   (c) Silty Gravel (GM).
   (d) Silty Gravel – Clayey Gravel (GM – GC).

   Following soils shall need minimum 60 cm thick blanket:
   (a) Clayey Gravel (GC).
   (b) Silty Sand (SM).
   (c) Clayey Sand (SC).
   (d) Clayey silty Sand (SM-SC).

   <u>Note:</u> The thickness of blanket on above type of soils shall be increased to 1 m, if the plasticity index exceeds 7.

   Following types of soils shall need minimum 1 m thick blanket:
   (a) Silt with low plasticity (ML).
   (b) Silty clay of low plasticity (ML-CL).
   (c) Clay of low plasticity (CL).
   (d) Silt of medium plasticity (MI).
   (e) Clay of medium plasticity (CI).
   (f) Rocks which are very susceptible to weathering.
2. **On Soils** having fines passing 75 micron sieve between 5 and 12% i.e. for soils with dual symbol e.g., GP-GC, SW-SM etc. thickness of blanket should be provided as per soil of

second symbol (of dual symbol). For example, if the soil of the sub-grade over which the blanket is to be provided is classified as GP – GC, then the blanket depth for GC type of soil should be i.e. 60 cm.

3. **Use of Geo-Synthetics** can be considered at places, where it is economical to use geo-synthetics in combination with a blanket as it reduces the requirement of thickness of blanket. It may be particularly useful in cases of rehabilitation of existing unstable formations and in new constructions, where availability of blanket material is scarce. Use and selection of geo-synthetics should be done in consultation with RDSO.
4. **For heavier Axle-Load Traffic** above 22.5 t and up to 25 t and above 25 t up to 30 t, additional blanket thickness of 30cm and 45cm respectively over and above as given in **Paragraph 8.8.2.1** should be provided**.** This additional blanket will consist of superior quality material, shown as upper blanket layer in **Fig. 8.9.**
5. **Blanket in new Lines of light Traffic Route:** Blanket ensures an important function of reducing induced stresses to acceptable value at top of sub-grade. In cohesive sub-grades even 100 cycles of repeated load in excess of threshold strength (permissible strength) of sub-grade soil will cause failure of formation resulting into large plastic deformations. Therefore, blanket of adequate depth should be provided even for predominantly passenger lines with light traffic.

8.8.3 Specifications of Blanket Material

The blanket material should generally conform to following specifications:

1. It should have a water content of 7 %.
2. It should be coarse, granular and well graded.
3. Skip graded material is not permitted.
4. Non-plastic fines (particles of size less than 75 micron) are limited to maximum 12%, whereas plastic fines are limited to maximum 5%.
5. The blanket material should have a particle size distribution curve more or less within the enveloping curves shown in **Fig.8.9.** The material should be well graded with Cu and Cc as under:
   (a) Uniformity Coefficient, Cu = D 60/D 10 > 4 (preferably > 7).
   (b) Coefficient of Curvature, CC = (D 30) 2/D 60 x D 10 should be within 1 and 3.
6. The material for upper blanket layer shall be well-graded sandy gravel or crushed rock within the enveloping curves for upper blanket layer as shown in **Fig.8.9**:

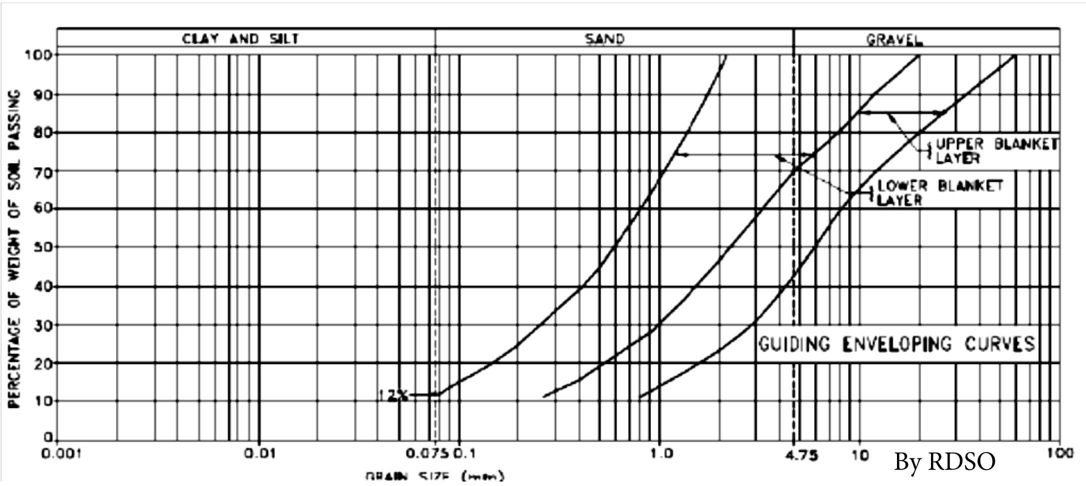

Fig.8.9: Enveloping Curves for Blanket Layer

8.9 UNSTABLE FORMATIONS

The main problems caused by unstable formations are:

1. Variation in track levels particularly during extreme hot or wet season causing the need for speed restriction or increased maintenance.

2. Loss of ballast, which sinks into the formation.
3. Instability of bank slopes resulting in slips and consequent disruption of traffic.

8.9.1 Causes of Formation Troubles

If any formation is suspected of giving trouble, the first step should be to investigate the cause of the trouble. To do so, ballast penetration profiles and other relevant data along with the history of section and the trouble should be obtained and analysed keeping in view various features of the site and probable causes of failures in the area or stretch.

In most cases the basic cause of trouble is found in deficient track structure, especially in the inadequate and clogged ballast-cushion. The remedy lies in deep-screening the ballast to recoup the ballast-cushion, preferably by raising the track instead of cutting into the formation on hardened layer of ballast-ash and soil.

In relation to instability, when formation too is a contributory factor in the chain of factor mentioned below, then instability entails remedial measures:

1. Instability problems due to railway cuttings and embankments not being stable resulting in excessive creep deformations.
2. Excessive swelling and shrinking of bank soil causing large volumetric changes, disrupting the track levels and alignment.
3. Bearing capacity failures are due to:
   (a) Inadequate cess width and/or bank slopes.
   (b) Inadequate thickness of ballast and blanket.
4. Other causes such as loss of formation soil caused by porcupines, ants, rats and seepage etc..
5. Whatever be the cause, the problem aggravates due to faulty drainage during monsoons. The rain water impairs the soil strength by wetting and higher pore water pressures. Hence the track foundations should be designed to be adequate.

In **Fig. 8.10** typical cumulative settlements are shown for stable and unstable sites. The small exponentially linear settlements for stable sites have been observed at several sites. This pattern of behaviour is used for:

1. Checking stability of a formation site.
2. Evaluating the efficacy of a treatment.
3. Predicting maintainability problems with heavier traffic or axle-loads.
4. Checking the comparative behavior of two sub-grade materials including the blanket material.

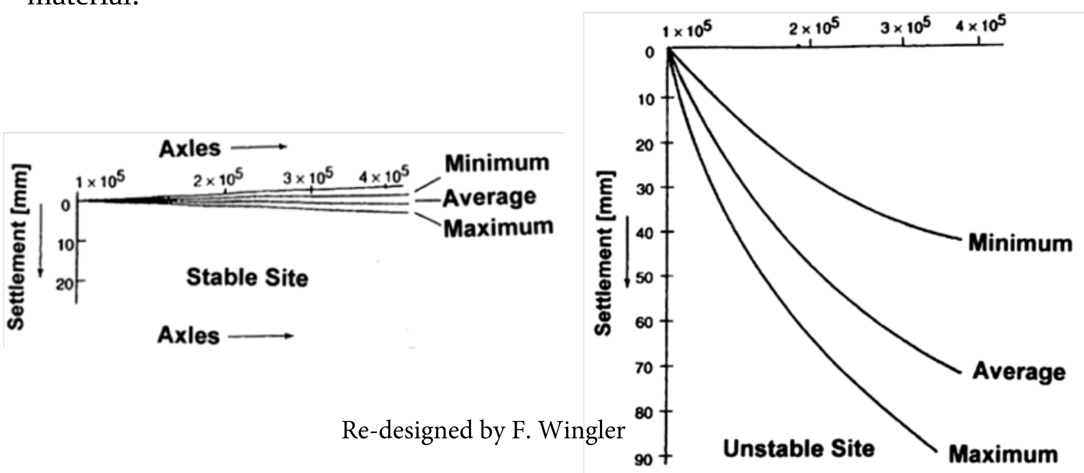

Fig. 8.10: Typical cumulative Settlement of Formation on stable and unstable Sites

It is necessary to treat any unstable formation as early as possible due to the following:

1. To eliminate the probability of disruption of traffic due to blockade or speed restrictions.
2. To economize in track maintenance.
3. To maintain track quality.
4. To avail full life of track components and to avoid untimely renewals, replacements and recoupments.

5. Systematic track maintenance is possible only over stable formation.
6. Any modernization of track such as introduction of concrete sleepers, LWRCWR, machine maintenance and high speed turnouts etc. would succeed only on stable formation.

Due to the above reasons, requirements of blocks and speed restrictions etc. will be reduced automatically.

8.9.2 Formation Treatment Methods

One or more of the following methods are employed depending on the situation:

1. Provision of a 30-100 cm deep blanket of coarse grained material.
2. Grouting of formation and bank with:
    a) Cement and sand-slurry.
    b) Lime-slurry pressure injection.
3. Slope and cess repairs with sub-surface drainage to provide a stable base for track foundation, i.e. ballast and blanket.

Grouting with cement or lime provides temporary relief for a few years only and would require repletion for re-stabilisation.

Several other methods had been tried in the past, but did not give satisfactory results. To mention a few:

1. Lime piles.
2. Vinyl drains.
3. Sand drains.
4. Moorum blanket.
5. Cationic bitumen emulsion.
6. Polyethylene sheet.
7. Maxphalt-crete.
8. Pouring sand on ballast section.
9. Geotextiles to check sub-grade failures.

It may be noted that vertical or surface sand drains, moorum blanket and geotextiles are useful civil engineering tools to tackle foundation and earthwork problems, and their judicious employment should be done if warranted in a project or at a location.

Main causes of formation trouble and remedial measures found effective are tabulated in **Table. 8.5:**

Table 8.5: Main Causes of Formation Trouble and remedial Measures

Remedial Measures suggested; based on the Site Investigations and Soil Testing the relevant remedial Measures should be formulated. **Some of the remedial Measures suggested for the Formation Troubles generally encountered are listed below:**	
1.Track level variations due to: (a) Inadequate drainage due to high cess and dirty ballast.	Suggested treatment (any one or in conjunction): Improve side drainage by lowering the cess and screening of ballast.
(b) Weakening of soil at formation top on contact with rain water resulting in mud pumping.	(a) Cationic bituminous emulsion below ballast. (b) Provision of moorum/sand blanket of 20-30 cm depth below ballast. (c) Laying of geo-textiles
(c) Strength failure below ballast cause heaving of cess or between sleepers.	(a) Provision of 30-60 cm deep blanket below ballast. (b) Provision of sub-ballast.
(d) Seasonal variation in moisture in formation top in expansive soils causing alternate heaving shrinkage of formation.	(a) Treatment with lime slurry pressure injection. (b) Moorum blanket 30-45cm with moorum lining.
(f) Gradual subsidence of the bank core under live loads due to inadequate initial compaction/consolidation of embankment.	(a) Cement grouting of ballast pockets if ballast pockets are permeable. (b) Sand or boulder drains.

(g) Gradual consolidation of earth below embankment.	(a) Lime piling in sub-soil. (b) Sand drains in sub-soil.
(h) Creep of formation soil.	Easing of side slopes
2. Instability of bank/cutting slopes due to (a) Inadequate side slopes causing bank slips-after prolonged rains.	Treatment: Flattening slopes and provision of berms Improvement in drainage.
(b) Consolidation/settlements of sub-soil causing bank slips.	Provision of sand drains to expedite consolidation
(c) Hydro-static pressure built up under live loads in ballast pockets containing water causing bank slips.	(a) Draining out of ballast pockets by sand or boulder drains. (b) Cement sand pressure grouting of ballast pockets.
(d) Creep of soil.	Reducing stresses by provision of side berms or flattening the slopes.
(e) Swelling of over consolidated clay side slopes in cutting causing loss of shear strength and slipping.	Flattening side slopes.
(f) Erosion of banks.	Provision of turfing mats etc.
R.D.S.O.'s help wherever necessary, may be taken for formulating the remedial measures.	

8.10 TRACK DRAINAGE; see also "*WATER THE ENEMY OF THE RAIL TRACK"*

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8.10.1 Introduction

"The worst enemy of track is 'water', and the further it can be kept away from the track or the sooner it can be diverted from it, the better the track will be protected. Therefore, the first and most important provision for good track is drainage".

The above statement comes from the first paragraph of a book titled "Rules and Instructions for the Government of the Employees of the Maintenance of Way Department of the Chesapeake and Ohio Railway" by H. Frazier, Supt. Maintenance of Way, dated October 1, 1889.

Today, one hundred and twenty five years later, this statement still applies and has probably even gained in importance as current rail traffic is seeing increased wheel and axle-loads and higher speeds.

In **Paragraph 8.7.8c** under the heading "drainage arrangement in banks and cuttings", the need for properly designed drains for the stability of the track structure has been emphasized.

Water penetrates from above into the rail track by rain fall, it can seep from the side banks, it can often flow as surface water together with mud particles from adjacent grounds on same level or from higher level from cutting slopes, it can creep up from the ground by capillary forces and can even percolate as ground water like a spring not seldom from adjacent higher water leading formation layers or stratus; **Fig. 8.11**:

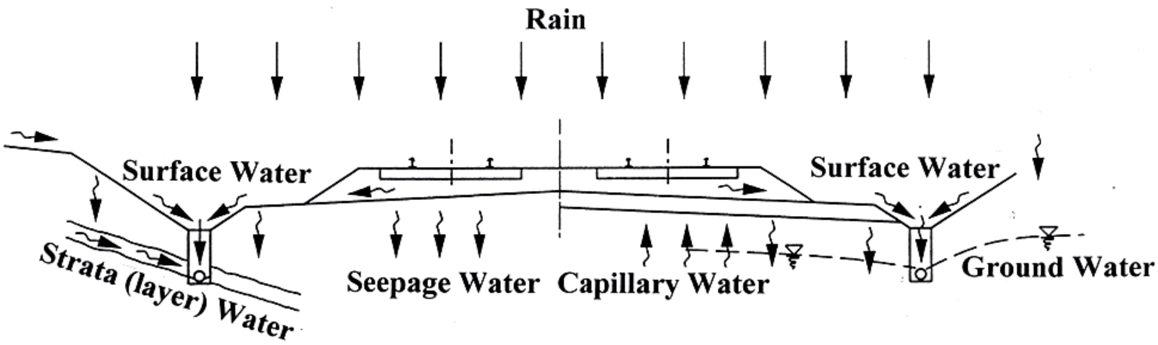


Fig. 8.11: Water Flow Scheme at Track Bed (from Cl. Göbel and Kl. Lieberenz; Handbuch Erdbauwerke der Bahn; modified)

8.10.2 Types of Drainages

The types of track drainages fall under two broad headings:

1. Surface-drainage.
2. Subsurface-drainage.

8.10.2.1 Surface-Drainage

Surface-drainage works consist of trench type open drains. These remove surface run-off water before it enters the track structure, as well as carrying off water percolating out of the track structure.

The two types of surface drains used are:

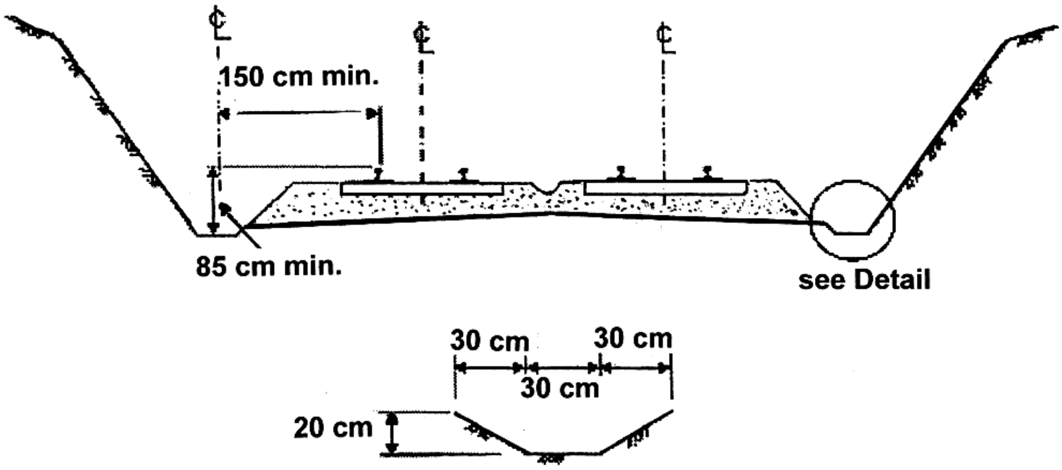
1) Cess-drains.
2) Catch-drains.

Another form of surface-drainage is the basic grading of the ground on either side of the tracks so that it falls away from the track and allows water flowing out of the track structure to be removed.

Grading may be used in very flat areas, where it is difficult to get sufficient fall for either surface or subsurface-drains.

● **Cess-Drains**

Cess-drains are surface-drains located at formation level at the side of tracks, to remove water, that has percolated through the ballast and is flowing along the capping layer towards the outside of the track formation. They are most frequently found in cuttings where water running off the formation cannot freely drain away; **Fig. 8.12**:



Re-designed by F. Wingler

Fig. 8.12: Typical Cess-Drain Dimensions

Cess-drains should be constructed with a minimum grade of 1 in 300 and at a minimum distance of 150 cm away from the field side rail not to cause formation yielding. Surface-drains can be constructed at flatter grades, as they are easily cleared of any sediment which may collect in them.

● **Catch-Drains**

These may also be called ***"Top-Drains"*** or ***"Surface-Drains"***. The purpose of catch-drains is to intercept overland flow or run-off water before it reaches the track and causes damage to the track or related structures, such as cuttings or embankments.

For example, catch-drains are generally located on the uphill side of a cutting to catch-water flowing down the hill and to remove it prior to reaching the cutting. If this water was allowed to flow over the cutting face, it may cause excessive erosion and subsequent silting up of cess-drains; **Fig. 8.13:**

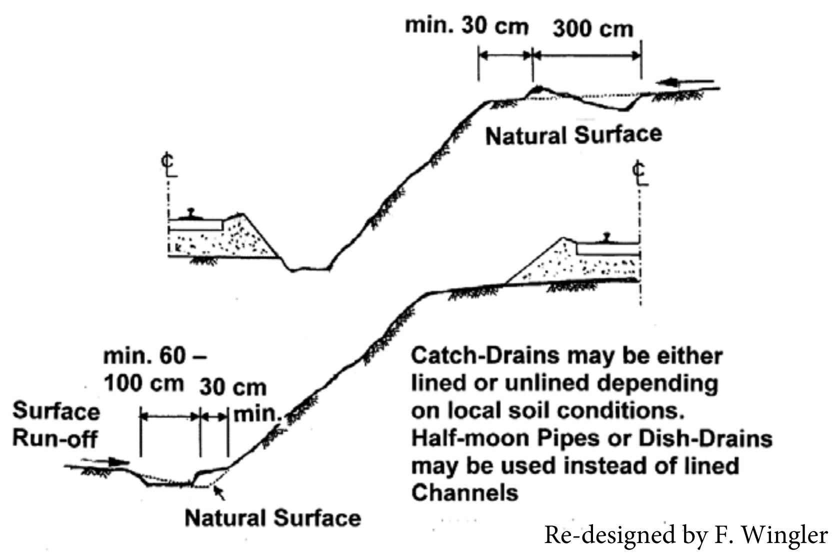


Fig. 8.13: Catch-Drains

This type of drain may also be used on the uphill side of other track formations, such as embankments. Catch-drains may be used to remove water and prevent ponding at the base of embankments or alongside tracks that cut across a slight downhill grade.

8.10.2.2 Sub-Surface Drainage

Adequate sub-surface drainage is necessary for maintaining the integrity of the track formation and ensuring the stability of earth slopes. Sub-surface drainage is used, where there is not enough room for open cess-drain systems, as for example at through platforms, under multiple tracks or at narrow cuttings.

Sub-surface drainage is used for:

1. Drainage of the track structure.
2. Control of ground water.
3. Drainage of slopes.

These requirements may overlap considerably in any given drainage system.

● Function of Sub-Surface Drains

Sub-surface drainage systems perform the following functions:

1. Collection of infiltration water, that seeps into the formation (capping layer) as shown in **Fig. 8.14.**
2. Draw-down or lowering of the water-table as illustrated in **Fig. 8.15a/b**.
3. Interception or cut-off of water seepage along an impervious boundary as illustrated in **Fig. 8.16**.
4. Drainage of local seepage such as spring inflow as shown in **Fig. 8.17:**

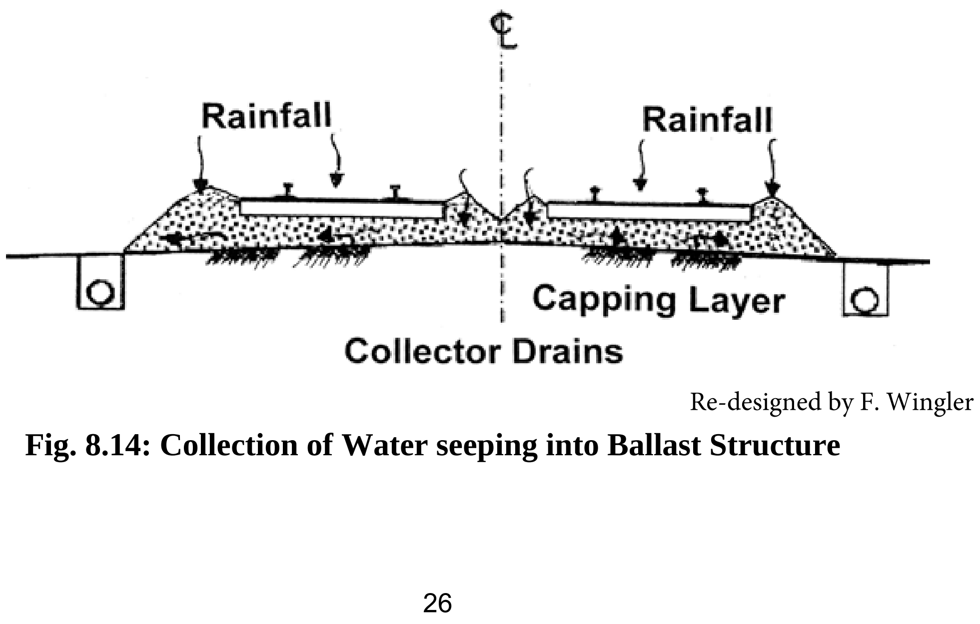
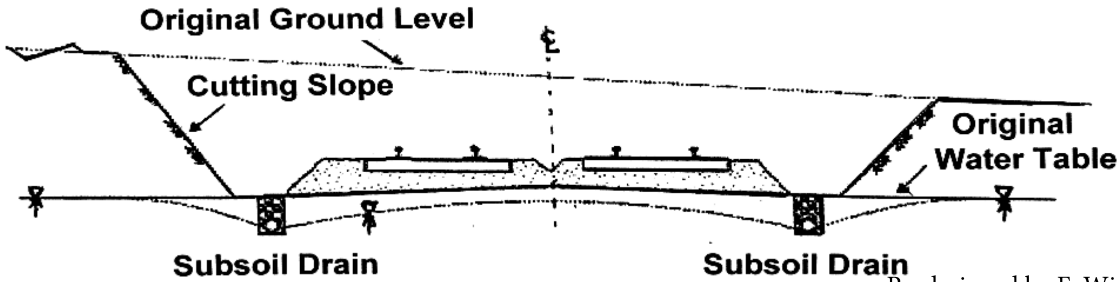


Fig. 8.14: Collection of Water seeping into Ballast Structure



Re-designed by F. Wingler

Fig. 8.15a: Lowering the GroundWater-Table

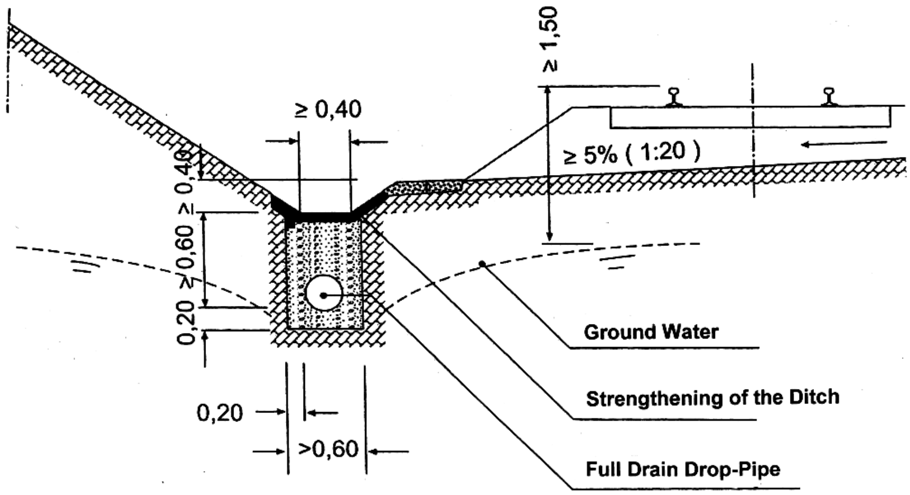
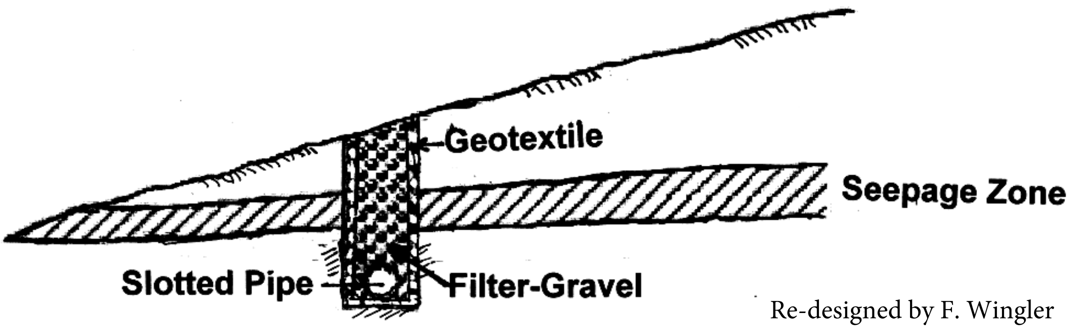


Fig. 8.15b: Dimensions for lowering the Water-Table with Sub-Soil Drains in [cm]
(from Cl. Göbel and Kl. Lieberenz; Handbuch Erdbauwerke der Bahn; modified)



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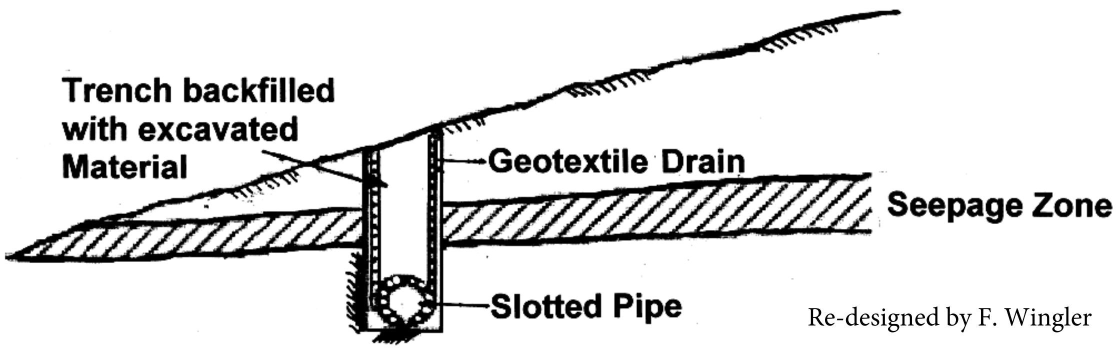
Type 1: Filter-Gravel, Geotextile and slotted Pipe Drain



Re-designed by F. Wingler

Type 2: Geo-Textile Drain
Fig. 8.16: Interception and Cut-Off of Seepage Water

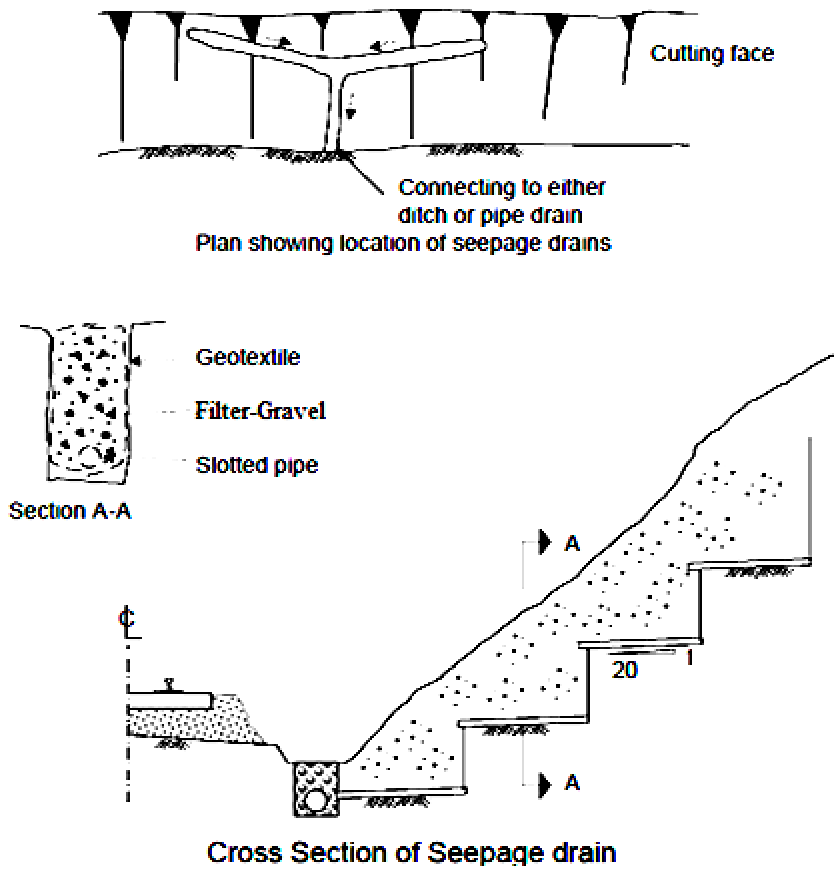


Fig. 8.17: Drainage of local Seepage

- **Types of Sub-Surface Drains**

  Sub-surface Drains can be classified into three types according to their location and geometry:

  1. Longitudinal drain; **Fig. 8.18.**
  2. Transverse drain; **Fig. 8.19.**
  3. Drainage blankets; **Fig. 8.20**.

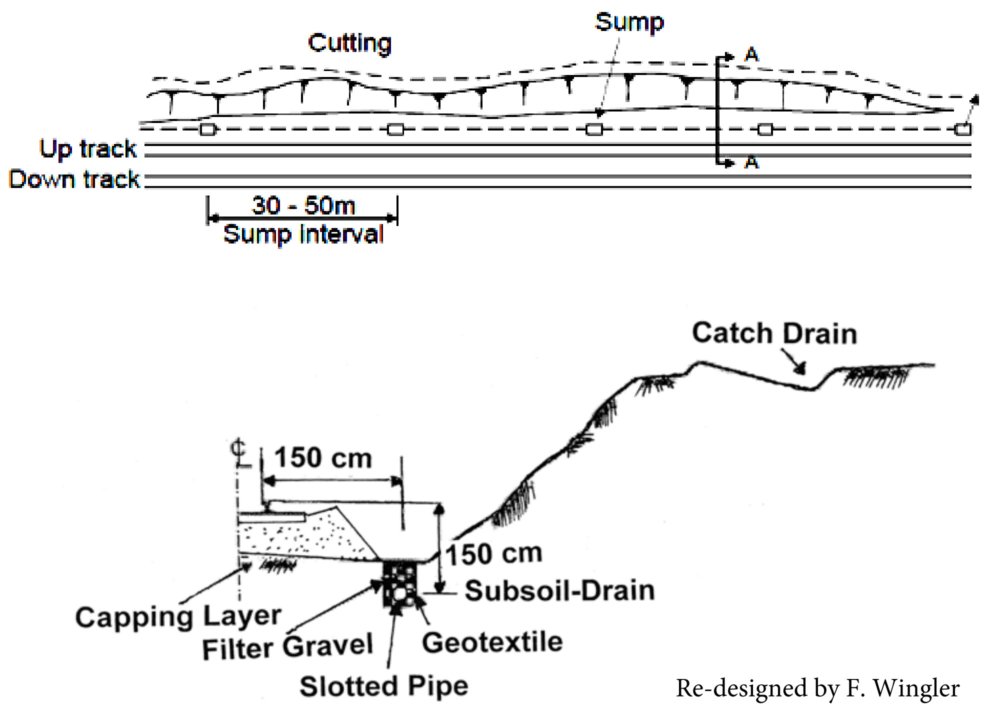


Fig. 8.18: Typical longitudinal Drain Arrangement

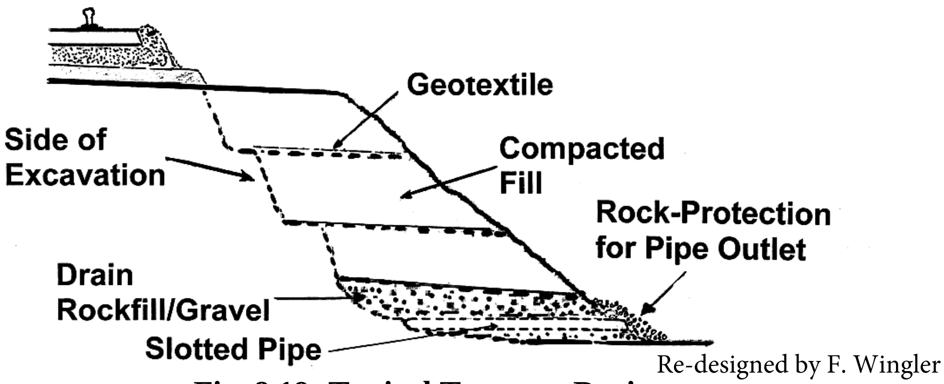


Fig. 8.19: Typical Traverse-Drain

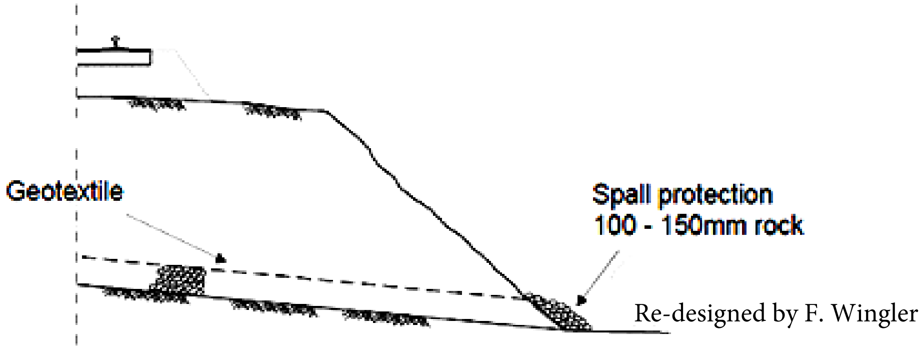


Fig. 8.20: Typical Drainage Blanket

8.11 INSPECTION AND MAINTENANCE OF DRAINAGE SYSTEMS

It is most important to inspect the track drainage system periodically followed by regular maintenance operations consisting of:

1. Weed control.
2. Removal of debris from other track maintenance activities.
3. Removal of sediment.
4. Re-grading.
5. General repair and maintenance.
6. Cleaning of sub-soil drainage pipes in regular intervals.

Fig. 8.21 shows a Man-hole provided at regular intervals for inspection and cleaning of sub-surface drains.

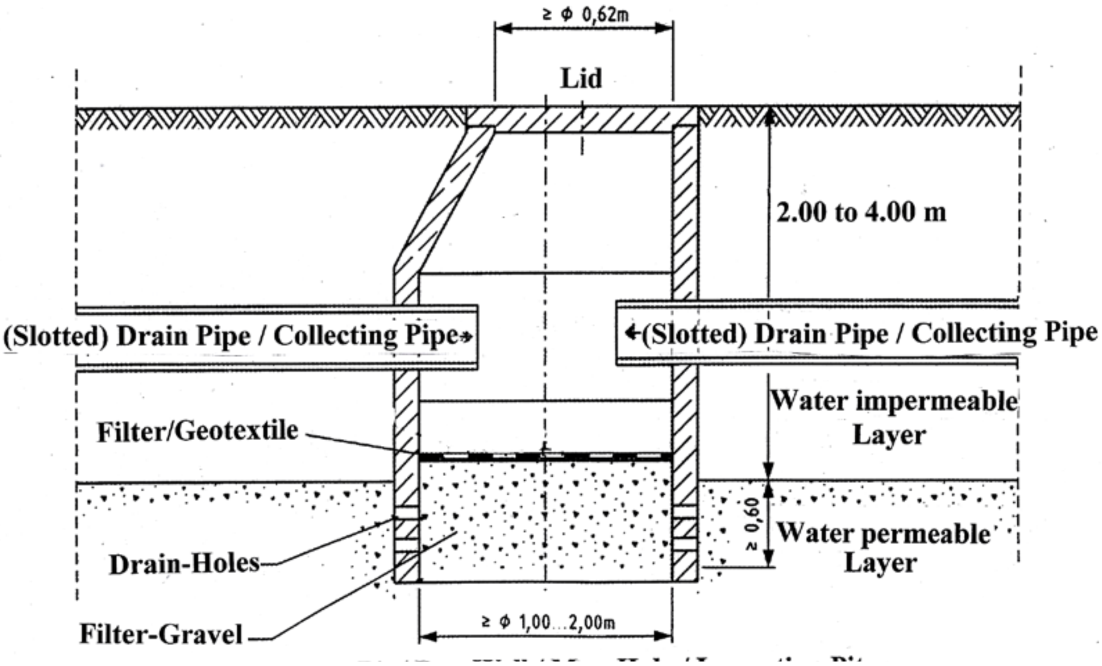


Fig. 8.21: Seepage Pit/Dry-Well/Man-Hole/Inspection Pit
(from Cl. Göbel and Kl. Lieberenz; Handbuch Erdbauwerke der Bahn; modified)

8.12 SUB-STRUCTURE MAINTENANCE MANAGEMENT USING GROUND-PENETRATING RADAR (GPR)

Track sub-structure is the term used to describe the different layers of rock and soil under the sleepers including the ballast, sub-ballast – or formation protection layer – and the sub-grade soil. Poorly performing sub-structure not only leads to high rates of track geometry degradation but also promotes higher rates of wear of the rail, sleepers, fastenings and other track components.

Sub-structure problems are typically associated with poor drainage, fouled ballast, sub-grade failure or deformation and longitudinal variation of conditions. Correction of chronic problems requires the root causes to be determined – typically one or more of the mentioned above. Ground penetrating radar technology can be used to assess the condition of track sub-structure and produce quantitative indices for use in the management of track maintenance.

8.12.1 How it works

The GPR method transmits pulses of radio energy into the subsurface and then receives returning pulses, which have reflected off layer boundaries below the track surface. GPR antenna pairs, consisting of transmitter and receiver pairs, are moved along the track with a continuous series of radar pulses giving a profile of the subsurface. Reflections of the GPR pulse occur at boundaries in the sub-surface, where there is a change in material properties. Only a portion of the pulsed signal is reflected at a layer boundary, and the remaining part of the pulse travels across the interface to be reflected again back to the receiver from another interface boundary. The time, the pulse takes to travel through the layer and back, is controlled by the thickness and properties of the material.

The data produced by GPR helps to identify in an easy way the substructure problems such as poor drainage, fouled ballast, sub-grade failures and deformation or longitudinal variation of conditions. An optimum solution to the problem can then be found.

ANNEXURE – I

BRIEF DETAILS OF SOIL CLASSIFICATION; see also Chapter 18

(Ref: IS: 1498-1970)
Background and Basis of Classification:

The Geotechnical Engineers/Agencies had evolved many soil classification systems over the world. The soil classification system developed by Casegrande had been subsequently modified as a standard and named as ***"Unified Classification System"***. It got revised in 1970. According to BIS classification system soils are primarily classified based on dominant particle sizes and its plasticity characteristic. Soil particles mainly consist of following four size fractions:

1. Gravel: 80 - 4.75 mm.
2. Sand: 4.7 mm – 0.075 mm (75 micron).
3. Silt: 75 - 2 micron.
4. Clay: less than 2 micron.

Particle size distribution of a soil determined by a combination of sieving and sedimentation analysis as per procedure detailed in IS: 2720 (Part 4) – 1985 and its plasticity characteristics are determined by Liquid Limit and Plastic Limit as per procedure detailed in **IS: 2720 (Part 5) – 1985**.

Symbols used in Soil Classification:

Symbols and other soil properties used for soil classification are given below. Brief procedure for classification of soil has been explained in tabular form and flow chart. Plasticity chart required for classification of fine grained soils has also been given:

Primary Letter	Secondary Letter
G: Gravel	W: Well – graded
S: Sand	P: Poorly graded
M: Silt	M: With non plastic fines
C: Clay	C: With plastic fines
O: Organic soil	L: of low plasticity
P: Peat	I: of medium plasticity
	H: of high plasticity

Other soil parameters required for soil classification:

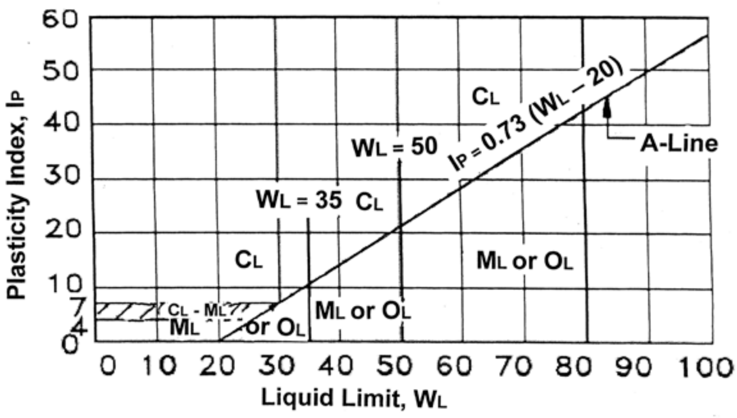
- Cu: Coefficient of Uniformity = D_{60} /$D_{10.}$
- CC: Coefficient of Curvature: $(D_{30})^2/D_{60}* D_{10}$).
- $D_{60}/D_{30\text{ and}}$ D_{10} are particle sizes, below which 60, 30 and 10 percent soil particles by weight are finer these sizes.
- Plasticity Index, PI = Liquid Limit (LL) – Plastic Limit (PL).
- Coarse grained soils: Soils having fines (particles of size less than 75 micron) < 50%.
- Fine grained soils: Soils having fines more than 50%.

Brief Procedure for soil Classification:

Conduct Sieve analysis and Hydrometer analysis on soil sample and plot particle size gradation curve and determine Cu and Cc.

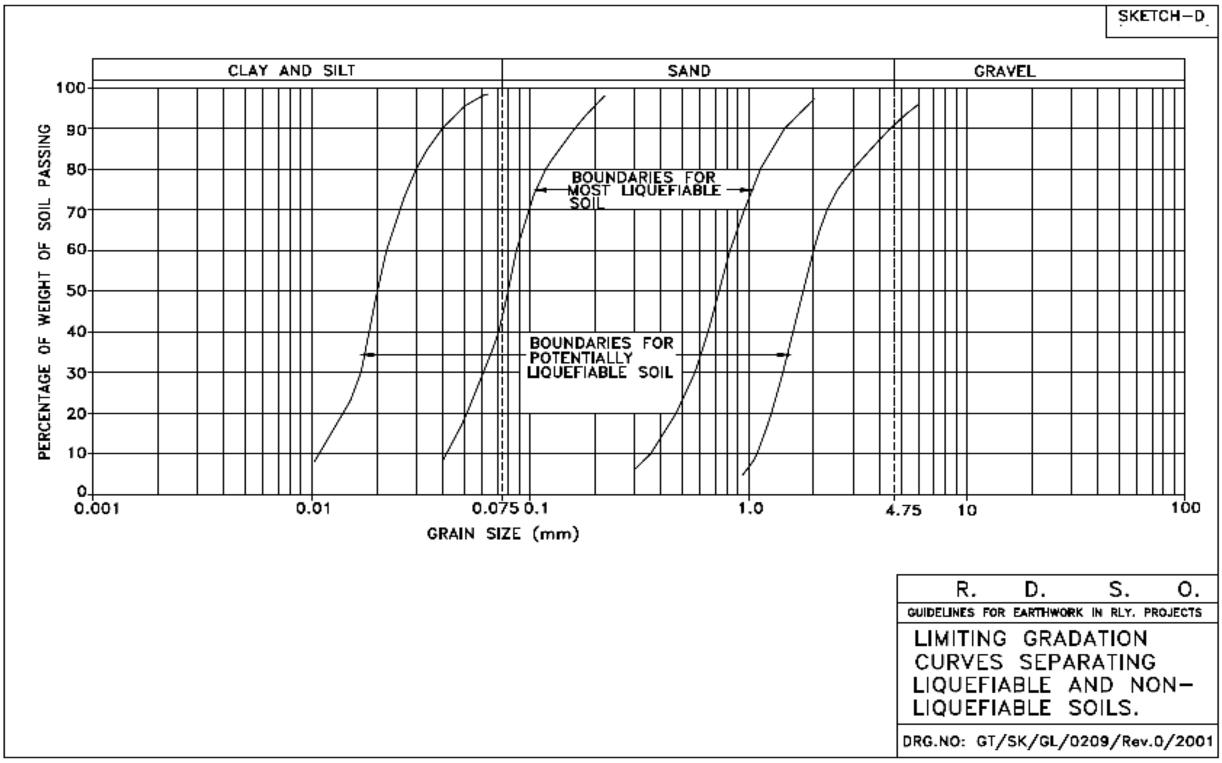
Conduct liquid limit and plastic limit test on soil samples.

Based on above soil parameters, classification should be done as per procedure explained in the following table/flow chart. The Classification should be done in conjunction with the Plasticity Charts given below:



Plasticity Chart RDSO: re-designed by F. Wingler

ANNEXURE-II



Clean and un-fouled Ballast is the Blood of the Rail Track

WATER THE ENEMY OF THE RAIL TRACK
Part II

Sri Lanka Railways, Upcountry Line, 2010

Water is the Enemy of the Rail Track and hence the Enemy of the Track Engineer.

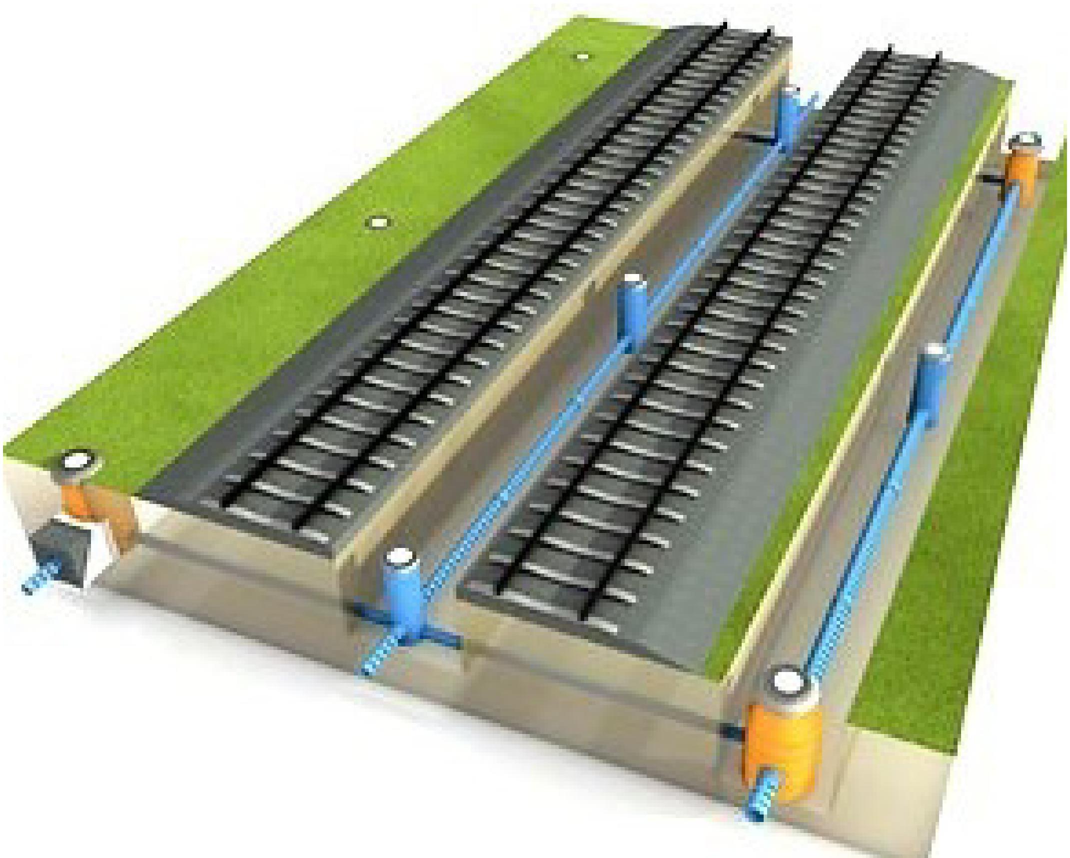
Wisdom tells: ***"One cannot be too careful in how to deal with his Enemy!"***
"One of the most time-consuming things is to have an Enemy!"

Stability and longevity of a Rail Track depend in large extend, if water can be taken out and kept away from the track-bed!

By Dr. Frank Wingler, June 2011,
Revised August 2016

Contents:

Stability and longevity of a rail track depend in large extend, if water can be taken out and kept away from the track-bed.



Representation by REHAU

Schematic Representation of a Rail Road drained by a Sub-Soil Drainage System

WATER THE ENEMY OF THE RAIL TRACK

I. Why Rail Track Drainage is so important:

Other than a road for rubber-tire vehicles, a ballasted rail road has no water tight tar sealing, which defends the sub-structure against rainfall.

Dr. Ernest T. Selig quotes in his publication ***RAILWAY SUBSTRUCTURE ENGINEERING:***

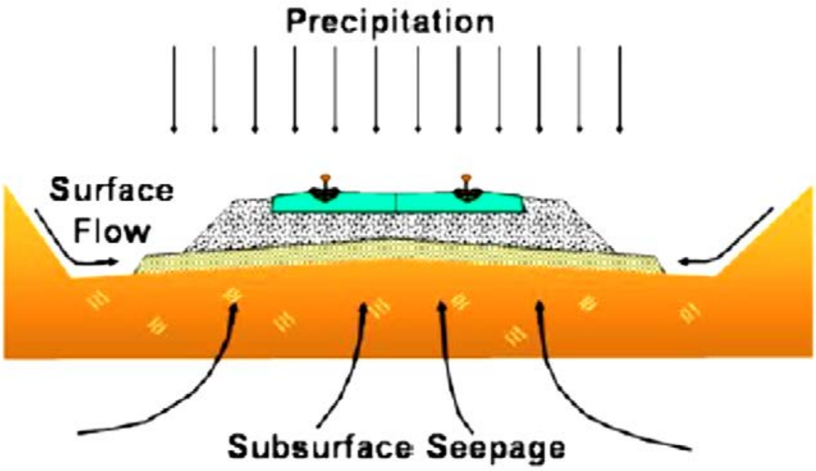
"It has often been said that the most important topic in track design and performance is drainage. Although the railroad industry recognizes this, drainage is nevertheless still one of the most neglected subjects in substructure design and maintenance. There are probably several reasons for this situation. One is that the principles of drainage are not adequately understood. Another is that the economic impact of neglecting drainage has not been quantified, and hence drainage has a diminished priority. Another reason is that drainage action, unlike surfacing, can be deferred. When geometry exceeds specified limits it must be corrected by smoothing the track in order to permit traffic to continue. Even though drainage problems may be the major factor causing the geometry deterioration, and fixing the drainage problem may reduce or diminish future geometry deterioration, it is not the first step that must be taken to correct the geometry problem. Finally, the technology for designing or repairing drainage systems needs to be better defined"; see: http://railwaysubstructure.org/railwiki/index.php?title=Track_Drainage.

Further, we can learn from E.T. Selig:

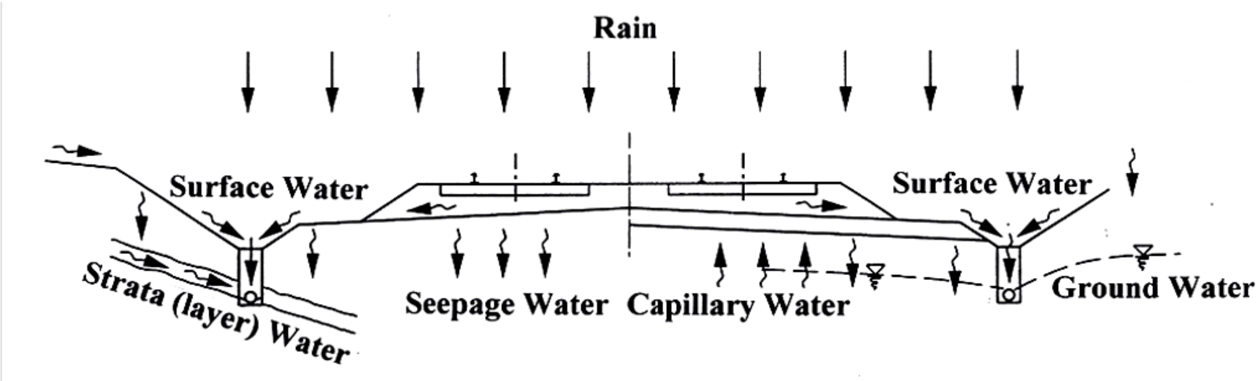
"The track substructure consists of the ballast, the sub-ballast under the ballast, and the upper part of the sub-grade under the sub-ballast. There are three basic sources of water into this substructure; see **Fig. below.** First, precipitation falling directly on the track will enter the substructure. Except in covered areas, principally tunnels, this cannot be prevented or restricted. Rain falling onto the ground at a higher elevation adjacent to the track can flow into the track substructure from the sides. This water can and should be intercepted to prevent it from entering the track substructure. Third, water can flow upward through the ground into the substructure – this water is more difficult to control. The goals of the drainage system are first to restrict the amount of the water getting into the substructure, and second to remove the water that does get into the substructure."

Stability and longevity of a rail track depend in large extend, if water can be taken out and kept away from the track-bed.

Water penetrates from above into the rail track by rain fall, it can seep from the side-banks, it can often flow as surface water with mud particles from adjacent ground on same or from higher level from cutting-slopes, it can creep up from the ground by capillary forces and can even percolate between the sleepers as ground water like a spring coming from adjacent higher water leading formation layers or stratas. Water can be retained in the pores of soil-mass or on the surface of soil particles as an integral part of the soil due to surface tension and absorption forces and by hydroscopic forces.



Sources of Water into Track Substructure
(from ***Railway Substructure Engineering*** by Dr. Ernest T. Selig)



Water Flow Scheme at Track Bed
(from Cl. Göbel and Kl. Lieberenz; ***Handbuch Erdbauwerke der Bahn***; modified)

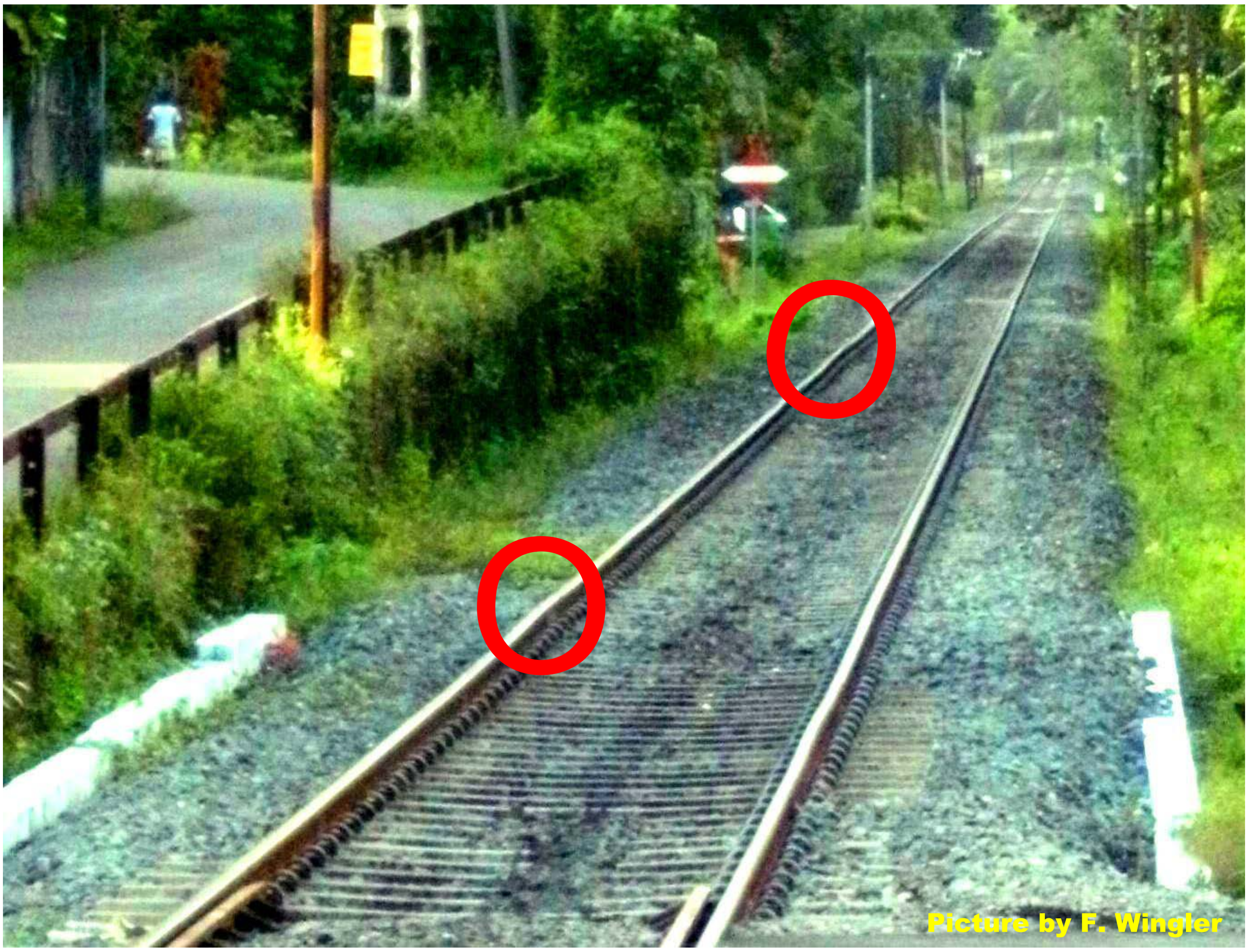
Water with Mud flows from adjacent **G**round into the un-drained Track Bed. Wet Mud and Earth clog the Ballast; Sri Lanka

Many of the problems, which arise in the track bed, occur where Track Drainage is not operating effectively, or where changes in the position of the water-table have created the need for additional drains. Water trapped below the ballast saturates and reduces the stiffness of the track bed, which can result in top and line faults that affect ride quality, and it leads to early deterioration of ballast.

Poor drainage causes a number of problems with track performance. Water and moisture content breaks down the bearing power or capacity of the sub-grade. They reduce the shear-strength of the soil. With water soil can be transformed into plastic slurry. Water pressure develops in the substructure layers under the repeated train loading which decreases the strength and stiffness of the materials and increases the deformation. The water content in the soil increases which also decreases the strength and stiffness of the materials and increases the deformation under the train loading. A mixture of fine particles in the voids together with water can form a slurry, which fouls the ballast and makes it difficult to maintain a smooth track surface. The slurry also erodes the ballast and concrete sleepers. The ***"mud-dancing"*** or ***"pumping"*** concrete sleeper crush and mill the ballast stones to fines. The **Picture below** shows ballast filled with fines-slurry often called "mud". This mud is often thought to be formed from the sub-grade, but this is not generally the case. The Picture shows the aggressive effect of pumping slurry:

"Mud pumping" Sleepers on Sri Lanka Railway`s gruelling Upcountry Track

Another problem caused by poor drainage is the hydraulic pumping of the sub-ballast and sub-grade layers which is one source of fouling of the ballast and also causes geometry deterioration. Another problem is swelling of expanding soils when they absorb water during wet (monsoon) season. This is followed by shrinking in periods of dry season when the water is removed from the soil by evaporation. Since the volume changes on swelling and shrinking are uneven, they usually result in substantial deterioration of track geometry. This leads to a ***"MEMORY"*** for track-misalignment buried in the sub-grade. Teaching shining samples for this sub-grade attrition phenomenon of un-drained sub-grade can be seen in Sri Lanka on several sections of the recently renewed Coast Line:



Memory-Effect: Track Bed Drainage missing; Misalignment caused by Water trapped in the Sub-Grade, shrinking and expanding with Weather Season; Sri Lanka Coast Line after Rehabilitation. Frequent Machine Tamping could not rectify the defects. Three month after each repeated Tamping and Aligning the same old Misalignment Pattern appeared again.

Opening of trapped Water in Ballast-Pocket

II. <u>Open longitudinal Side Ditch-Drains:</u>

The method to drain surface water and soil water from the track support system, as there are formation and embankment, by open longitudinal side ditch-drains is from the times of the British common to Indian and Srilankan Track Men.

There are unlined and lined open longitudinal Side Ditch-Drains.

Open **<u>unlined</u>** drainage systems have the advantage that they are easy to access and maintain and they are relatively cheap. But they need enough space along both sides of the track. The function is to collect precipitations running off track embankments and slopes of cuttings and hillsides.

Unlined ditch-drains should be trapezoidal in cross section with 45 ^{0} side-slopes. V-shaped ditches are easily blocked by debris and are susceptible to erosion. The longitudinal inclination of the ditches should be at least 1 in 300 but not steeper than 1 in 30. A steeper gradient might enable water to flow too rapid causing erosion. If the underground is enough water permeable, the incline can be less than 1 in 300.The drainage ditch should not be too near to the formation (not nearer than 3.15 m to the rail grid centre) , not to cause formation-yielding; but also not too far (not far away than 4.75 m), because long flow path restricts drainage.

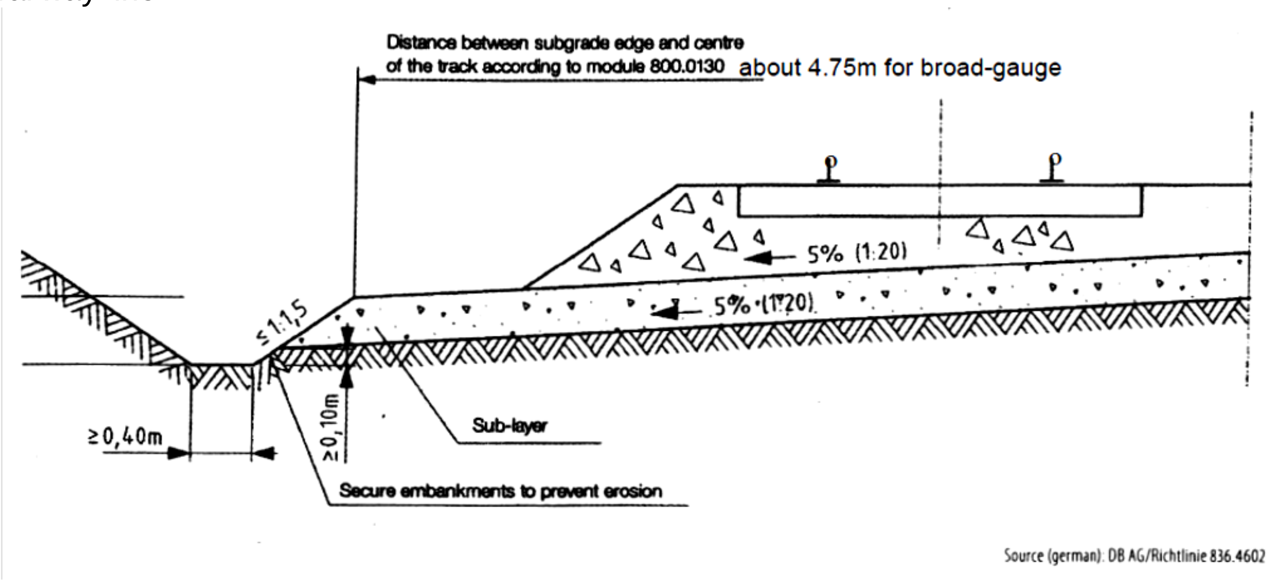
The drains should be deeper than the formation protective layer (blanket/sub-ballast), latter should be inclined 1 in 25 (4%) to allow water to flow towards the drain.

A formation protective layer (blanket/sub-ballast) enhances the bearing capacity of the rail road, but a wet formation protection layer (blanket/sub-ballast) can aggravate the situation. The fine material might turn to plastic slurry leading to track misalignments.

To discharge the water the open side ditch-drain should be connected via a **Carrier Drain or Culvert** to a lower situated outfall.

Stagnant Water in open unlined Side Ditch-Drain due to insufficient Gradient and **Water Flow** blocking Debris

Open drainage systems need constant maintenance, cleaning and re-profiling. Vegetation blocks the water-flow or reduces the flowing velocity. The drains should lead to water-outlets/chutes/culvets or water-courses guiding the water away from the railway line.



Cross-Section with Dimensions for open unlined Ditch-Drain

Unlined open Ditch-Drains can be also useful to drain the toe of high embankments:

Open unlined High Embankment-Toe Ditch-Drain
Picture from ***Railway Drainage Systems Manual,*** Network Rail, UK

Open **lined Side-Drains** (Gutters, Flumes) have the advantage of easier maintenance. They can be lined with concrete or masonry cement/stone walls or made out of prefabricated cement troughs.

For the renewal of the Sri Lanka Railways Coast Line Rail Track there had been due to encroachment and land-grab on many sections not enough space any more to harbour a broad formation for a well ballasted track and for unlined open Side-Drains.

Masonry build Stone Side-Gutters cum Ballast Retaining Walls; Coast Line, SLR

The contractor IRCON from India got by local sub-contractors lined open side-drains fortified by masonry cement/stone works. The construct serves as a gutter and as a ballast-retaining wall. There had been many avoidable mistakes made:

The local sub-contractors used less than the prescribed amount of cement in the mortar mixture.

The gutters had not been properly levelled with the prescribed incline of 1 in 200 to 1 in 300, so that at many spots the water is stagnant providing a breeding ground for health hazardous mosquitoes:

Stagnant Water in open masonry Gutter, a hazardous Mosquito Breeding Ground; SLR Coast Line

The side walls, which should also retain the ballast, had not been erected high enough, so that ballast stones flow into the gutter, blocking the water flow.

The water-seepage or outlet pipes are arranged too high, so that behind the retaining wall not only the ballast is retained, but also the water in the track bed:

Opened Track-Bed (right); Water-Level in Track-Bed remains higher than in the Gutter (left); SLR Coast Line

Image of Gap between Track-Embankment and Retaining/Gutter masonry Stone-Wall under Construction; SLR, Coast Line

Not only that the seepage pipes are arranged too high (30-40 cm above the fundament) and not at the bottom, the gap between the wall and the embankment got hereafter filled with poor water permeable clay-earth instead with water permeable fill-material/filter-gravel. Such a stone wall retains the water in the track-bed; see picture above.

The author has noticed in India on the “KK-Line” (Koraput/Kirandul) that at the bottom of the first stone layer no cement is filled between the stones thus allowing water to seep out of the track-bed at the low bottom.

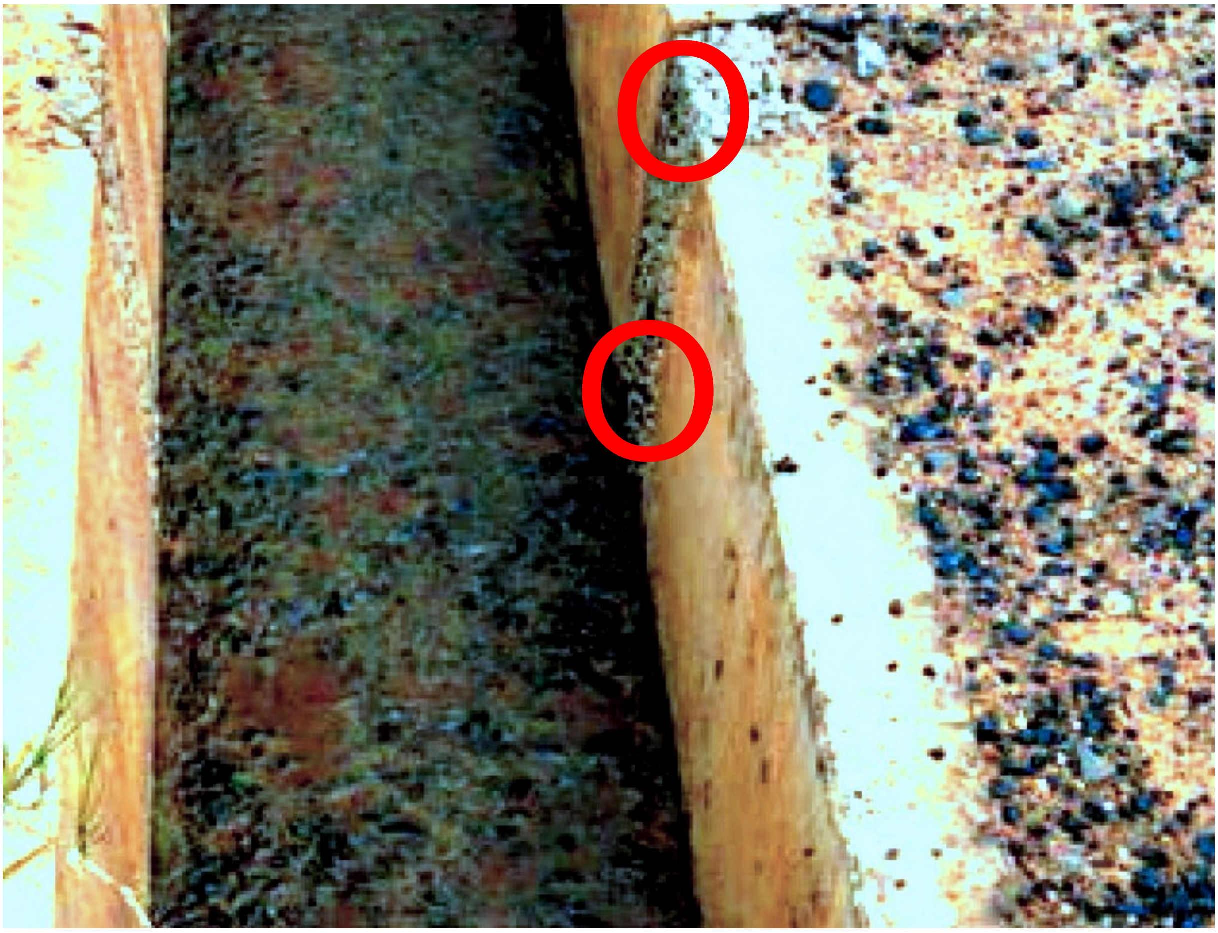
Shallow laid not properly working open masonry Side-Drain/Gutter, SLR, Coast Line

Deep laid open lined Side Ditch-Drain; Agra-Gwalior, India

Retaining masonry Walls cum open lined Side-Drains; KK-Line, India

To drain the water out of the track-bed, the open side-drains must be laid deep enough and must have water-passages at the toe, or side-wall slots to allow the water to seep into the drain, otherwise they will retain the water in the track-bed:

German Federal Railway Concrete lined open Side-Drain



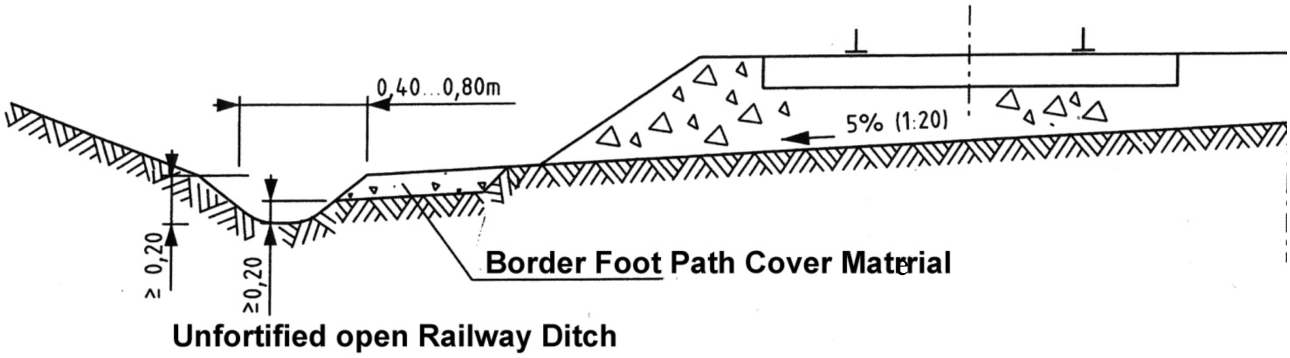
Concrete lined open Side-Drain with Water permeable Slots
(from ***Railway Substructure Engineering*** by Dr. Ernest T. Selig)

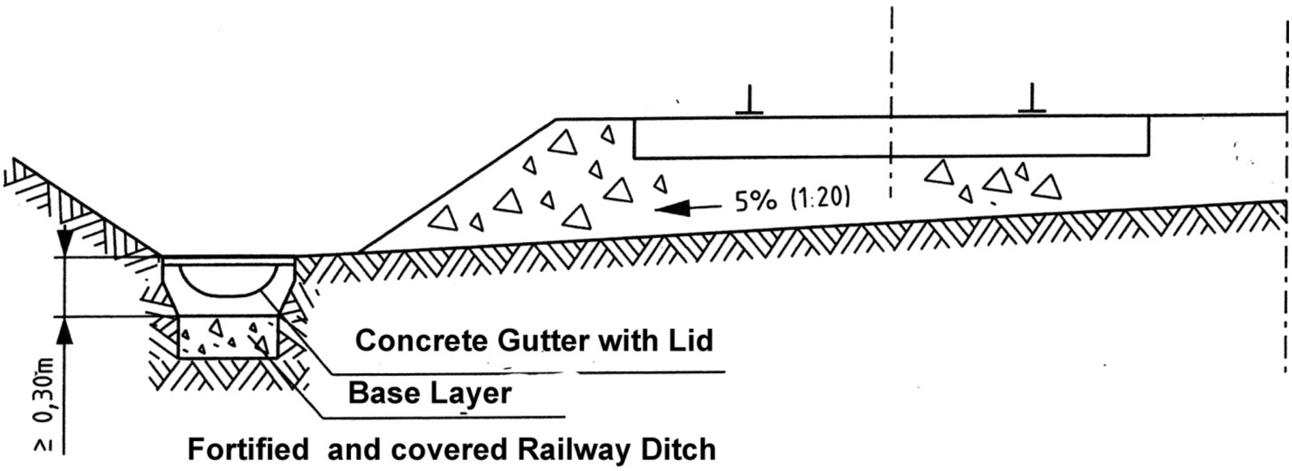
Lined open Side- and Toe-Drains; UK
Picture from ***Railway Drainage Systems Manual,*** Network Rail, UK

Lined open Side- and Crest-Drains; UK
Picture from ***Railway Drainage Systems Manual,*** Network Rail, UK

Silted and blocked open lined Side-Drain Gutters

In the following diagrams some more embodiments and application systems are delineated; see Cl. Göbel and Kl. Lieberenz; ***Handbuch Erdbauwerke der Bahn***:





III. Enclosed Underground Drainage Systems:

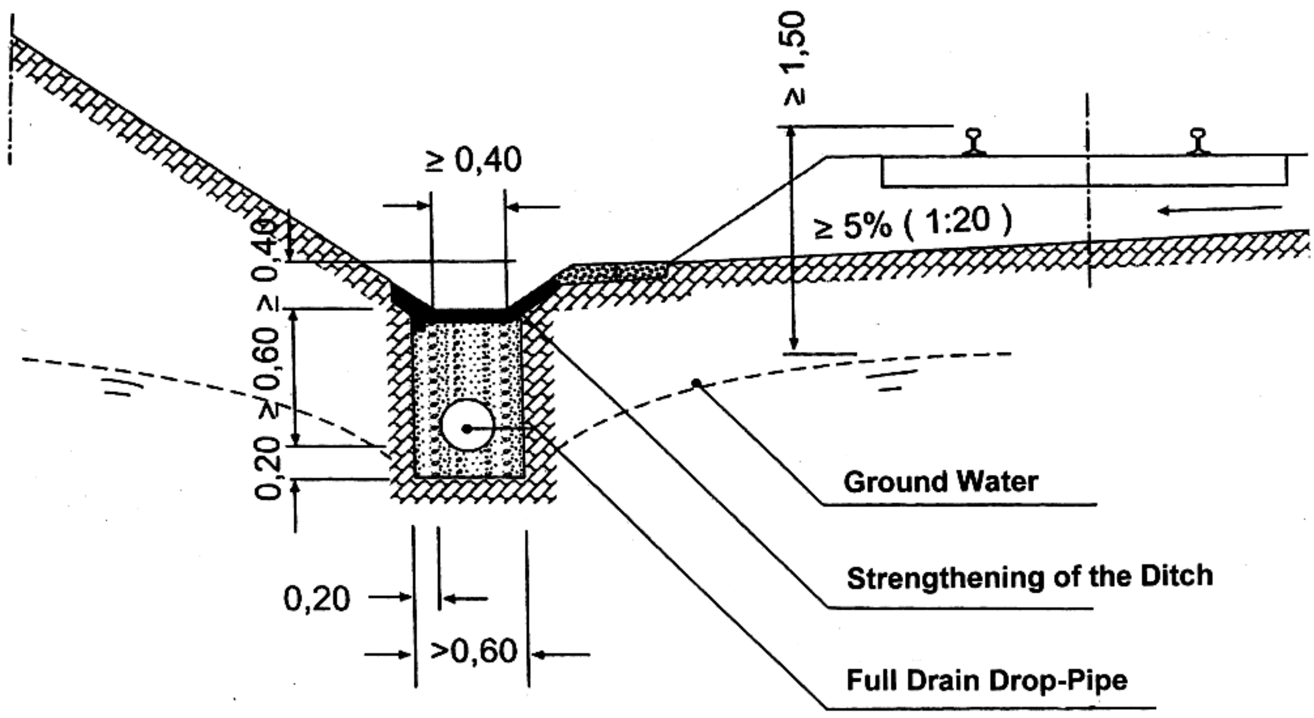
Where the free space along the track is limited, and where open ditch-drains might endanger the stability of the track-bed, enclosed **Underground Drainage Facilities** or **Sub-Surface Drains** are asked, which need no frequent re-profiling and weeding

Underground drainage system is implemented if the groundwater-level is to be lowered, if the soil surrounding the track formation is to e drained, or if leachate and stratum water are to be diverted.

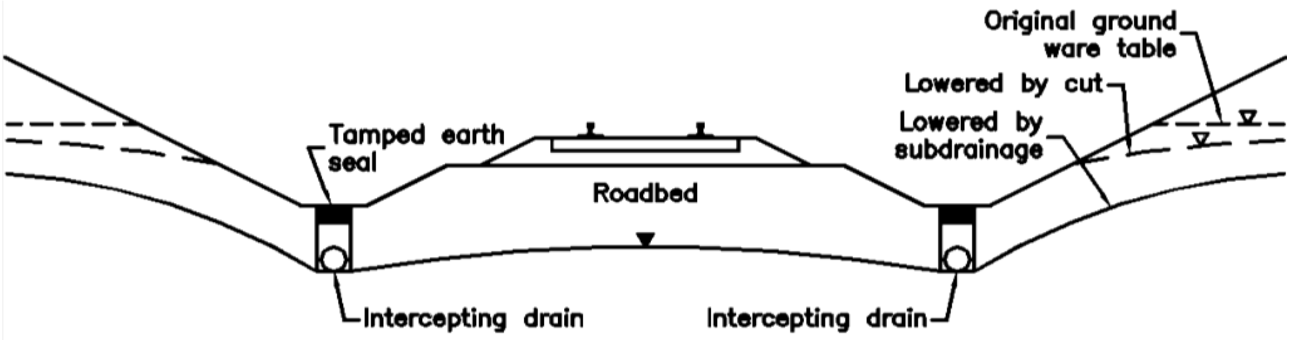
These systems are favourable in cramped conditions, as they can be installed beneath the track border path. They have a longitudinal incline of 1 in 200 to 1 in 300, which takes up little space. However those systems need higher capital investment and they have to be regularly flushed from impurities.

Water from sub-soil can be drained by so-called ***"French-Drains"***. A **French Drain** - also called **Blind-Drain**, **Rubble-Drain**, **Rock-Drain**, **Drain-Tile**, **Perimeter-Drain**, **Land-Drain**, **French-Ditch**, **Sub-Surface Drain**, **Sub-Soil Drain** or **intercepting Drain** - is a trench filled with gravel or rock or containing a perforated pipe that re-directs surface-water and ground-water away from an area. A French-Drain has a perforated hollow drain drop- or slot-pipes along the bottom to quickly vent water, which seeps down through the upper filter gravel or filter rock. The trenches are often lined with geotextile and/or the drop-pipe is wrapped with Geotextile to prevent fines blocking the pipe-slots or pipe-perforations.

French Drains are named after ***Henry Flagg French*** (1813–1885) of Concord, Massachusetts, a lawyer and Assistant US Treasury Secretary, who had first described and popularized those drains in his book "***FARM DRAINAGE***".

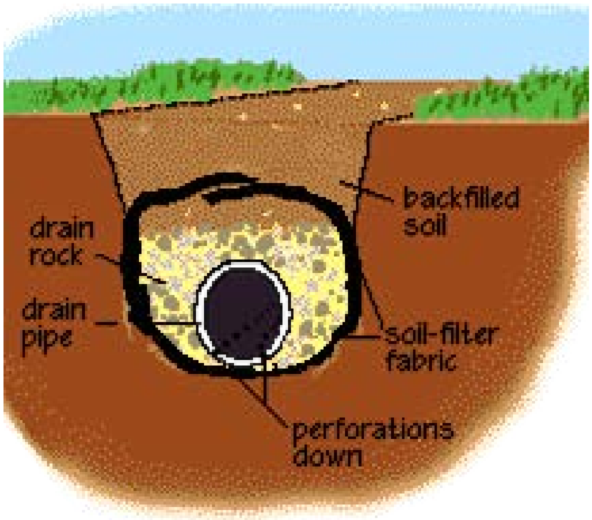


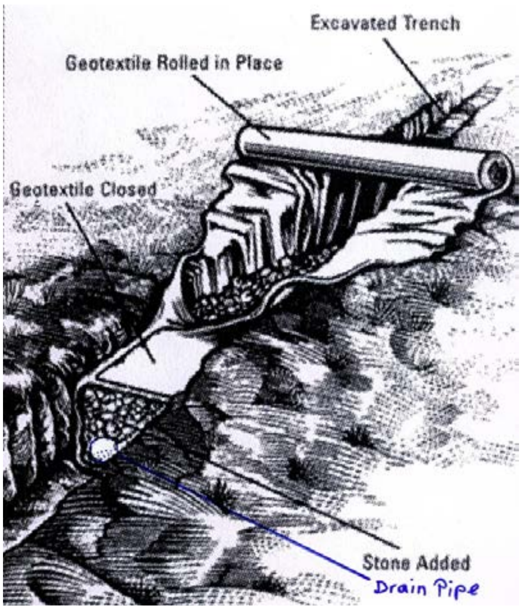
Dimensions and Arrangements for Sub-Soil Drainage System
(Graph from B. Lichtberger, Track Compendium)

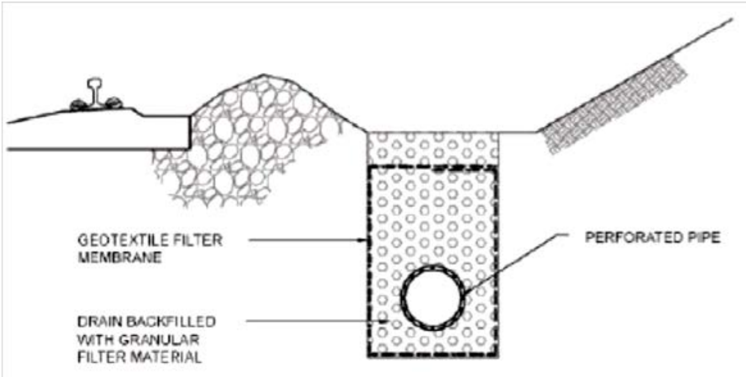


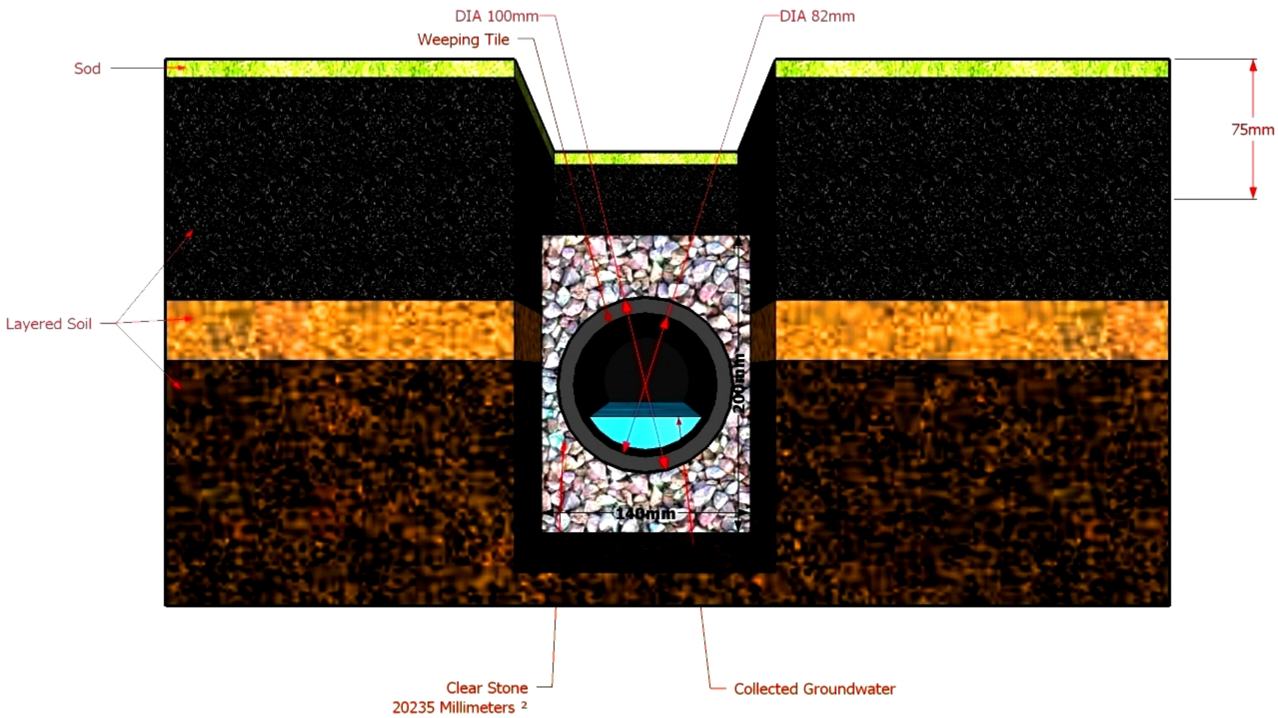
Lowering the Ground-Water Level in a Cutting

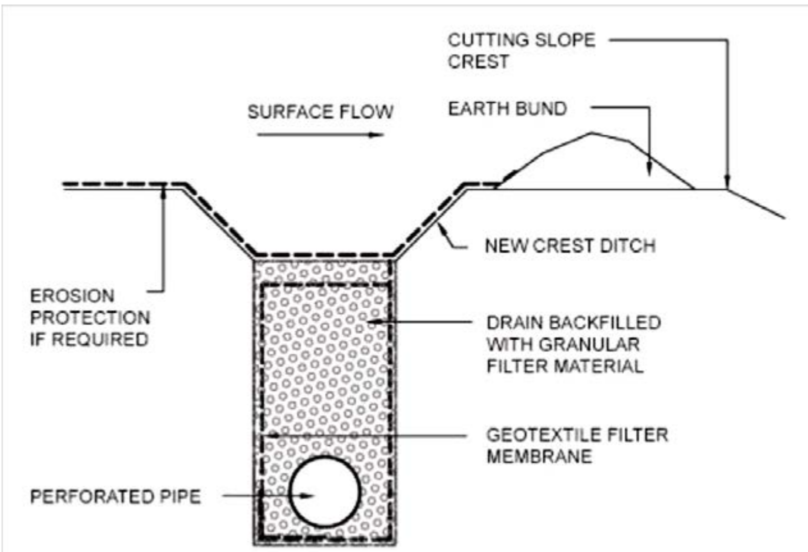
The ***"French-Drain"*** is installed 1.50 m below the rail-top. The following **PICTURES** delineate the systems:



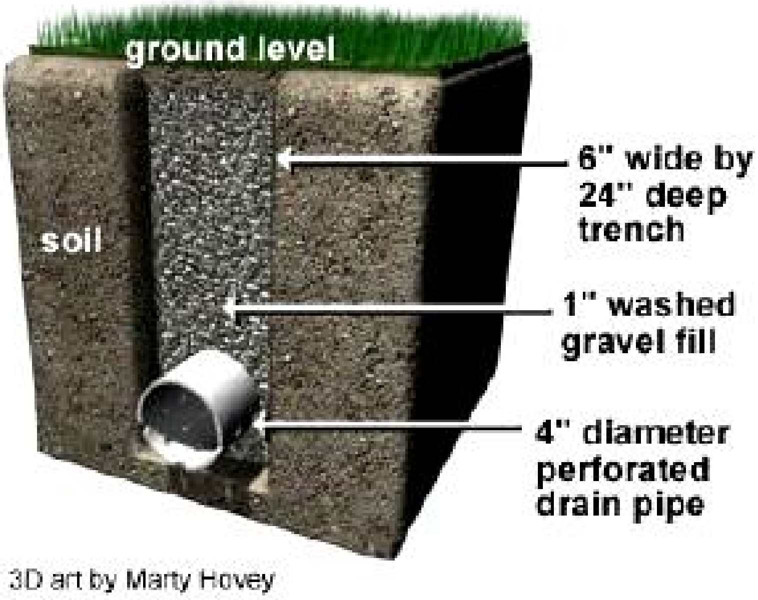








Example of Crest-Drain; Diagram from ***Railway Drainage Systems Manual,*** Network Rail, UK



The sub-surface are filled with washed filter-gravel and should be lined with a **Geotextile** (erosion stable and water permeable woven or non-woven synthetic textiles) with an effective pore opening width of approx. 0.08 to 0.16 mm. The thickness should be approx. 10-times of the pore opening width, and the weight should be greater than 150 g/m². The Geotextile should cover the filter-gravel from all sides.

The trench should be topped with a water permeable material, best with a sand/gravel mixture, which can be replaced for cleaning if clogged. On locations, where mud surface-water is flowing from adjacent lanes or roads towards the track-bed, the top can be paved with tiles or readymade concrete troughs. Best is to guide away surface mud-water by a separate drain-system.

The washed **Filter-Gravel** should have no fines smaller than 2 mm and an average grain-size up to approx. 22 mm. Best are spherical and sieved river gravel-stones without sharp edges. Crushed stones with sharp edges may harm the drop-pipes.

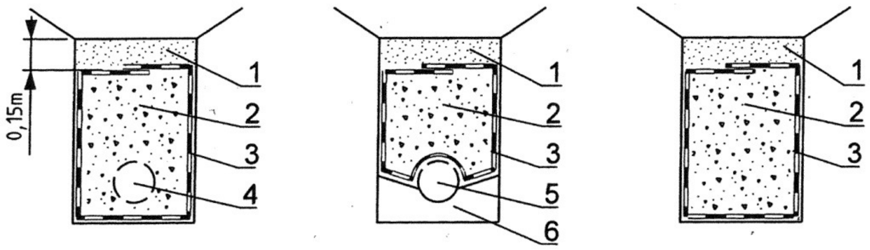
Depending of the water amount to be drained away and the water permeability of the ground material, the trench can be fitted with or without perforated or slotted **Drop-Pipes**. Such plastic pipes made out of Polyvinylchloride (PVC) or Polypropylene (PP) are perforated with holes or slots of 0.5 to 2.0 mm.

Partial-drain drop-pipes with the perforation (slots or holes) only on the upper side can be embedded in a correct fitting water impermeable gutter shaped grooved bottom. Full drain drop-pipes with perforation all around or only at the down-side are laid on a gravel or sand layer without any semi-enclosing water impermeable bottom. The latter system is easier and cheaper to install.

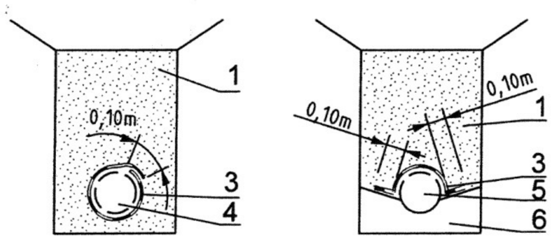
The diameter of the drain-pipes is between 10 and 20 cm. One should use loose fitting rigid pipes. Flexible pipes, if not properly laid, may create sags vulnerable by clogging. Clogged pipes have to be laid bare, cleaned or replaced. The down-gradient should be at least 1 in 300.

The following graphs delineate the variants; see Cl. Göbel and Kl. Lieberenz; ***Handbuch Erdbauwerke der Bahn***:

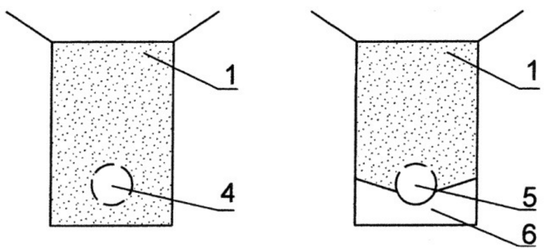
Trench Filter



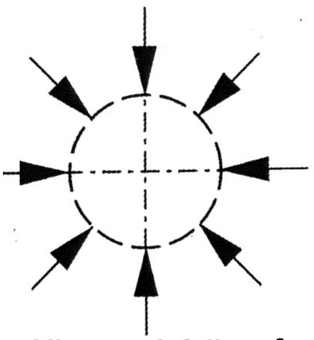
Pipe Filter



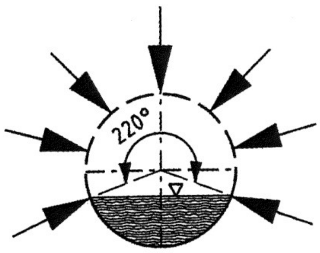
Simple Filter



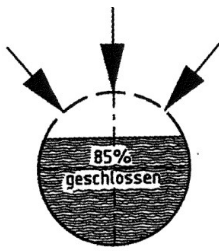
1 **Filter Material/Gravel**
2 **Drain Material/Gravel**
3 **Geotextile**
4 **All round Slot Pipe**
5 **Half round Slot Pipe**
6 **Pipe Sole**



All around full perforated Drain-Pipe



Partial perforated Drain-Pipe



Multi Purpose Top perforated Drain-Pipe

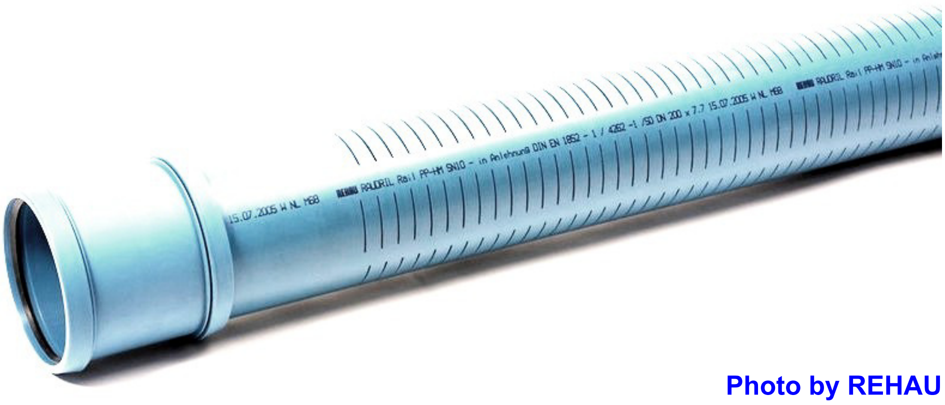


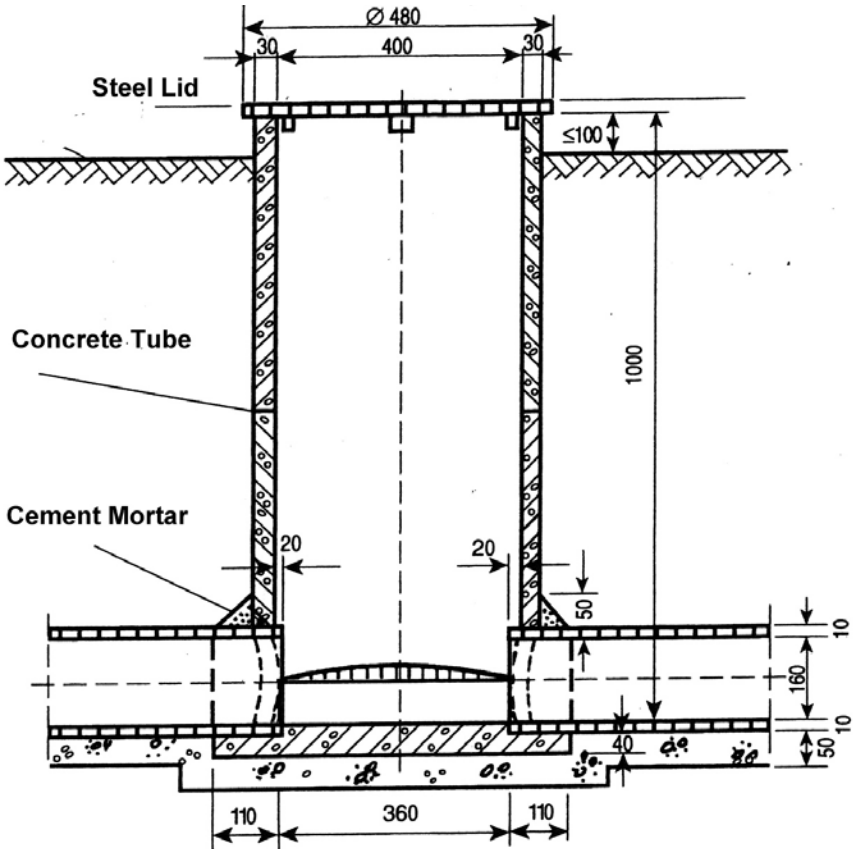
Photo by REHAU

Slotted PP full Drain-Pipe

Laying of rigid and loose-fitting **slotted PP** Drain-Pipes; German Federal Railway

Laying of Sub-Soil **slotted Drain**-Pipe to drain a Tunnel connected to a Water collecting **Chute**; German Federal Railway

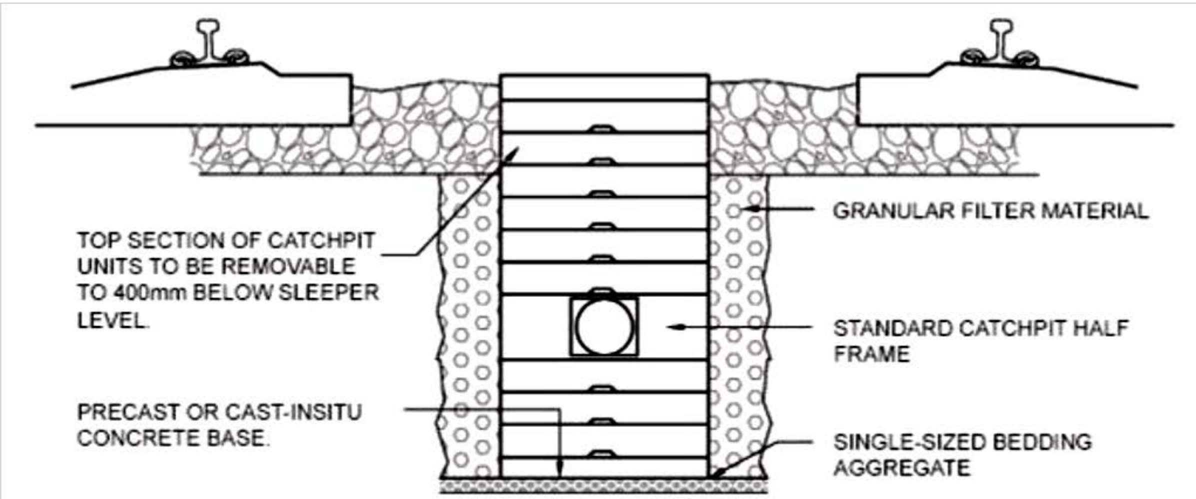
The drain-pipes are connected after approx. 50 m to an approx. 1.00 to 1.50 m deep man-hole, inspection/cleaning pit or seepage-pit known as ***DRY WELL***, either to collect the water to a lower surface drain, water-outlet or culvert, or to allow the effluent to leach into the soil. The man-hole or dry-well should have a solid lid for inspection and/or cleaning. The following figures delineate systems of German Federal Railway and British Rail Net:



Dimensions of a Man-Hole/Inspection & Collecting Pit; German Federal Railway
(from Cl. Göbel and Kl. Lieberenz; ***Handbuch Erdbauwerke der Bahn***)

Cleaning of Man-Hole, Seepage-Pit, German Federal Railway

Laying of new Track with Sub-Soil Drains and Catch-Pits/Man-Holes/Inspection-Pits
German Federal Railway

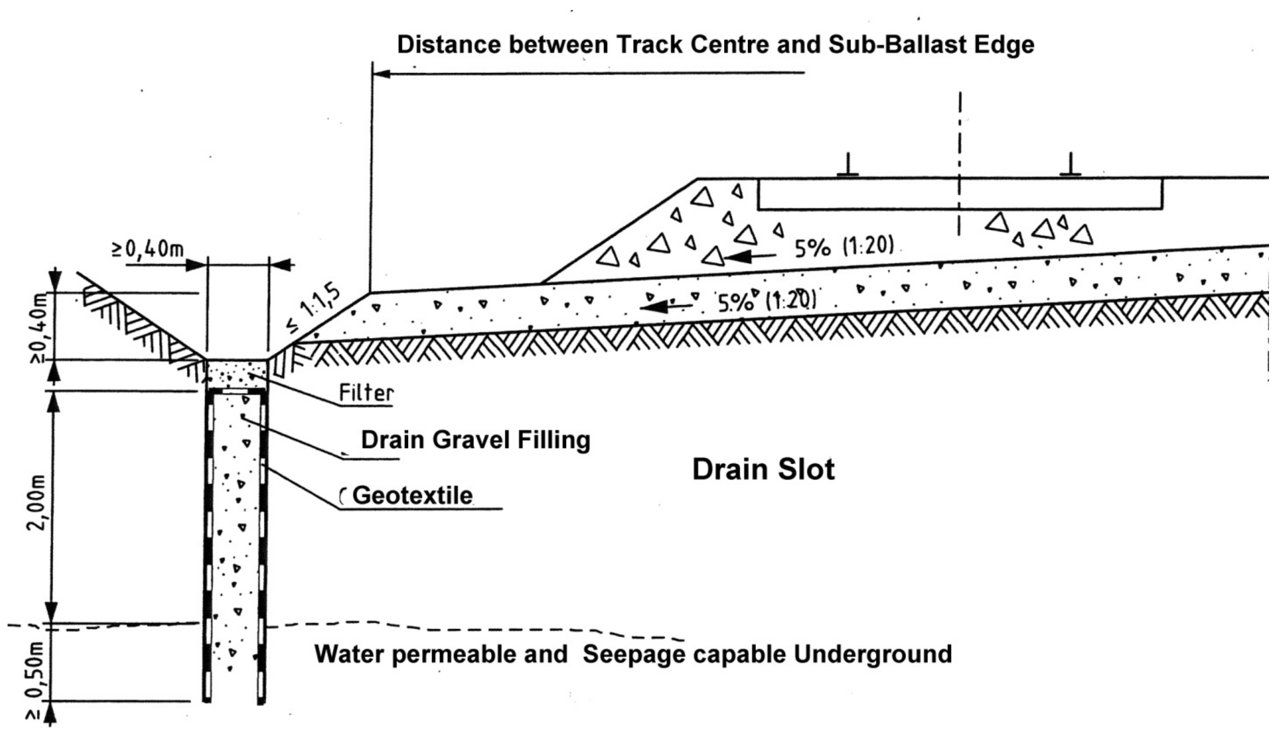


Typical rectangular Catch-Pit Concrete Elements with Slots; British Net. Rail, UK

Open Catch-Pit/Inspection-Pit/Man-Hole

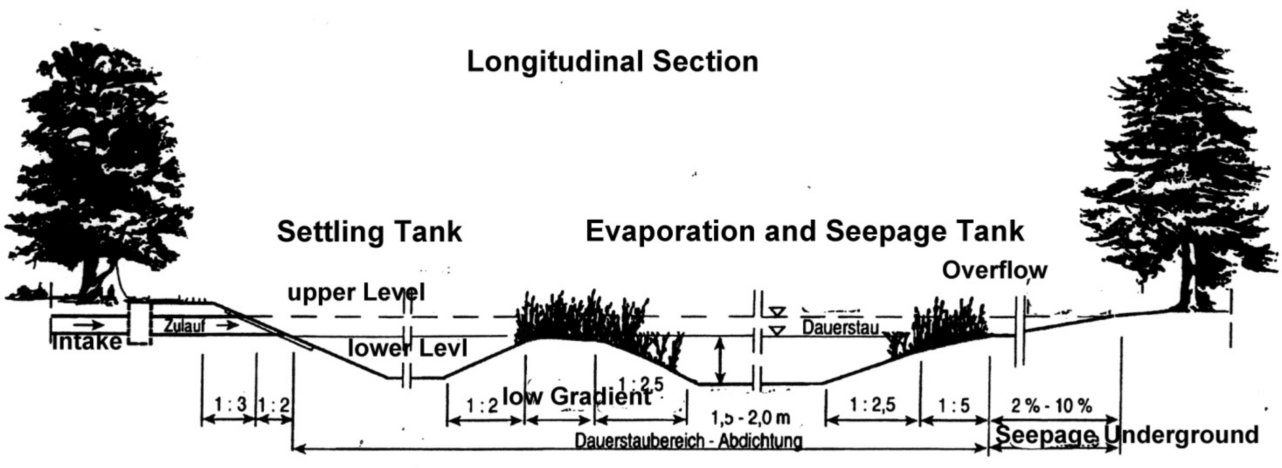
Catch-Pits between the Tracks at Station
British Network Rail, UK

On water impermeable ground **Seepage-Rigoles** or **Drain-Slot** can be drilled through the water barrier until a water permeable layer is reached to drain the water away by leaching. The rigoles are lined with Geotextile and filled with filter-gravel; see Cl. Göbel and Kl. Lieberenz; ***Handbuch Erdbauwerke der Bahn***:

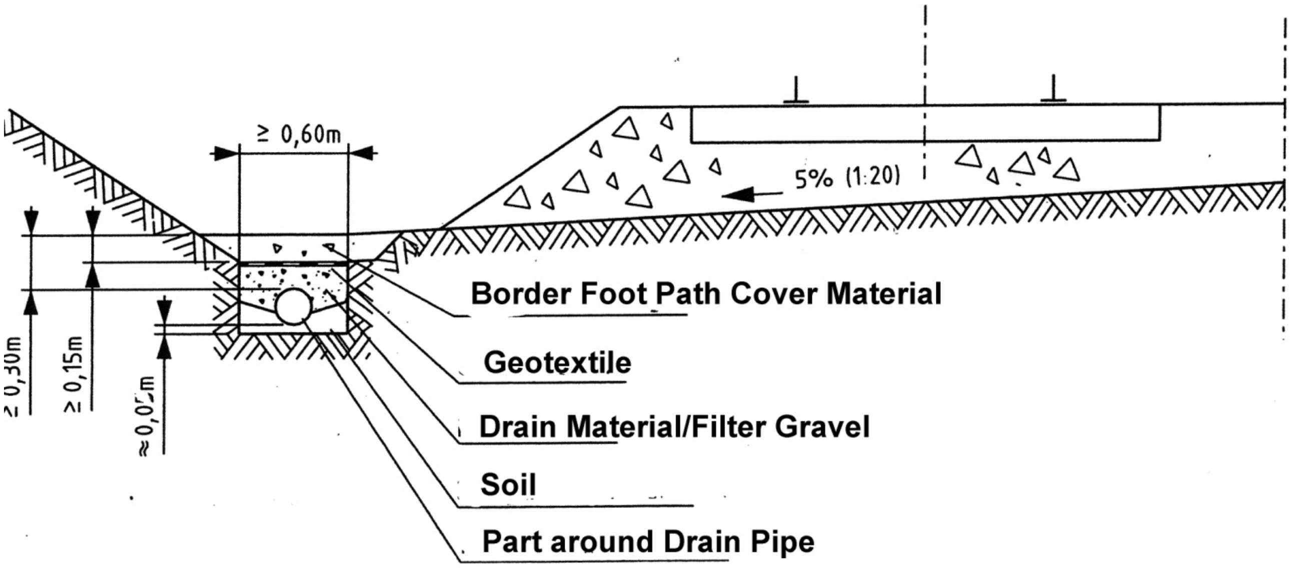


Arrangement of Drain Rigole/Slot to leach the Water into deeper Water permeable Layer

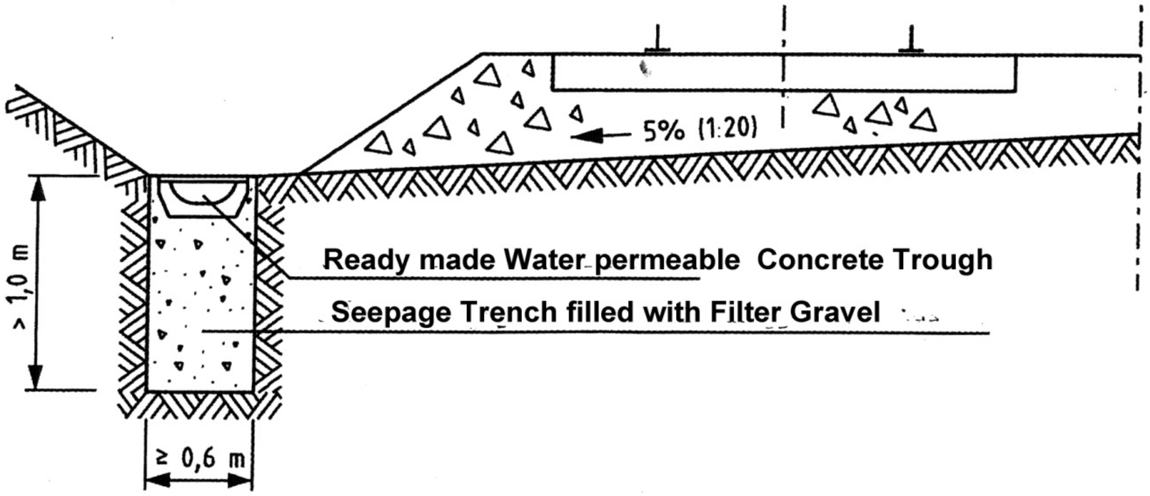
Under circumstances when the collected water cannot be guided away into a lower canal system, dry-well system or rigole-system, an evaporation and seepage tank can be used; see Cl. Göbel and Kl. Lieberenz; ***Handbuch Erdbauwerke der Bahn***:

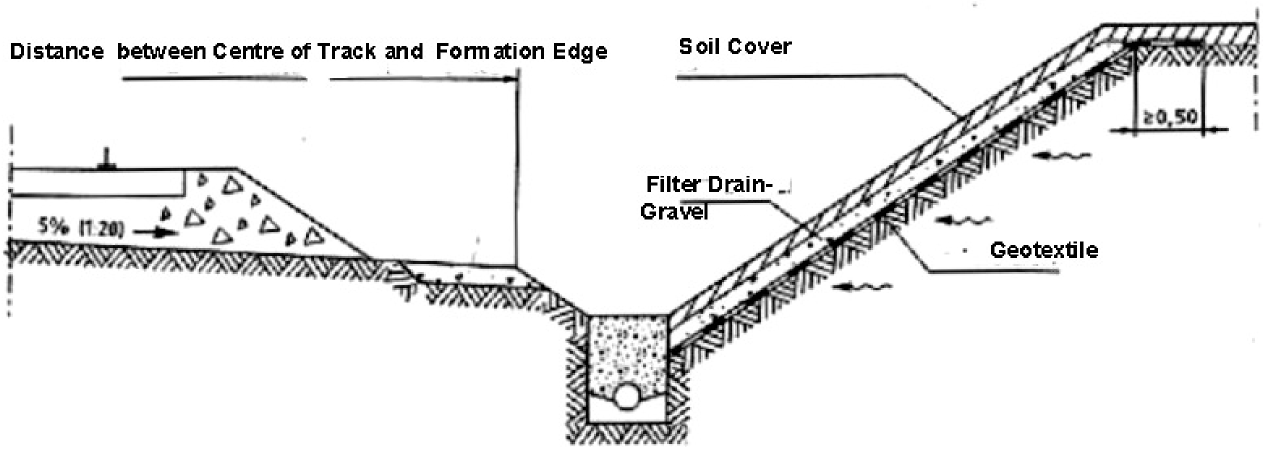


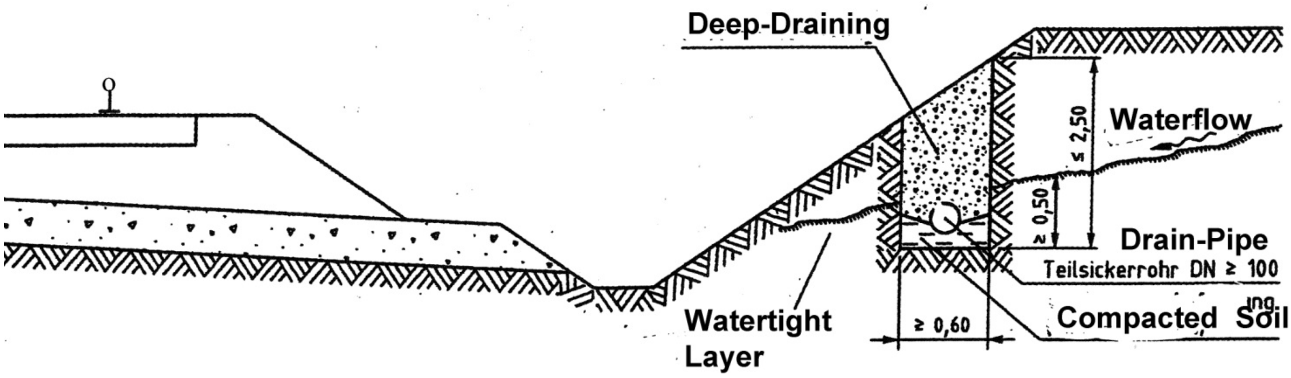
In the following self-explaining graphs of some embodiments and applications for enclosed underground/sub-soil drain systems are delineated; see Cl. Göbel and Kl. Lieberenz; ***Handbuch Erdbauwerke der Bahn***:

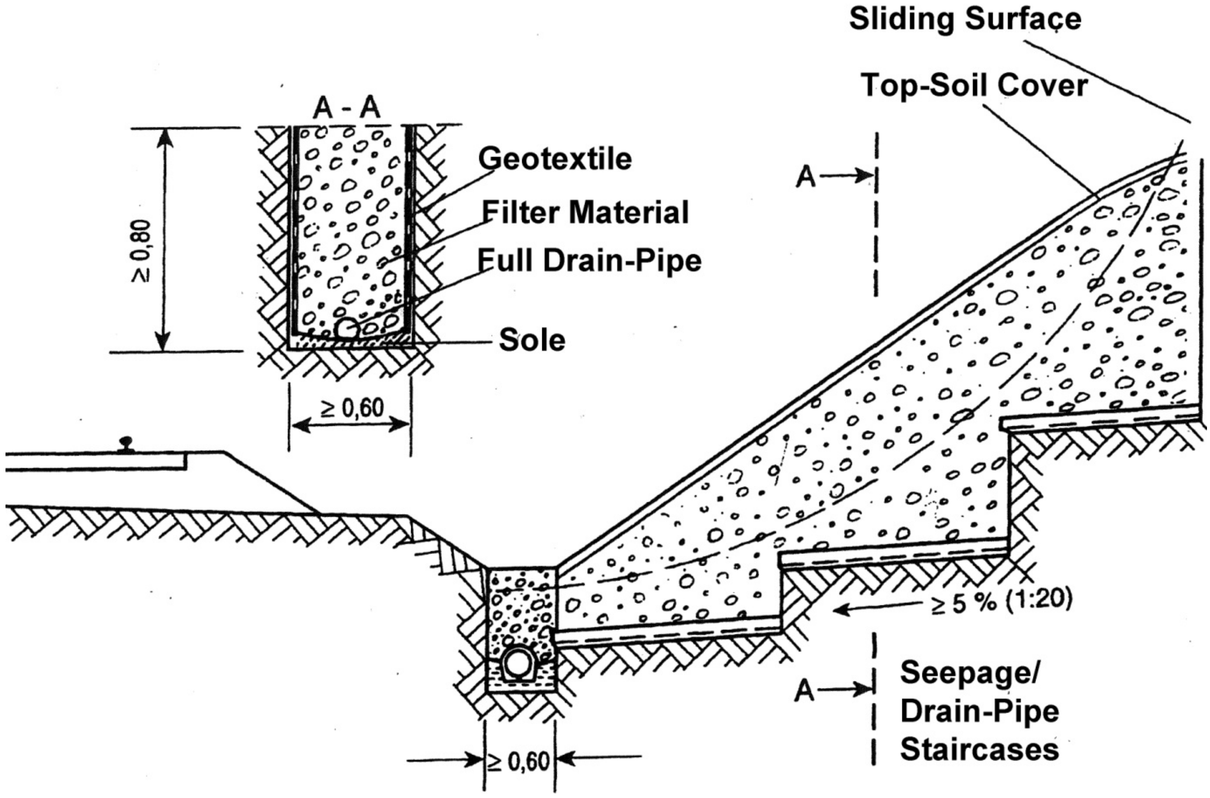


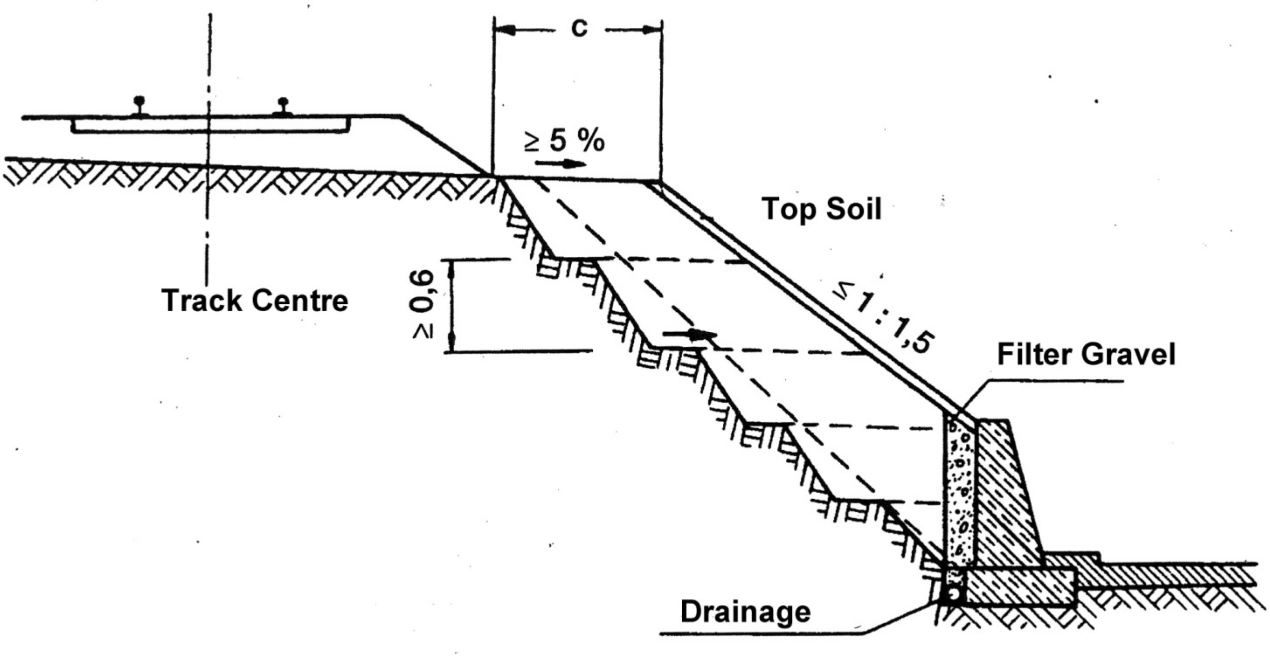
Closed Water Pipe/ Drain Pipe Railway Ditch






Deep-Draining
Waterflow
≤ 2,50
≥ 0,50
Drain-Pipe
Teilsickerrohr DN ≥ 100
Watertight
Layer
≥ 0,60
Compacted Soil


Sliding Surface
Top-Soil Cover
A - A
≥ 0,80
Geotextile
Filter Material
Full Drain-Pipe
Sole
≥ 0,60
A
A
≥ 5 % (1:20)
Seepage/
Drain-Pipe
Staircases
≥ 0,60


c
≥ 5 %
Top Soil
Track Centre
≥ 0,6
≤ 1 : 1,5
Filter Gravel
Drainage

IV. <u>Catch-Drains to prevent Land-, Mud-, Earth- and Rock-Slides:</u>

A **<u>cutting or a graded hill-side slope</u>** is an injury to the nature. The natural water-flow gets disturbed. Nature takes revenge by land-, mud-, earth- and rock-slides, soil-slipping or bolder-falls. This leads to train accidents, where passengers lose their live or get severely injured:

Reuters

Train stuck in a Mud/Rock-Slide **near Vaibhavwadi, 22th June, 2003** Konkan Railway, India

In the year 1998, when the Konkan Railway started to operated passenger trains on its full length from Mangalore in Karnataka to Roha in Maharashtra, the author travel this section in 4 days and had several discussions with personnel engaged in this project.

The difficult terrain had been a big challenge to India`s Engineering Capability and Skill. The author predicted during his exploration travel in 1998 ***"NASTY ACCIDENTS ON THE WAY TO COME"***, mostly because the injury done to the nature by deep and narrow cuttings of up to 50 m. And nature took revenge with the predicted ***"NASTY ACCIDENTS"*** to happen.

The German Black Forest Railway, build between 1863 and 1873 to cross the Central Black Forest from Offenburg to Donaueschingen according a plan-drawing of Robert Gerwig is a shining sample, that a railway build in a difficult mountainous terrain is best secured, if as much as possible tunnels are used instead of cuttings or laying lines along graded hill-side slopes. The higher capital invest-costs pay off by less unwanted bad events.

Land-Slide blocking KK Line; India

Narrow Cuttings of Konkan Railway

Once the terrain is opened by a cutting, the injury cannot be closed any more. Flimsy protection walls will not withstand the mass of a water drenched soil and earth. On the Konkan Railway more tunnels instead of cuttings should have been used. But to drill a tunnel is a costly and time consuming undertaking. To dig narrow cuttings is cheaper and faster elaborated. Limited funds did not allow building the Konkan Railway Line from the beginning in a more safe and secured condition. Only after several "***NASTY ACCIDENTS"*** had happened, more money could be allocated to make the line more safe. This raised the question if accidents are needed to make railway lines more save.

Retaining Wall wash-away by Land-Slide Konkan Railway Line; Karnataka, India

One could have learned from the beginning of this project not only from the 1860-ties German Black Forest Railway Engineering bringing the track in more tunnels instead in cuttings, but also from the Incas of the 15^{th} century (in what is now Peru), which fortified and secured the hillsides of their citadel on a 2430 m high mountain by sub-surface drained terraces:

Terrace **Sub-Surface** Drainage and Stabilization of the Hill-Side Slopes of Machu Picchu in the Andes of Peru **by 15th Century Incas**

On the Konkan Railway Line one can nowadays notices several efforts to widen and flatten grueling cuttings and to provide stepwise terraces.

See: UNEP Report; Impact Assessment and Management Framework for Infrastructure Assets: ***A Case Study of Konkan Railways,*** by Amit Garg, Pakriti Naswa and P.R. Shukala, Indian Institute of Management Ahmedabad; ISBN: 978-87-92706-25-6; *www.unep.org/transport/lowcarbon/PDFs/ImpactAssessment*

After nasty Accidents: Flattening of Cutting-Slope **providing** Terraces; Konkan Railway**, India**

With **<u>Catch-Drains or intercepting Drains</u>** water can be collected from catchment areas on hill-tops, terraces or hillsides and guided with step-cascades to lower areas before the water will penetrate into the soil causing hill-slides, soil-slippings, rock- and bolder falls:

Constructing an open Hill-Side Drain-Ditch

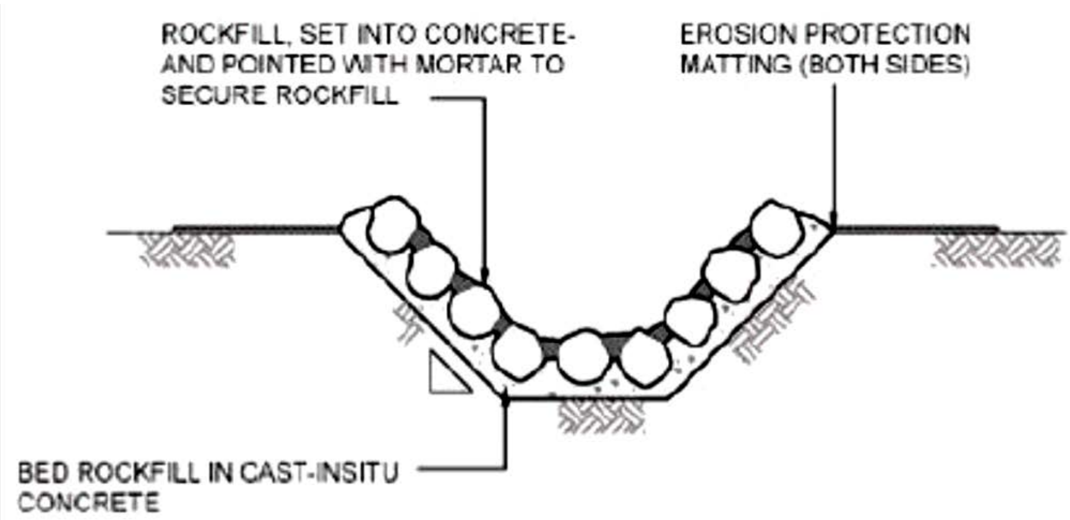
Constructing an open Hill-Side Drain-Ditch

Open Hill-Side Catch-Drain

Step-Cascade for Intercepting Drain (left Side), KK Line; India

Unless the drains excavated in rock, cascades are usually lined to prevent channel erosion. However, unlined flumes can be used where the quantity of water to be carried is small. If the gradient is steep, the sole of the drain is designed as a step cascade:

Typical Step-Cascade; Pictures from ***Railway Drainage Systems Manual,*** Network Rail, UK



Rock lined Cascade; Diagram from ***Railway Drainage Systems Manual,*** Network Rail, UK

Unless the drains excavated in rock, cascades are usually lined to prevent channel erosion. However, unlined flumes can be used where the quantity of water to be carried is small.

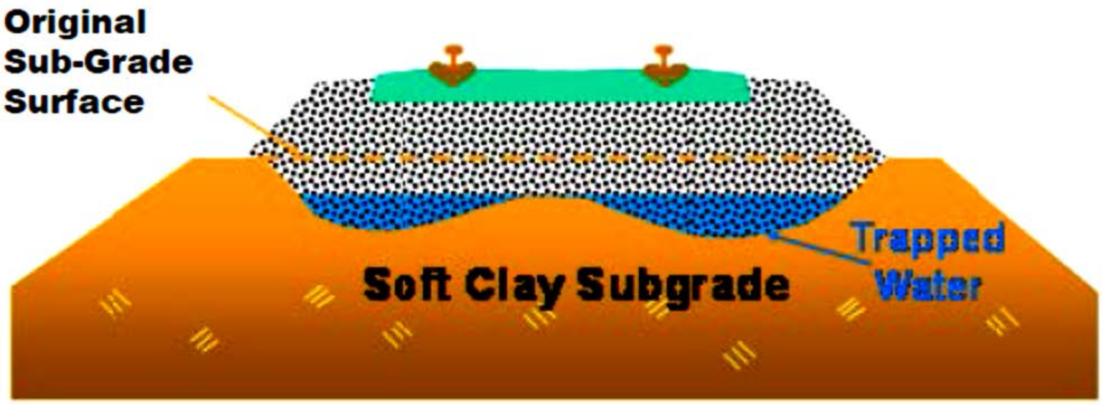
Step-Cascade of an Intercepting Drain

On the Srilankan grueling upcountry line at Watawala the series of hill-slides and wash-awys, leading to accidents and interruption of railway-services, could be stopped by catching the hill-side water with as well open drains as underground perforated drop-pipe drains. This had been a successful endeavor; **see <u>Ranjith Dissanayake</u> in the Magazine *RAIL2000*, page 191 ff, ISBN 955-8363-00-6, Vishwa Lekha Printers, Ratmalana, Sri Lanka.**

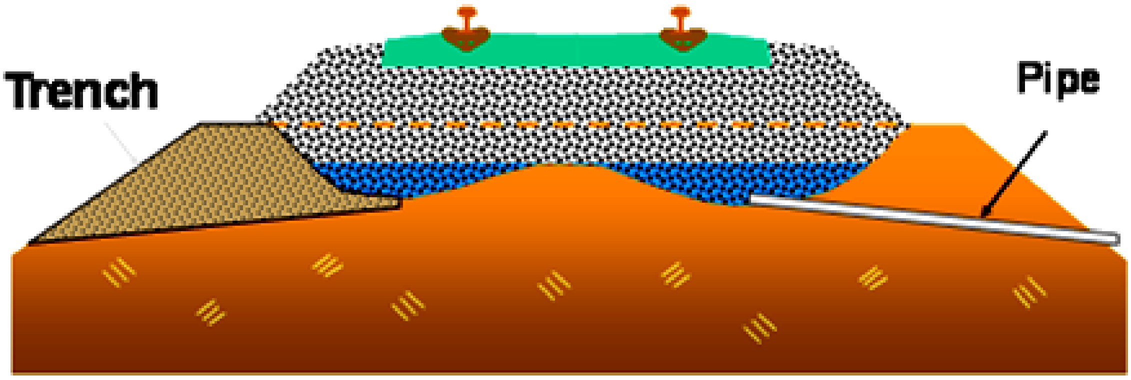
Under the Sri Lankan track engineer Ranjith Dissanayake the famous upcountry SLR 18 Degree Rozella broad gauge curve had been new aligned and lifted on bolder to allow the water seeping from the hill-side a free flow under the track-bed towards surface water intercepting lined open drain on the hillside.

V. <u>Drainage of Ballast-Pockets:</u>

Elder railway tracks have mostly no blanket or sub-ballast layer between top formation or sub-grade surface and ballast. Not seldom the ballast penetrates over the years into the unprotected formation/sub-grade yielding to so-called ***<u>"BALLAST POCKETS</u>***", which can get drenched with water and form a ***"BATH-TUBE"*** under the ballast. Opening and draining will become inevitable:



(from ***Railway Substructure Engineering*** by Dr. Ernest T. Selig)



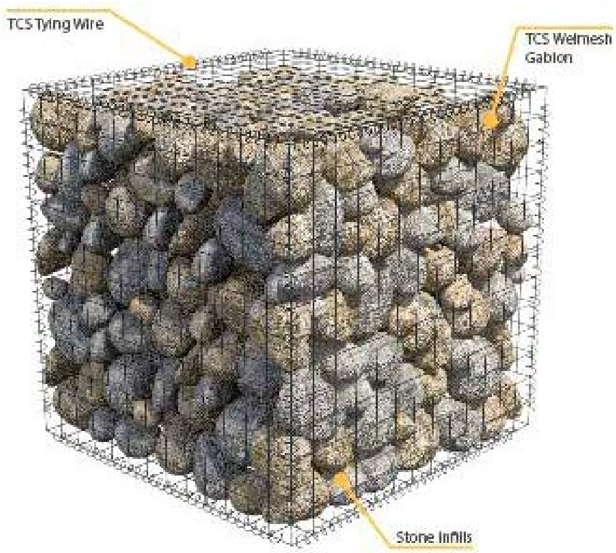
(from ***Railway Substructure Engineering*** by Dr. Ernest T. Selig)

Opening of trapped Water in Ballast-Pocket
from ***Railway Substructure Engineering*** by Dr. Ernest T. Selig)

More guidance for Track Draining, especially for Ballast-Pocket Draining you find in the book: ***A TEXT BOOK OF RAILWAY ENGINEERING*** by S.C. Saxena and S.P. ARORA, Dhanbad Rai Publications, New Delhi, India, Reprint 2011, ISBN 978-81-89928-83-4 under **Chapter 23**, ***Track Drainage***. See also **Chapter 8** in ***INDIAN RAILWAY TRACKS*** – a revision by F. Wingler of Drafts by J.S. Mundrey for free download under http://www.drwingler.com.

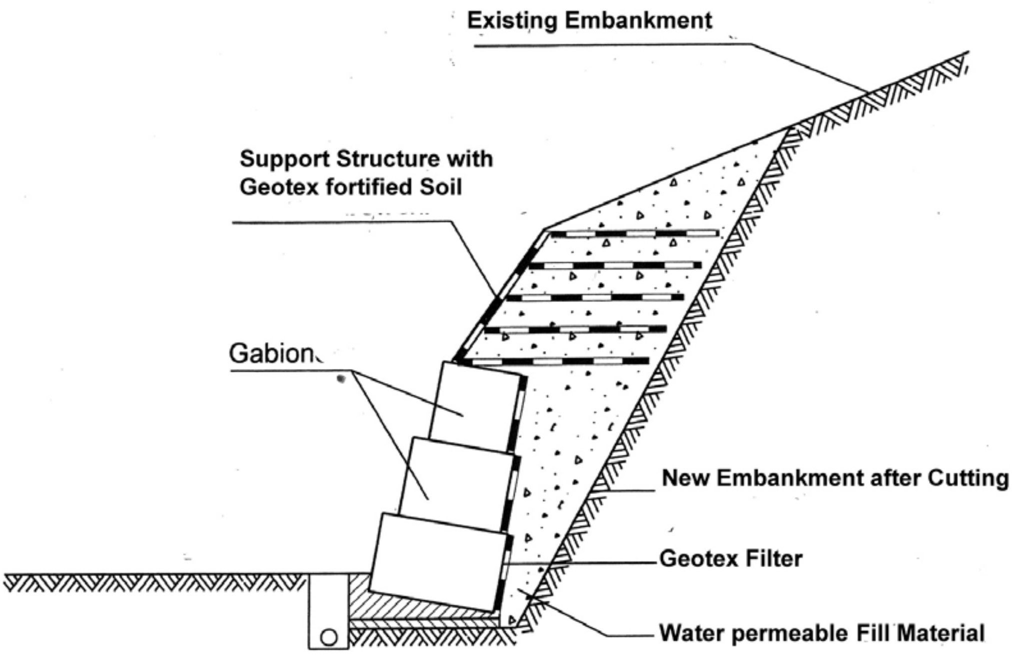
VI. The Use of Gabions to protect Hill-Side Slopes, Cutting Slopes and Embankments:

Gabions are wire-netted baskets filled with stones or boulders. By their nature Gabions are water permeable. They are relatively cheap, easy and quick to erect.



Gabion - a Wire netted Basket fill with Stones/Boulders

Railways use gabions to stabilize embankments, hill- and cutting slopes. They work by their weight. Gabions should be erected with an incline of 1 in 10 and should be based on a solid fundament:



Graph of a Gabion-Arrangement to secure a Hill-Side or Embankment Slope after Cutting
(from Cl. Göbel and Kl. Lieberenz; ***Handbuch Erdbauwerke der Bahn***)

Gabion Wall **as a Gravity Dam** securing wet Hill-Slope

Water permeable Gabions are a valuable tool in disaster management for quick restoration of railway traffic after a natural calamity. Gabions can bring temporary relief. Gabions had been used to rebuild the track-embankments, to secure hill-sides and water-passages after parts of the scenic Matheran Hill Rail-Road had been washed away by heavy monsoon rain in Maharashtra July 2005:

With Gabions rebuild Rail Road after the 2005 Monsoon Wash-Away;
Matharan NG Hill Railway, Maharashtra, India

Gabions at Rail Track Embankments can not be regarded as a permanent solution. Gabions helped in Sri Lanka after the December 2004 Tsunami Catastrophe to rebuild rail-track embankments. But they had been hastily erected without providing solid fundaments. With the time they are decaying, moving and deforming:

After the Tsunami hastily erected Gabions without solid Fundament at Bridge Abutment; after 10 years they have decayed;
Ambalangoda, Coast Line, Sri Lanka, 2014

Cutting-Slope Retention with Gabions on Sakleshpur-Subramanya Rd. Section; Karnataka, India