TRACK STRUCTURE
CHAPTER-V
FORMATION

1. INTRODUCTION

Formation for Rail-road in general terms refer to the whole sub-grade and sub-soil which support the track structure and its foundation, which includes ballast, sub ballast, blanket etc. (Fig. 5.1).

The formation must have sufficient bearing strength and stability, reasonable settlement behavior and must provide good drainage of rain water from the ballast bed. If existing sub-grade can not meet these requirements properly, the soil can be improved either by digging a trench and replacing the poor soil with good soils, consolidating the ground by mechanical means or stabilizing the ground by chemical means.

2. DESIGN OF FORMATION

2.1 Objective

To achieve trouble free service, the formation of rail-road should be able to sustain the track geometry under anticipated traffic densities and axle loads during service under most adverse conditions of weather and maintenance of track structure, which are likely to be encountered. This necessitates that:

(a) Sub-grade for bank or cutting should be structurally sound so as not to fail in shear strength under its own loads and live loads; and

(b) Any settlement due to compaction and consolidation in sub-grade supporting soil mass should be within the permissible limits.

2.2 Various aspects of designing a sub-grade

The formation should be termed unsuitable if the uneven settlements in the track are excessive. The reasons of settlement may be due to one or more factors, as described below.

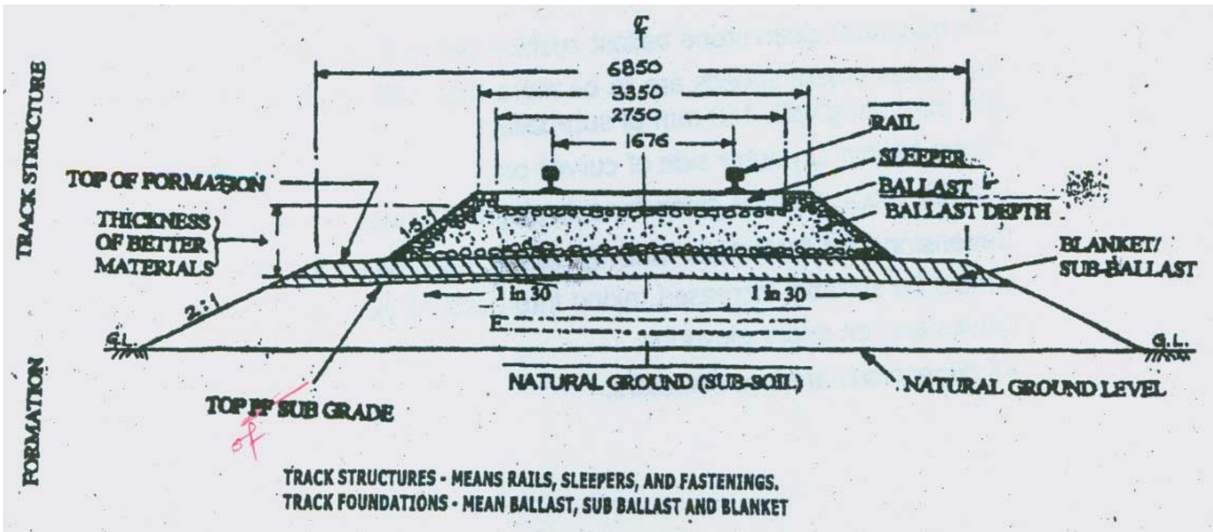

FIG. 5.1 FORMATION FOR BG TRACK

2.2.1 Deficient shear strength of sub-grade or bank soil or sub-soil leads to

(a) Bearing capacity failure of sub-grade resulting into cess and crib heave. Deep ballast pockets are formed as a result of such failure.

(b) Interpenetration failure or mud pumping failure, resulting into vitiation of clean ballast cushion; and

(c) Slips in bank slopes or creep deformation, if factor of safety against slope instability is not adequate.

2.2.2 Large deformation without strength failure due to

(a) In service compaction and consolidation of bank soil or sub soil; and

(b) Settlement and heave due to swelling and shrinkage characteristics of bank soil or sub-soil.

3. STABILITY ANALYSIS OF SLOPES

3.1 Objectives

The side slopes of the formation should be designed to ensure that :

- Embankment or cuttings do not fail (slip) during construction or service.
- There should not be excessive deformation resulting in continued settlement of formation top.
- Erosion of the slope should be minimum; and
- If facilitates economical construction & maintenance.

3.2 Types of Slope failure

3.2.1 Slip (slides) :(fig. 5.1)

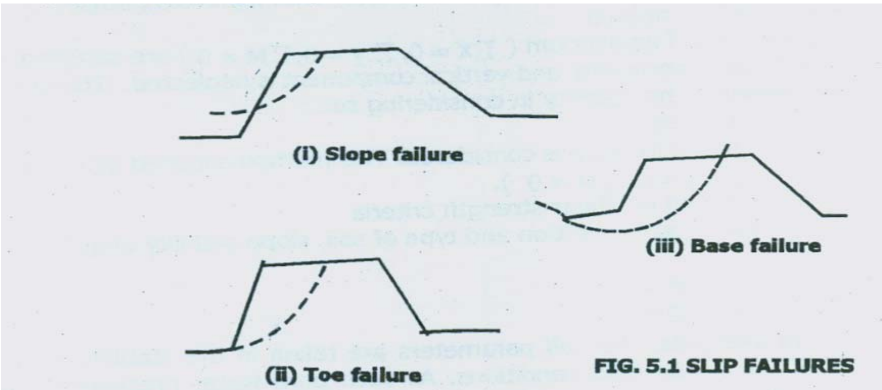

FIG. 5.1 SLIP FAILURES

Soil mass located beneath the sloping surface has the tendency to move downward and outward under the influence of gravity. When the shearing resistance falls short to counteract this tendency sliding failure occurs. Slides in the natural deposit may be caused either due to external disturbances such as undercutting of toe of formation, by temporary increase in hydrostatic (Pore Pressure) pressure or due to progressive deterioration in the strength of the soil. Depending upon location of sliding surface slips are generally classified as slope failure and base failure.

3.2.2 Creep

Some slopes do not slide as a defined slope failure but they flatten i.e the steepness of the slope decreases without undergoing much surface deformation, toe moves out from the centre of embankment and thus bank settles.

3.2.3 Erosion

Erosion of slope is caused due to disturbance to solid particles by rain, wind, jerks, etc. Erosion has nothing to do with stability computation of slope and rendering of slope protection measures like turfing asphalt mulching, coir netting, stone pitching etc. will arrest erosion. Storm water erosion may be minimized by providing small berms like steps at slope.

3.3 Factor of safety against slope failure

Factor of safety of a soil slope is the ratio of permissible stress to allowable stress (elastic theory) or the ratio of failure load on structure (Plastic theory).

$$FS = \frac{\text{Available shear strength along failure surface}}{\text{Mobilised sheer strength along failure surface}}$$

A factor of safety of 1.4 should normally be adopted against slope failure, however a minimum factor of safety of 1.6 should be ensured for slope stability of small embankment of height up to 4m.

3.4 Methods of stability analysis

3.4.1 Depending upon different criteria, slope stability computations may broadly be classified in three categories.

(a) Conventional method of slices

Felonious method & Taylor's friction circle method fall under this category. Only one out of three conditions (Sigma X=0, Sigma Y=0, Sigma M=0) is satisfied in this method, and inter-slice forces are completely ignored. This method is more prone to error with increasing angle.

(b) Bishop's simplified method

In this two conditions of equilibrium (Sigma X=0, Sigma Y=0, Sigma M=0) are satisfied by considering the inter-slices forces to be horizontal and vertical component is neglected. The error is minimized and advantageous towards the stability in considering so.

(c) Bishop's rigorous method

In this method interslice forces are considered. This method satisfied all the three conditions of equilibrium (Sigma X=0, Sigma Y=0, Sigma M=0).

3.4.2 Stability analysis based on shear strength criteria

Depending upon the critical condition and type of soil, slope stability analysis is computed by two methods:

(i) Total stress method and

(ii) Effectives stress method.

In **total stress analysis,** the soil parameters are taken in the stability computations are simulated values of the actual field conditions. As such pore water pressure is not separately calculated, only static water pressure is considered. This type of analysis is purely empirical when phi $_{U}$ =0.

In **effective stress analysis,** pore water pressure is considered separately. The failure criterion in this method is semi-empirical and this analysis gives more reliable results than that obtained by total stress analysis.

In general, slope stability can be computed in the following lines-

(i) Total stress analysis in the conventional methods can be adopted only in the case of phi $_{U}$ =0 condition except in the case of cutting where phi $_{U}$ =0 condition is not the critical one.

(ii) Effective stress analysis with Bishop's simplified method can be used in general.

Students are advised to refer to any standard textbook on soil mechanics for details of slope stability analysis.

3.5 Critical conditions of analysis

(i) In Embankments

(ii) End of construction

(iii) Long term stability with ineffective surface drainage

(iv) In cutting

Long terms stability with adverse conditions of drainage likely to develop in conjunction with modified surface drainage pattern due to changed topography.

3.6 Types of Test

Shear strength and pore pressure parameters are determined depending upon the approach to be adopted in the design.

3.7 Drainage

Drainage as a method of slope stabilization can be very effective provided drains are maintained properly. While designing the drains, its maintainability should be planned. Drains can do three things.

- They can control the movement of surface water,
- They can influence the hydraulic boundary conditions to the seepage regime in a slope; and
- Bring about the desired reductions in pore water pressure at depth.

Shallow or surface drains are easiest to maintain but most likely to fall rapidly into disrepair.

Deep drains act to modify the seepage pattern within the soil or rock mass. These are more costly than shallow drains but they are more effective because they remove water and decrease pore water pressure, directly at the seat of the problem.

Third category of drains is those drains, which are installed to dissipate undrained pore water pressure arising from total stress' change. These drains may be shallow or deep but are normally short lived.

4. FORMATION CROSS SECTION

Final cross section of the formation depends upon :

* Depth of cutting or height of embankment.
* Adequate side slope.
* Top width and spacing of tracks (In case of double line).
* Formation top cross slope.
* Location, sizes and section of side drains.

Indian Railway have prescribed standards for the formation cross section, which are exhibited in **Figure-5.3.** Various cross section requirements for the Railway formation are discussed in following sections.

4.1 Minimum top width:

Table I : Top width of Formation

B.G.				**M.G.**			
Single Line		Double Line		Single Line		Double Line	
Emank	Cutting	Embank	Cutting	Embank	Cutting	Embank	Cutting
6.85	6.25	12.15m	11.55m	5.85m	5.25m	9.81m	9.21m

Widths in Table-I have been decided based on 300mm of ballast cushion, shoulder width, length required for concrete sleeper and cess width on either side of 90 cm in embankment and 60 cm in cutting. Spacing of track centres, in case of new constructions, has been assumed as 5.3m.

On curves, the formation width should be widened extra by 0.15 m on single line and 0.30m on double line to accommodate extra ballast shoulder width. Further, sufficient allowance shall be given for top width to cater for extra spacing of tracks on curves in terms of 'Schedule' of Dimensions' prescribed for the Railways for double line section.

4.2 Side Slope

Side slopes of an embankment should generally be 2 in 1. In poor soils and on high banks flatter slopes may be found necessary (after carrying out slope stability analysis). Alternatively berms may be provided at intermediate levels with steeper side slopes. In favourable conditions, side slope of 1.5:1 can be provided in bank upto 3 m height and upto 1.8:1 in bank upto 8m height.

In cutting involving good soils, a slope of 1:1 may be provided. However, in case of poor soil and adverse ground water conditions, detailed slope stability analysis should be carried out.

4.3 Height of bank/depth of cutting

Normally height of bank or depth of cutting depends upon topography and desired rail level; however, in flat terrain, for ensuring proper drainage and stability of the formation and for preventing tress-passing, it is recommended to provide well defined bank of height not less than 1 m or well defined cutting of depth at least 1m.

Gauge	**Minimum formation widths (m)**			
	In Banks Single Line	Double Line	**In Cuttings** Single Line	Double Line
BG (1676 mm)	6.85	12.15	6.25	11.55
MG (1000 mm)	5.85	9.81	5.25	9.21

(i) For extra ballast cushion on outer-side of the curve 0.15 m on single line and 0.30 m on double line (including 0.15 m increase in centres).

(ii) For extra clearance required on double line due to effect of super elevation.

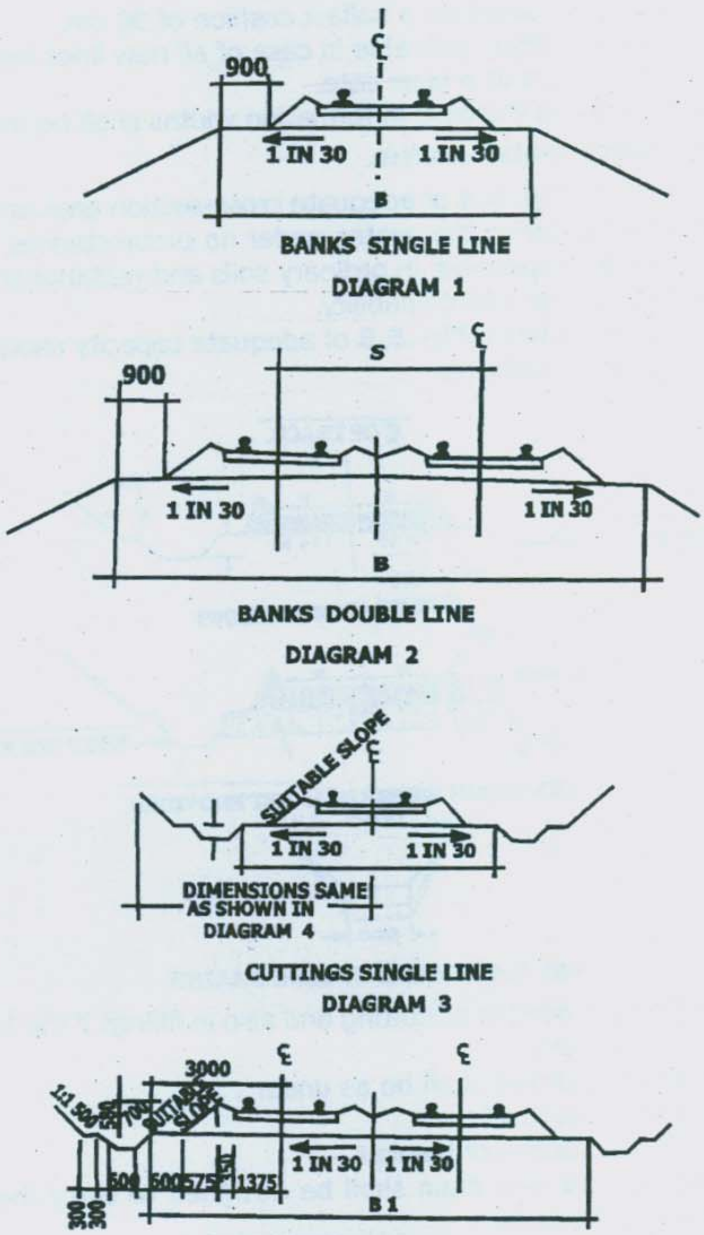

FIG. 5.3 MINIMUM/RECOMMENDED FORMATION WIDTHS FOR BANKS/CUTTINGS FOR CONCRETE SLEEPER TRACK.

Note :

1. All dimensions shown in the diagram are in millimeters.
2. On BG and MG double lines, the minimum formation width is based ontrack centres of 5.300 m and 3.96 m respectively.
3. In the terrains the height of bank/Depth of cuttings should preferably be not less than 1 m. for ensuring good drainage, formation stability and to avoid tress-passing.

4. These dimensions are based on a ballast cushion of 30 cm.
5. These dimensions are also applicable in case of all new lines because on the possibility of use of concrete sleepers.
6. On curves the following increase in formation widths shall be made.

4.4 Side drains and catch water drains.

Side drains, as shown in **Fig. 5.4** of adequate cross-section area and longitudinal slopes shall be provided to drain off all water so that water, under no circumstances, reaches the cess level. A section for the drain may be trapezoidal in ordinary soils and rectangular in rocks. It is preferable to line the drain to ensure better maintainability.

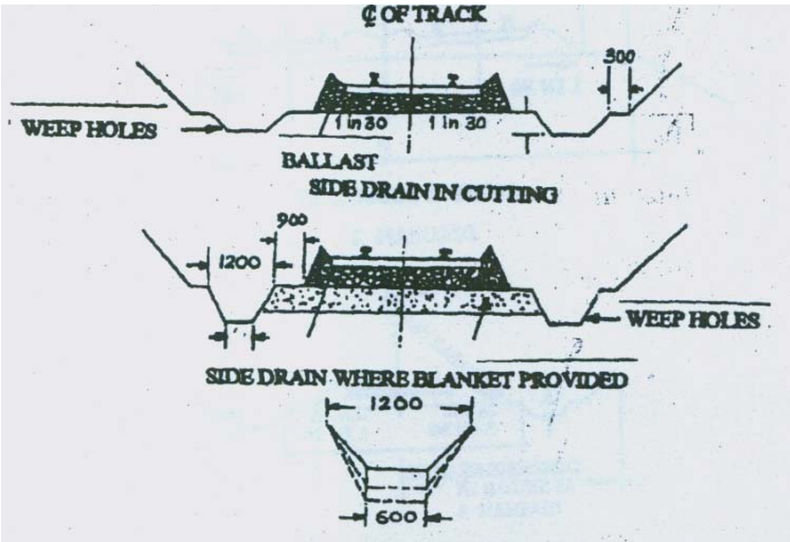

FIG. 5.4 DETAILS OF SIDE DRAINS

1. Side drains shall be pro
2. vided in all cutting and also in fillings if the height of the bank is less than the depth of blanket.
2. The minimum depth of drains shall be as under :
   A1:36 cm below the cess level
   B1 : 15 cm below the bottom of blanket.
3. The cross section of the side drain shall be designed to carry the design discharges for maximum rainfall in the area.
4. Longitudinal slope of the drain shall ensure development of self-cleaning velocity.
5. The side drain shall have off side berm of 300 mm width to prevent materials rolling down from the slope into the drain and also provide space to keep muck during the cleaning of drains.
6. Kutcha side drains are desirable for effective drainage of formations pucca side drains with side constructed monolithically with base provide confinement to the formation soil resulting in increase in its capacity.
7. The side drains shall be trapezoidal in section to increase confining pressure to increase shearing bearing capacity to the formation. The soil shall be dressed to this section and side drain cast against the so dressed earth.

8. The top of the side drain shall be 1.2 m wide and bottom shall be 0.6 m. The side slope of the trapezoidal section shall change with change in depth.
9. The side drain must have weep holes of 75/100 mm, 75 mm above the bed of the drainage.
10. The side drain shall have proper outfall which may fall into adjacent culvert/bridge or lower ground. Care shall be taken to arrest soil erosion.
11. Where ever kutcha side drains are provided and if they are more than 0.6 m depth they shall be filled with locally available granular materials. Coarse materials shall be in its mid section to give an affect of inverted filter.

Catch water drains, as shown in **Fig .5.5** of adequate capacity should be provided to prevent surrounding water to come into cutting.

1. Catch water drains shall be provided in all cutting more than 4 m deep those which are likely to get flooded due to surface run off.
2. Catch water drain shall be at least 700 cm deep and trapezoidal in section.
3. Catch water drain shall be designed to carry 50% more than designed discharge.
4. Catch water drain shall have bed slope to ensure development of self-cleaning velocity
5. Catch water drains shall be pucca without any weep holes, so as not to permit percolation of any water in the body of soil encompassing cutting.
6. Catch water drain shall discharge into either culvert/bridge or low lying areas.
7. Catch water drain shall have provision to arrest tail end erosion.

4.5 Cross slope

Formation should be given 1:30 cross slope on top of it to drain off the rainwater:

5. MATERIALS FOR CONSTRUCTION

5.1 Sub-Grades

Only good soils should be used for making Railways formations. Organic clays, silts and peat shall not be used for making up of embankments. Cuttings in these types of soils should be avoided and if this is not possible, special investigations and soil treatment/stabilization/replacement measures will be necessary. It is further recommended that soil having Max. Dry Density less than 1.8 gm/cm_3 may be avoided for making up the embankments. The sub-grade material is normally obtained from the borrow pits in the adjoining land. The selection of soils for sub grade is, therefore, quite difficult unless either the alignment is changed or the sub-grade material is imported from outside place.

The requirements of sub-grade material are :

(i) It should be able to bear the load transferred to it by the ballast section.
(ii) It should prevent the ballast from puncturing into it.
(iii) It should drain off water entering from top.
(vi) It should not change its volume due to variation in moisture.

5.2 Blanket/sub-ballast

It is a layer of coarse, granular and hard material placed between ballast and the sub-grade. The blanket/sub-ballast apart from reducing stresses induced into sub-grade due to wheel loads performs number of other useful functions such as prevention of puncturing of ballast into sub-grade soil or pumping of sub-grade fine into ballast (Mud Pumping), improvement in damping of vibrations and drainage. Therefore, a layer of blanket/sub-ballast is necessarily required for all sub-grades except for granular sub-grades keeping in view of the future wheel loads, speed of trains and the gross traffic tonnage (GMT) to be carried by the track. Figure -5.1 exhibits the details of blanket/sub-ballast for Railway formation.

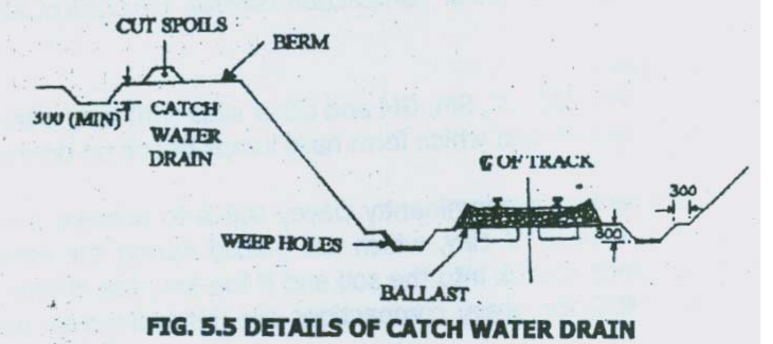

FIG. 5.5 DETAILS OF CATCH WATER DRAIN

1. Catch water drains shall be provided in all cutting more than 4 m deep those which are likely to get flooded due to surface run off.
2. Catch water drain shall be at least 700 cm deep and trapezoidal in section.
3. Catch water drain shall be designed to carry 50% more than designed discharge.
4. Catch water drain shall have bed slope to ensure development of self-cleaning velocity
5. Catch water drains shall be pucca without any weep holes, so as not to permit percolation of any water in the body of soil encompassing cutting.
6. Catch water drain shall discharge into either culvert/bridge or low lying areas.
7. Catch water drain shall have provision to arrest tail end erosion.

A sub-ballast/blanket layer of preferred soils of thickness 15 cm to 100 cm depending upon traffic density; axle load and speed of trains should be provided in all new constructions.

The suggested specifications for blanketing/sub-ballast material should be as follows:

- Should be coarse, granular and from hard rock.
- The material should have small quantity of fines (<75 microns size). Quality of fines (if fines are plastic) should be between 2-5% and if fines are non plastic, it should be between 8-12%
- Material should be properly graded and Uniformity Coefficient (D60/D10) should be above 4 and preferably above 7, and Coefficient of curvature ($D_{30}xD_{30}/D_{60}xD_{10}$) should be within 1 and 3.

6. CONSTRUCTION OF EMBANKMENTS

6.1 Compaction

Compaction of soil is essential for obtaining a uniform mass of desired density and known soil properties. The method of compaction should satisfy the conditions of economy and efficient earthwork construction. Compaction of earthwork is a necessary condition to achieve a stable bank and sub-grade.

Detailed investigations and vast experience with earthwork done world over indicate that no one method of compaction is equally suitable for all types of soils. The method of construction can be divided into three groups based on soil conditions.

6.1.1 Compaction of sandy or silty soils with moderate cohesion:

These soils on drying do not form hard lumps of soils, which would not break under roller. In these types of soils, the compaction in layers by roller is most effective. Use of vibratory rollers has been found to be more effective than static rollers. Embankments are required to be compacted to achieve 98% of the Maximum Dry Density (Determined as per IS2720 (pt. VIII)-1983 for heavy compaction). Moisture content, thickness of layer and no. of passes of rollers are determined in field trials, so that required dry density is achieved during the construction. Earthwork should be done in layers not exceeding 300 mm and 600 mm in loose state with static and vibratory rollers respectively. Compaction is done at or near to Optimum Moisture Content (OMC) to achieve the 98% of maximum Dry Density (MDD). For compaction control, IS-2720(pt.XXXVIII)-1976 should be used for field trials.

6.1.2 Compaction of clays

Cohesive soils, such as ML, SC, GC, SM, GM and other soils with boundary lines classifications having predominantly clay fraction and which form hard lumps of soil on drying and are difficult to break under roller.

Main objective of compacting predominantly clayey soil is to achieve a uniform mass of soil with no voids between the chunks of clay, which are placed during the earthwork. If moisture content is too high, roller tends to sink into the soil and if too low, the chunks would not yield to rolling by roller. OMC and MDD for heavy compactions are determined as per IS 2720(pt.VIII)

-1983. The practically achievable values of densities and OMC as obtained from field trials as per IS10379-1982. Sheep foot roller confirming to IS-4616-1968, are most effective in breaking the clods and filling large spaces. The Compaction in layers is effective in breaking the clods and filling large spaces. The layer thickness should be equal to the depth of the feet of roller plus 50 mm.

6.1.3. Compaction of cohesion less soil

These soils remain loose under dry and wet conditions. Most effective method of compacting cohesion less soil is the use of vibratory compaction. Moisture content being redundant is not necessary. Banks formed from these soils, may show small settlement due to vibrations caused by moving loads. It would be advantageous to use this kind of cohesion less soil in top 1 meter layer of a bank.

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.

Minimum 70% of Relative Density must be achieved during compaction which shall be done in layers of uniform thickness not exceeding 60 cm. Compaction of cohesion less soils is governed by IS-2720 (pt.XIV)-1983.

Extra wide bank by 50 cm on either side shall be rolled and then dressed to size for avoiding any loose earth at the shoulder on all embankments.

6.2 Construction of cuttings

In case sub-grade soil is not fit to take the stresses due to traffic, cutting should be made deeper to take a layer of blanket/sub-ballast of adequate thickness which shall be compacted at 70% of the Relative Density with vibratory rollers.

In cutting slope, softening of soil occurs with passage of time and therefore, long-term stability should be considered while designing the slopes for the cutting.

7. REHABILITATION OF WEAK FORMATIONS

7.1 Identification of weak formation

Enlisting probable locations of weak formation include:

(i) Stretches having speed restriction due to weak formations.

(ii) Stretches where frequency of track attention is more than six per year.

7.1.2. Identification of stretches

The extent of weak formation in the stretch mentioned above, is identified by taking ballast penetration profile, which is the profile of the interface of ballast and sub-grade soil. If ballast penetration profile is of 'W' shape and maximum depth of penetration is more than 30 cm, it is a positive indication of weak formation. The depth of ballast penetration corresponds to the severity of weakness of formation.

7.1.3. Five step action plan

Any stretch where track geometry need frequent (6 or more attention per year) attention, following 5 stage plan is being adopted by India Railways :

(i) Make the formation width, cess level and side drains strictly in accordance with prescribed profile.

(ii) Carry out shallow screening of ballast section (or deep screening where required).

(iii) Ensure no loose or missing fittings in track.

(iv) Increase the depth of ballast section to 30 cm or even 35cm.

(v) If problem still persists, increase sleeper density to 60 cm c/c spacing or even upto 55 cm c/c spacing.

If even after adoption of above measures track maintenance problems persist, further investigations are called for to devise remedial measures for rehabilitation/strengthening of the formation.

7.2 Rehabilitation by providing blanketing

7.2.1 Identified length of weak formation shall be planned for rehabilitation by providing blanket. The blanket material shall meet the specifications as described in para 5.2 Further,

* The material should be sufficiently impervious to divert most of the water falling over it to sides so as to prevent softening of sub-grade soil.
* It must be reasonably pervious to permit escape of capillary water or seepage water.
* It must have sufficient strength to withstand the imposed loads.
* It should get easily compacted to a desirable degree.
* Finished surface of blanket should give a stable platform for placing ballast/sub-ballast without any rutting or any other surface irregularity which may accumulate water.

7.2.2 Blending of two or more materials

There is hardly any single material available which satisfies these specifications. However, it can be obtained by blending silty clay soil with fine sand, coarse sand and quarry grit/caked–up ballast.

Laboratory tests have indicated that mixing (using disc harrow used by cultivators, attached to a tractor) 5 to 12% of silty clay having clay content of 60%-40% with coarse sand of fineness modulus more than 2.5 gives satisfactory material for blanket. Exact ratio of blending should be determined based on grain size analysis of soils.

7.2.3. Depth of blanket:

Depth of blanket depends upon the depth of ballast penetration.

Depth of ballast penetration	Depth of blanket
45 cm	30 cm
45-60 cm	45 cm

7.3 Remedial measures for weak formation:

Various remedial measures for different types of formation troubles generally encountered are listed below:

Name of problem	Suggested remedial measures
1. Inadequate drainage due to high cess, dirty ballast	Improved side drainage by lowering the cess and screening of ballast
2. Weakening of soil at formation top on contact with rain water. Resulting in mud pumping.	(i) Cationic bituminous emulsion below ballast. or (ii) Provision of a moorum or sand blanket of 20 to 30 cm. depth below ballast or (iii) Laying of Geo-textile.
3. Strength failure below ballast causing heaving up for cess or heaving up between sleepers.	(i) Provision of 30 to 60 cm. deep blanket below ballast. or (ii) Provision of sub-ballast.
4. Seasonal variation in moisture in formation top in expansive soils causing alternate heaving, shrinkage of formation	(i) Treatment with lime slurry pressure injection. or (ii) Moorum blanket 30 to 45 cm. with moorum lining.

5.	Gradual subsidence of the bank under live loads due to inadequate initial compaction/ consolidation of embankment.	(i) Cement grouting of ballast pockets, if ballast pockets are permeable. (ii) Sand or boulder drains.
6.	Gradual consolidation of earth below embankment.	(i) Lime piling in sub-soil. (ii) Sand drains in sub-soil.
7.	Creep of formation soil	Easing of side slopes.
8.	Coal ash pockets due to treatment of previous slips. of coal ash.	(i) Sand drains below deepest level of coal ash. (ii) Cement pressure grouting.
9.	**Instability of Bank and Cutting Slopes due to:**	
	(a) Inadequate side slopes causing bank slips after prolonged rains.	Flattening of slopes and provision of berms, improvement in drainage.
	(b) Consolidation/settlements of subsoil causing bank slips.	Provision of sand drains to expedite consolidation.
	(c) Hydrostatic pressure built up under live loads in ballast pockets containing water causing bank slips.	(i) Draining out of ballast pocket by sand or boulder drains. (ii) 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.

7.4 Method of construction :

Formation and the blanket material shall be compacted with the help of vibratory plate compactor. Top of formation shall have cross slope of 1:30. It is also desirable that drainage of such lengths is improved upon by providing cross drains and longitudinal drains.

7.4.1. Mechanical compaction of Earth Work

For mechanical compaction, earthwork should be done in layers not exceeding 300mm to 600mm thick in the loose state with static and vibratory rollers respectively. The layer should be compacted preferably at or near the optimum moisture content with suitable rollers so as to achieve the maximum dry density of 98%.

The top of formation should be finished to a slope of 1 in 30 away from centre. Extra wide bank by 50cm on either side should be rolled and then dressed to size for avoiding any loose earth at the shoulder.

Proper quality control should be kept during mechanical compaction. Coarse grained soil which contains fines passing through 75 micron Sieve up to 5% should be compacted to get relative density of a minimum of 70 per cent. However, all other types of soil when compacted should normally have at least 98% of the maximum dry density as determined by using compaction.