

CHAPTER-5

SLOPE STABILITY ANALYSIS

The side slopes of the embankment should be such that they are stable from Slope Stability point of view.

5.1 General

Usually, side slopes of 2:1 would be safe for most of the soils up to Embankment height of 4m. However, this analysis has to be carried out in detail for any height of Embankment in following situations:

a) When subsoil is soft, compressible & marshy type for any depth.

b) When subgrade soil (fill material) has very low value of cohesion "C" such that $C'/\gamma H$ (where 'H' is height of Embankment and γ is bulk density of soil) is negligible, i.e., in range of 0.01 or so.

5.1.1 In case of embankment of more than 6m height on soft sub-soil, a flatter slope and/or with berm/sub-bank may be required. The same shall be provided as per the results of the slope stability analysis done.

5.1.2 In case berm is required to be provided, the minimum width of berm may be kept as 2.0 m, which may be increased as per requirement of rolling equipment, to ensure proper compaction, provision of drain on inner side of berm as required and use of berm as road during maintenance etc. & also fulfilling design requirements.

5.1.3 When the highest water table is within $1.5 \times H$ (H is the height of Embankment), below ground level, then submerged unit weight of soil below water level should be taken.

5.2 Slope in Cutting

In cutting slope, softening of soil occurs with the passage of time, and therefore, long term stability is the most critical, and should be taken into consideration while designing the cuttings.

5.3 Software's for Slope Stability Analysis

This procedure for slope stability analysis manually or with the help of suitable Software like SLOPE/W (of Geo-Studio group), SLIDE (of Roc-Science group) and Slope Stability (of GEO5 group) or equivalent will be adequate for most of the cases. However, in certain situations, further detailed analysis may be required due to the site conditions and the same may be done by an expert consultant.

Manual Slope stability analysis can be carried out using procedure given in **Para 5.4**. A typical worked out example of slope stability analysis is given at **Para 5.8** for guidance.

5.4 Method of slope stability analysis

(Ref: -RDSO's Circular No. GT/SPEC/007/Rev 0/1991 (earlier Circular No. 20 dt.4.9.91)

Based on experience gained, especially with the behavior of old embankments and construction of new embankments over soft clays, it has been decided that effective stress analysis shall be adopted for analysing end- of-construction and long - term -

stability conditions, adopting realistic values of shear strength and pore water pressure parameters.

5.4.1 Conditions of analysis

Minimum factor of safety should be ensured for the following critical conditions:

- i) In Embankments for **a)** End of construction, and **b)** Long term stability with vitiated spoilt surface drainage such as when ballast is due for deep screening and during monsoon when drains get choked.
- ii) In cuttings, for long term stability with adverse conditions of drainage likely to develop in conjunction with modified sub-surface drainage patterns due to change of topography.

5.4.2 Factor of safety:

- i) A factor of safety of 1.4 should normally be adopted against slope failure.
- ii) At the end of construction stage, when pore water pressure dissipates partially, a minimum factor of safety of 1.2 can be allowed to achieve economy but without sacrificing safety for long term – stability. However, a minimum factor of safety of 1.4 must be ensured for the long term-stability.
- iii) Moving train loads need not be considered in the slope stability analysis for Embankments. In case of low height embankments, overstressing zones in soil mass due to live loads would affect the slope stability adversely because the bearing capacity failure mechanism gets mixed up with slope failure mechanism. Hence, minimum FOS of 1.6 should be ensured for slope stability of smaller Embankments of height upto 4m.

5.5 Computation procedure:

Computations shall be done using Bishop's simplified method for determining factor of safety against slips. For designing and checking slopes of Railway embankments and cuttings, stability tables from Table no. 5.3 to Table no. 5.20 as given should be used. **These tables were developed by Bishop's and Morgenstern 1960 with extension by O' Conner & Mitchel, 1977 and further by Chandler & Peiris, 1989.**

5.5.1 Formula to be used for the computation of factor of safety with Bishop's simplified method is:

$$F.O.S. = m - n \cdot r_u \text{ ----- (1)}$$

Where: m & n are the stability co-efficient based on $C'/\gamma H, \phi'$, depth factor and assumed slopes. **(See Table no. 5.3 to 5.20)**

C' = effective cohesion

ϕ' = effective angle of internal friction

γ = saturated unit weight of soil(s)

H = height of Embankment

r_u = pore pressure ratio

D = depth factor

- Note:** i) Above parameters are explained in Fig. – 5.1
 ii) Linear interpolation/extrapolation should be done for intermediate values of m & n

5.5.2 Pore pressure ratio, $r_u = U/\gamma.h$ ----- (2)

Where:

U = pore water pressure

γ = bulk density of soil

h = height of soil mass above the point where pore water pressure is being measured

5.5.3 Depth factor, $D = DH/H$ ----- (3)

Where:

DH = total depth from the top of formation to hard stratum of sub-soil

H = height of Embankment

a) Determination of Depth Factor:

Work out critical pore pressure ratio (r_{ue}), for depth factors, $D=1.0$ & 1.25 , as given below.

$$r_{ue} = m_{1.25} - m_{1.00} / n_{1.25} - n_{1.00} \text{ -----(4)}$$

Where: $m_{1.25}$, $m_{1.00}$, $n_{1.25}$ & $n_{1.00}$ are values of m & n at depth factors of 1.0 & 1.25

b) If $r_{ue} > r_u$ (eq. 2), depth factor, $D = 1.0$

If $r_{ue} < r_u$ (eq. 2), revised r_{ue} will be worked out as

$$r_{ue} = m_{1.50} - m_{1.25} / n_{1.50} - n_{1.25} \text{ -----(5)}$$

Where: $m_{1.50}$, $n_{1.50}$ etc. are values of m & n at depth factor of 1.50 etc.

ii) If this revised $r_{ue} > r_u$ (eq. 2), then $D = 1.25$

iii) If this revised $r_{ue} < r_u$ (eq. 2), then $D = 1.50$

Thus, depth factor will be taken 1.0, 1.25 or 1.5 depending upon conditions of r_{ue} with respect to r_u (eq. 2) as worked out from i), ii) & iii)

Note: 1. Maximum value of depth factor is taken equal to 1.5 even if hard strata is not found up to $1.5H$ depth below formation level.

2. r_{ue} is worked out to decide depth factor only. For calculation of FOS, r_u as given in **Table 5.2** will be used.

5.5.4 Determination of Shear Strength ϕ' and pore pressure parameters of sub-soils and embankment soils for stability analysis shall be done as given in **Fig-5.1 & Table-5.1**. However, for preliminary design or small projects, ϕ' and r_u values for different conditions can be taken **from Fig-5.2 & Table –5.2**.

5.6. Side Slope of Embankment: Side slopes of Embankments should not be steeper than 2:1.

5.7. Design Parameters & Computation Tables

Design parameters adopted for slope stability analysis should have the approval of the competent authority at SAG level (i.e. Chief Engineer of Zonal Railway or equivalent). Design calculations for each Embankment profile carried out should be recorded in the

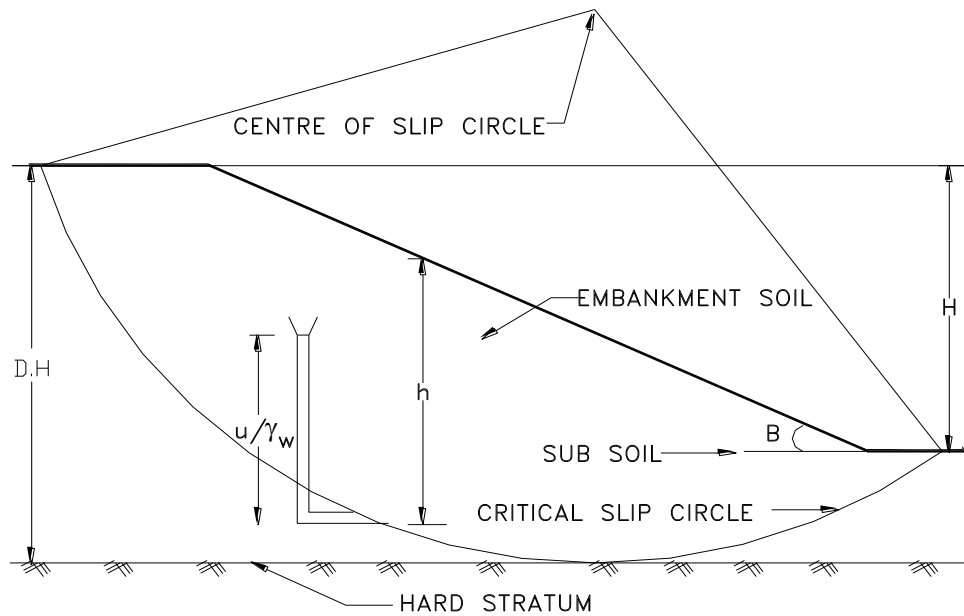


Fig: 5.1

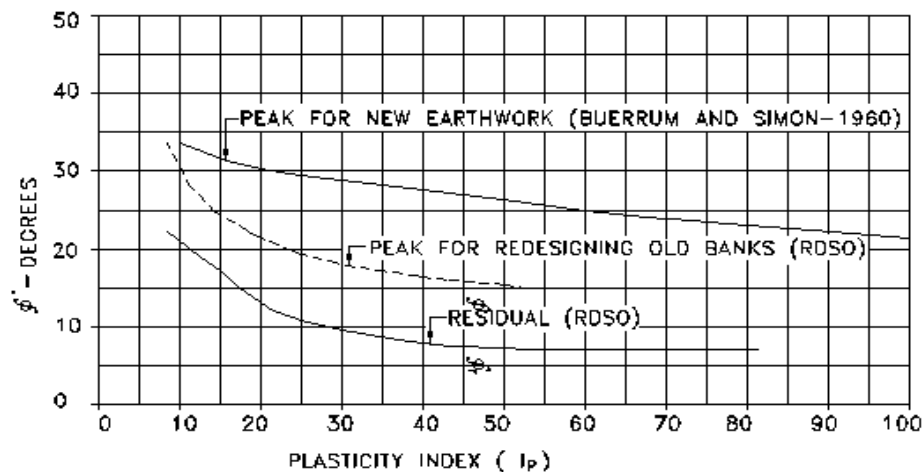


Fig-5.2: Determination of I_p & ϕ for Railway Embankment

Table – 5.1

Determination of shear strength parameters required for subsoil & embankment soil

Subsoil	Embankment
CU – tests on undisturbed samples with pore-pressure measurements in a triaxial apparatus;	CU – tests on remolded samples made from soils compacted to achieve similar densities at which placement of soil is contemplated during construction in a triaxial apparatus as per IS Specification.
IS: 2720 (pt. XII)-latest version.	IS: 2720 (pt.XII) – latest version.

Note: Peak and residual effective stress parameters from undisturbed samples should be determined both for subsoil and Embankment soil while dealing with old embankments.

Table – 5.2

r_u Values for Different Conditions

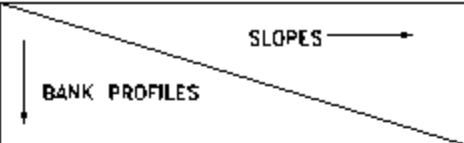
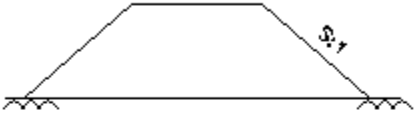



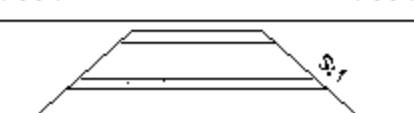
	2:1	2.5:1	2.75:1	3:1	3.5:1	4:1
	0.25	0.23	0.22	0.21	0.19	0.17
	0.13	0.12	0.11	0.10	0.09	0.08
	0.30	0.27	0.26	0.25	0.22	0.20
	0.15	0.14	0.13	0.12	0.11	0.10
	0.00	0.00	0.00	0.00	0.00	0.00

TABLE –5.3

Stability Coefficients m and n for $C'/\gamma H = 0$

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
10.0	0.353	0.441	0.529	0.588	0.705	0.749	0.882	0.917
12.5	0.443	0.554	0.665	0.739	0.887	0.943	1.109	1.153
15.0	0.516	0.670	0.804	0.893	1.72	1.139	1.340	1.393
17.5	0.631	0.789	0.946	1.051	1.261	1.340	1.577	1.639
20.0	0.632	0.728	0.910	1.092	1.213	1.456	1.820	1.892
22.5	0.828	1.035	1.243	1.381	1.657	1.761	2.071	2.153
25.0	0.933	1.166	1.399	1.554	1.864	1.982	2.332	2.424
27.5	1.041	1.301	1.562	1.736	2.082	2.213	2.603	2.706
30.0	1.155	1.444	1.732	1.924	2.309	2.454	2.887	3.001
32.5	1.274	1.593	1.911	2.123	2.548	2.708	3.185	3.311

35.0	1.400	1.750	2.101	2.334	2.801	2.877	3.501	3.639
37.5	1.535	1.919	2.302	2.558	3.069	3.261	3.837	3.989
40.0	1.678	2.098	2.517	2.797	3.356	3.566	4.196	4.362

TABLE -5.4

Stability Coefficients m and n for $C'/\gamma H = 0.025$ & $D=1.00$

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
10.0	0.678	0.534	0.906	0.683	1.130	0.846	1.365	1.031
12.5	0.790	0.655	1.066	0.849	1.337	1.061	1.620	1.282
15.0	0.901	0.776	1.224	1.014	1.544	1.273	1.868	1.534
17.5	1.012	0.898	1.380	1.179	1.751	1.485	2.121	1.789
20.0	1.124	1.022	1.542	1.347	1.962	1.698	2.380	2.050
22.5	1.239	1.150	1.705	1.518	2.177	1.916	2.646	2.317
25.0	1.356	1.282	1.875	1.696	2.400	2.141	2.921	2.596
27.5	1.478	1.421	2.050	1.882	2.631	2.375	3.207	2.886
30.0	1.606	1.567	2.235	2.078	2.873	2.622	3.508	3.191
32.5	1.739	1.721	2.431	2.285	3.127	2.883	3.823	3.511
35.0	1.880	1.885	2.635	2.505	3.396	3.160	4.156	3.849
37.5	2.030	2.060	2.855	2.741	3.681	3.458	4.510	4.209
40.0	2.190	2.247	3.090	2.993	3.984	3.778	4.885	4.592

TABLE -5.5

Stability Coefficients m and n for $C'/\gamma H = 0.025$ & $D=1.25$

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
10.0	0.737	0.614	0.901	0.728	1.283	0.887	1.288	1.014
12.5	0.878	0.759	1.076	0.908	1.299	1.089	1.543	1.278
15.0	1.019	0.907	1.253	1.093	1.515	1.312	1.803	1.545
17.5	1.162	1.059	1.433	1.282	1.736	1.541	2.065	1.814
20.0	1.309	1.216	1.618	1.478	1.926	1.776	2.334	2.060
22.5	1.461	1.379	1.808	1.680	2.194	2.017	2.610	2.373
25.0	1.619	1.547	2.007	1.891	2.437	2.269	2.897	2.660
27.5	1.783	1.728	2.213	2.111	2.609	2.531	3.193	2.976
30.0	1.957	1.915	2.431	2.342	2.953	2.808	3.511	3.299
32.5	2.139	2.112	2.659	2.585	3.231	3.095	3.841	3.638
35.0	2.331	2.321	2.901	2.841	3.624	3.400	4.191	3.998
37.5	2.536	2.541	3.158	3.112	3.835	3.723	4.563	4.379
40.0	2.753	2.775	3.431	3.399	4.164	4.064	4.958	4.784

TABLE -5.6
Stability Coefficients m and n for **C'/ γ H = 0.05 & D=1.00**

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
10.0	0.913	0.563	1.181	0.717	1.469	0.910	1.733	1.069
12.5	1.030	0.690	1.343	0.878	1.688	1.136	1.995	1.316
15.0	1.145	0.816	1.506	1.043	1.904	1.353	2.258	1.567
17.5	1.262	0.942	1.671	1.121	2.117	1.565	2.317	1.825
20.0	1.380	1.071	1.840	1.387	2.333	1.776	2.783	2.091
22.5	1.500	1.202	2.014	1.568	2.551	1.989	3.055	2.365
25.0	1.624	1.338	2.193	1.757	2.778	2.211	3.336	2.651
27.5	1.753	1.480	2.380	1.952	3.013	2.444	3.628	2.948
30.0	1.888	1.630	2.574	2.157	3.261	2.693	3.934	3.259
32.5	2.029	1.789	2.777	2.370	3.523	2.961	4.256	3.585
35.0	2.178	1.958	2.990	2.592	3.803	3.253	4.597	3.927
37.5	2.336	2.138	3.215	2.826	4.803	3.574	4.959	4.288
40.0	2.505	2.332	3.451	3.671	4.425	3.926	5.344	4.669

TABLE -5.7
Stability Coefficients m and n for **C'/ γ H = 0.05 & D=1.25**

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
10.0	0.919	0.633	1.119	0.766	1.344	0.886	1.594	1.042
12.5	0.655	0.792	1.294	0.941	1.563	1.112	1.850	1.300
15.0	1.211	0.950	1.471	1.119	1.782	1.338	2.109	1.562
17.5	1.359	1.108	1.650	1.303	2.004	1.567	2.373	1.831
20.0	1.509	1.266	1.834	1.493	2.230	1.799	2.643	2.107
22.5	1.663	1.428	2.024	1.690	2.463	2.038	2.921	2.392
25.0	1.822	1.595	2.222	1.897	2.705	2.287	3.211	2.690
27.5	1.988	1.769	2.428	2.113	2.957	2.546	3.513	2.999
30.0	2.161	1.950	2.645	2.342	3.221	2.819	3.829	3.324
32.5	2.343	2.141	2.873	2.583	3.500	3.107	4.161	3.665
35.0	2.535	2.344	3.114	2.839	3.795	3.413	4.511	4.025
37.5	2.738	2.560	3.370	3.111	4.109	3.740	4.881	4.405
40.0	2.953	2.791	3.642	3.400	4.442	4.090	5.273	4.806

TABLE -5.8
Stability Coefficients m and n for **C'/ γ H = 0.05 & D=1.5**

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
10.0	1.022	0.751	1.170	0.828	1.343	0.974	1.547	1.108
12.5	1.202	0.936	1.376	1.043	1.589	1.227	1.829	1.399
15.0	1.383	1.122	1.583	1.260	1.835	1.480	2.112	1.690
17.5	1.565	1.309	1.795	1.480	2.084	1.734	2.398	1.983

20.0	1.752	1.501	2.011	1.705	2.337	1.993	2.690	2.280
22.5	1.943	1.698	2.234	1.937	2.597	2.258	2.990	2.585
25.0	2.143	1.903	2.467	2.179	2.867	2.534	3.302	2.902
27.5	2.350	2.117	2.709	2.431	3.148	2.820	3.626	3.231
30.0	2.568	2.342	2.964	2.696	3.443	3.120	3.967	3.577
32.5	2.798	2.580	3.232	2.975	3.753	3.436	4.326	3.840
35.0	3.041	2.832	3.515	3.269	4.082	3.771	4.707	4.325
37.5	3.299	3.102	3.817	3.583	4.431	4.128	4.112	4.753
40.0	3.574	3.389	4.136	3.915	4.803	4.507	5.343	5.171

Further extensions to the Bishop & Morgenstern slope stability tables

The design charts for the effective stress stability analysis of slopes given by Bishop & Morgenstern (1960) are extended up to $C' / \gamma H = 0.15$, $\phi' = 20^\circ$ to 40° by & Mitchell (1977) and further by Chandler & Peiris (1989).

Table-5.9

Stability Coefficients m and n for $C' / \gamma H = 0.075$ & $D=1.00$

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	1.610	1.100	2.141	1.443	2.664	1.801	3.173	2.130
25.0	1.872	1.386	2.502	1.815	3.126	2.259	3.742	2.715
30.0	2.142	1.686	2.884	2.201	3.623	2.758	4.357	3.331
35.0	2.443	2.030	3.306	2.659	4.177	3.331	5.024	4.001
40.0	2.772	2.386	3.775	3.145	4.785	3.945	5.776	4.759

TABLE -5.10

Stability Coefficients m and n for $C' / \gamma H = 0.075$ & $D=1.25$

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	1.688	1.285	2.071	1.543	2.492	1.815	2.954	2.173
25.0	2.004	1.641	2.469	1.957	2.972	2.315	3.523	2.730
30.0	2.352	2.015	2.888	2.385	3.499	2.857	4.149	3.357
35.0	2.728	2.385	3.357	2.870	4.079	3.457	4.831	4.043
40.0	3.154	2.841	3.889	3.428	4.729	4.128	5.603	4.830

TABLE -5.11

Stability Coefficients m and n for $C' / \gamma H = 0.075$ & $D=1.50$

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	1.918	1.514	2.199	1.728	2.548	1.985	2.931	2.272
25.0	2.308	1.914	2.660	2.200	3.083	2.530	3.552	2.915
30.0	2.735	2.355	3.158	2.714	3.659	3.128	4.218	3.585
35.0	3.211	2.854	3.708	3.285	4.302	3.786	4.961	4.343
40.0	3.742	3.397	4.332	3.926	5.026	4.526	5.788	5.185

TABLE -5.12
Stability Coefficients m and n for **C'/ γ H = 0.100 & D=1.00**

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	1.841	1.143	2.421	1.472	2.982	1.815	3.549	2.157
25.0	2.102	1.430	2.785	1.845	3.358	2.303	4.131	2.743
30.0	2.378	1.714	3.183	2.258	3.973	2.830	4.751	3.372
35.0	2.692	2.086	3.612	2.715	4.516	3.359	5.426	4.059
40.0	3.025	2.445	4.103	3.230	5.144	4.001	6.187	4.831

TABLE -5.13
Stability Coefficients m and n for **C'/ γ H = 0.100 & D=1.25**

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	1.874	1.301	2.283	1.558	2.751	1.843	3.253	2.158
25.0	2.197	1.642	2.681	1.972	3.233	2.330	3.833	2.758
30.0	2.540	2.000	3.112	2.415	3.753	2.858	4.451	3.372
35.0	2.922	2.415	3.588	2.914	4.333	3.458	5.141	4.072
40.0	3.345	2.855	4.119	3.457	4.987	4.142	5.921	4.872

TABLE -5.14
Stability Coefficients m and n for **C'/ γ H = 0.100 & D=1.50**

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	2.079	1.528	2.387	1.742	2.768	2.014	3.158	2.285
25.0	2.477	1.942	2.852	2.215	3.297	2.542	3.796	2.927
30.0	2.908	2.385	3.349	2.728	3.881	3.143	4.468	3.614
35.0	3.385	2.884	3.900	3.300	4.520	3.800	5.211	4.372
40.0	3.924	3.441	4.524	3.941	5.247	4.542	6.040	5.200

TABLE -5.15
Stability Coefficients m and n for **C'/ γ H = 0.125 & D=1.00**

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	2.042	1.148	2.689	1.541	3.263	1.784	3.868	2.124
25.0	2.323	1.447	3.062	1.908	3.737	2.271	4.446	2.721
30.0	2.618	1.777	3.457	2.298	4.253	2.810	5.073	3.368
35.0	2.929	2.115	3.880	2.705	4.823	3.407	5.767	4.048
40.0	3.272	2.483	4.356	3.183	5.457	4.060	6.551	4.893

TABLE -5.16
Stability Coefficients m and n for **C'/ γ H = 0.125 & D=1.25**

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	2.054	1.324	2.492	1.579	2.983	1.861	3.496	2.167
25.0	2.377	1.671	2.894	1.993	3.481	2.379	4.078	2.753

30.0	2.727	2.042	3.324	2.431	4.009	2.916	4.712	3.405
35.0	3.110	2.451	3.801	2.928	4.586	3.500	5.414	4.128
40.0	3.542	2.913	4.338	3.494	5.237	4.161	6.207	4.945

TABLE -5.17

Stability Coefficients m and n for $C'/\gamma H = 0.125$ & $D=1.50$

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	2.234	1.545	2.565	1.749	2.963	2.004	3.400	2.287
25.0	2.638	1.972	3.028	2.229	3.500	2.550	4.019	2.913
30.0	3.072	2.425	3.529	2.749	4.083	3.149	4.692	3.598
35.0	3.549	2.923	4.084	3.324	4.727	3.813	5.436	4.362
40.0	4.089	3.485	4.712	3.980	5.456	4.566	6.278	5.226

TABLE -5.18

Stability Coefficients m and n for $C'/\gamma H = 0.150$ & $D=1.00$

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	2.261	1.170	2.895	1.448	3.579	1.806	4.230	2.159
25.0	2.536	1.462	3.259	1.814	4.052	2.280	4.817	2.765
30.0	2.836	1.791	3.657	2.245	4.567	2.811	5.451	3.416
35.0	3.161	2.153	4.098	2.721	5.137	3.408	6.143	4.117
40.0	3.512	2.535	4.597	3.258	5.782	4.083	6.913	4.888

TABLE -5.19

Stability Coefficients m and n for $C'/\gamma H = 0.150$ & $D=1.25$

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	2.229	1.334	2.701	1.600	3.225	1.873	3.780	2.182
25.0	2.560	1.692	3.107	2.015	3.724	2.384	4.363	2.769
30.0	2.909	2.065	3.542	2.464	4.262	2.941	5.995	3.406
35.0	3.295	2.475	4.018	2.946	4.846	3.534	6.697	4.129
40.0	3.728	2.938	4.556	3.509	5.498	4.195	7.490	4.947

TABLE -5.20

Stability Coefficients m and n for $C'/\gamma H = 0.150$ & $D=1.50$

ϕ'	Slope 2:1		Slope 3:1		Slope 4:1		Slope 5:1	
	m	n	m	n	m	n	m	n
20.0	2.394	1.550	2.748	1.756	3.174	2.020	3.641	2.308
25.0	2.798	1.978	3.212	2.237	3.711	2.561	4.259	2.924
30.0	3.236	2.441	3.718	2.758	4.293	3.156	4.931	3.604
35.0	3.715	2.940	4.269	3.333	4.938	3.819	5.675	4.364
40.0	4.255	3.503	4.896	3.983	5.667	4.569	6.517	5.228

5.8 Design Examples for Calculation for Slope Stability Analysis

Example 1:-

Design Data:

- a) Height of Embankment = 6 m (Given)
- b) Effective cohesion, $C' = 8.2 \text{ kN/m}^2$ (Measured in lab.)
- c) Effective angle of shear resistance, $\phi' = 25^\circ$ (Measured in lab.)
- d) Saturated density of soil, $\gamma_{\text{sat}} = 21.53 \text{ kN/m}^3$ (Calculated from lab test results)
- e) Pore pressure ratio, $r_u = 0.25$ (For Side Slope 2H: 1V on new construction)-Ref. table-5.2.

1. Value of $C' / \gamma H = 8.2 / 21.53 \times 6 = 0.063$
There is no direct table for this value therefore linear interpolation would be required between values of $C' / \gamma H$ of 0.05 & 0.075.

2. For $C' / \gamma H = 0.075$ (as 0.063 is more closer to 0.075 than 0.05), $\phi' = 25^\circ$ and Side Slope = 2H: 1V

- a) For $D = 1.00$; from table – 5.9
 $m = 1.872$ & $n = 1.386$
- b) For $D = 1.25$; from table – 5.10
 $m = 2.004$ & $n = 1.641$

3. To decide depth factor, r_{ue} will be computed as:

$$\begin{aligned} r_{ue} &= m_{1.25} - m_{1.00} / n_{1.25} - n_{1.00} \\ &= 2.004 - 1.872 / 1.641 - 1.386 \\ &= 0.52 > 0.25 (r_u) \end{aligned}$$

Hence $D = 1$ will be considered as more critical (Ref. Para 5.5.3-b)

4. Therefore, $FOS = m - n * r_u$ will be calculated for the value of $C' / \gamma H = 0.063$ at $D = 1.00$ as follows:

(i) From table 5.6, $FOS (\text{for } C' / \gamma H = 0.05) = 1.624 - 1.338 \times 0.25 = 1.289$

(ii) From table 5.9, $FOS (\text{for } C' / \gamma H = 0.075) = 1.872 - 1.386 \times 0.25 = 1.525$

(iii) Linear interpolation for $C' / \gamma H = 0.063$

$$\begin{aligned} FOS &= (1.525 - 1.289 / 0.075 - 0.05) \times (0.063 - 0.05) + 1.289 \\ &= 1.41 > 1.4 \end{aligned}$$

Hence, the side slope of 2H: 1V is safe.

Example 2:-

Design Data:

- a) Height of Embankment = 10m (Given)
- b) Effective cohesion, $C' = 10.5 \text{ kN/m}^2$ (Measured in lab.)

- c) Effective angle of shear resistance, $\phi' = 20^\circ$ (Measured in lab.)
- d) Saturated density of soil, $\gamma_{\text{sat}} = 22 \text{ kN/m}^3$ (Calculated from lab test results)
- e) Pore pressure ratio, $r_u = 0.25$ (For Side Slope 2H:1V on new construction) Ref. table-5.2

1. Value of $C' / \gamma H = 10.5/22 \times 10 = 0.048$

There is no direct table for this value therefore linear interpolation would be required between values of $C' / \gamma H$ of 0.025 & 0.05.

- 1. For $C' / \gamma H = 0.05$ (as 0.048 is more closer to 0.05 than 0.025), $\phi' = 20^\circ$ and Side Slope = 2H: 1V

- a) For $D = 1.00$; from table – 5.6

$$m = 1.380 \text{ \& } n = 1.071$$

- b) For $D = 1.25$; from table – 5.7

$$m = 1.509 \text{ \& } n = 1.226$$

- 2. To decide depth factor, r_{ue} will be computed as:

$$\begin{aligned} r_{ue} &= m_{1.25} - m_{1.00} / n_{1.25} - n_{1.00} \\ &= 1.509 - 1.380 / 1.226 - 1.071 \\ &= 0.66 > 0.25 (r_u) \end{aligned}$$

Hence $D = 1$ will be considered as more critical (Ref. Para 5.5.3-i)

- 3. Therefore, $FOS = m - n * r_u$ will be calculated for the value of $C' / \gamma H = 0.048$ at $D = 1.00$ as follows:

(i) From table 5.4, $FOS \text{ (for } C' / \gamma H = 0.025) = 1.124 - 1.022 \times 0.25 = 0.868$

(ii) From table 5.6, $FOS \text{ (for } C' / \gamma H = 0.05) = 1.380 - 1.071 \times 0.25 = 1.112$

- (iii) Linear interpolation for $C' / \gamma H = 0.048$

$$\begin{aligned} FOS &= (1.112 - 0.868 / 0.05 - 0.025) \times (0.048 - 0.025) + 0.868 \\ &= 1.09 < 1.4 \end{aligned}$$

Hence, the side slope of 2H: 1V is unsafe.

- 4. Therefore, FOS will be calculated for the Side Slope = 3H: 1V and the value of $C' / \gamma H = 0.048$, $\phi' = 20^\circ$ remains the same. (Pore pressure ratio will be changed to $r_u = 0.21$ for the Side Slope = 3: 1, from table -5.2)

- 5. For $C' / \gamma H = 0.05$, $\phi' = 20^\circ$ and Side Slope = 3: 1

- a) For $D = 1.00$; from table – 5.6

$$m = 1.840 \text{ \& } n = 1.387$$

- b) For $D = 1.25$; from table – 5.7

$$m = 1.834 \text{ \& } n = 1.493$$

- c) Calculate r_{ue} to decide depth factor.

$$\begin{aligned} r_{ue} &= m_{1.25} - m_{1.00} / n_{1.25} - n_{1.00} \\ &= 1.834 - 1.840 / 1.493 - 1.387 \\ &= -0.05 < 0.25 (r_u) \end{aligned}$$

Therefore, workout r_{ue} for $D = 1.25$ & 1.50

d) For $D = 1.50$; from table – 5.8
 $m = 2.011$ & $n = 1.705$

e) Calculate r_{ue} again.

$$\begin{aligned} r_{ue} &= m_{1.50} - m_{1.25} / n_{1.50} - n_{1.25} \\ &= 2.011 - 1.834 / 1.705 - 1.493 \\ &= 0.83 > 0.25 (r_u) \end{aligned}$$

Hence $D=1.25$ will be considered as more critical.

6. Therefore, $FOS = m - n * r_u$ will be calculated for the value of $C' / \gamma H = 0.048$ at $D = 1.25$ as follows:

- (i) From table 5.5, FOS (for $C' / \gamma H = 0.025$) = $1.618 - 1.478 \times 0.21 = 1.308$
- (ii) From table 5.7, FOS (for $C' / \gamma H = 0.050$) = $1.834 - 1.493 \times 0.21 = 1.521$
- (iii) Linear interpolation for $C' / \gamma H = 0.048$

$$\begin{aligned} FOS &= (1.521 - 1.308 / 0.050 - 0.025) \times (0.048 - 0.025) + 1.308 \\ &= 1.50 > 1.4 \end{aligned}$$

Hence, the side slope of 3H: 1V is safe.

CHAPTER-6

EXECUTION OF EARTHWORK

6.1 General

Before taking up of actual execution of work, detailed drawings need to be prepared for the entire length of the project to give alignment, formation levels, formation width at ground level, cross sections of catch water drains & side drains, cross section & levels of subgrade, blanket levels, etc. to facilitate smooth execution at site. Execution of work has to be carried out in a systematic manner so as to construct formations of satisfactory quality which would give trouble free service.

6.2 The activities and adoption of good practices involved in execution of earthwork are covered under following headings

- i) Preliminary works
- ii) General aspects
- iii) Compaction of earth work
- iv) Sandwich Construction of Embankments with Cohesive Soils
- v) Placement of Back-Fills on Bridge Approaches and Similar Locations
- vi) Drainage Arrangement in Embankment/Cutting
- vii) Finishing and Blanketing
- viii) Setting up of GE lab at Construction Site
- ix) Maintenance of Records

6.2.1 Preliminary Works

A. Preparation of Natural Ground

Preparation of natural ground surface may be carried out as follows:

(i) Site clearances: Full formation width at ground level plus additional extra width of 1 m on both sides should be cleared of all obstructions viz. vegetation, trees, bushes, building, fences, abandoned structures etc. and thereafter it should be dressed and leveled. Depressions if any should be filled with suitable soil duly compacted. Finally, the leveled surface should be properly compacted by mechanical means to get a leveled and uniform ground surface.

(ii) When Embankment is constructed on Ground having steep slope, then the ground surface should be suitably benched so that new material of embankment gets well bonded with the existing ground surface.

Surface drainage shall be constructed, wherever required, so as to maintain the natural water drainage facilities and limit the introduction of water into the earthworks.

B. Setting out of Construction Limits

Centerline of the alignment (@200 m c/c or so) and full construction width should be demarcated with reference pegs/dug belling about 90 cm away from proposed toe of the embankment. Care should be taken not to disturb the pegs during construction. Pegs should be preferably painted for identification.

C. Selection of Borrow Area

- (i) Borrow area should be selected sufficiently away from the alignment, as far as possible at the extreme of Railway land but normally not less than 3 m plus height of the Embankment to prevent base failure due to lateral escapement of the soil.
- (ii) Borrow area should be selected for soil suitable to be used in construction. Embankment is to be constructed normally with soil available in nearby area, with properly designed slope. However, there are some soils, which are normally unsuitable for construction of formation & hence it is to be normally avoided (as described in Para 3.7 of Chapter 3).

6.2.2 General Aspects

- (i) A field trial for compaction on a test section shall be conducted on fill material to assess the optimum thickness of layer and optimum number of passes for the type of roller planned to be used to arrive at desired density. It optimises compaction efforts of earthwork while achieving desired level of density based on lab tests. Procedure for field compaction trials is given in **para 6.2.3** below.
- (ii) If the soil has less than required moisture content, necessary amount of water shall be added to it either in borrow pits or after the soil has been spread loosely on the Embankment. Addition of water may be done through flooding or irrigating the borrow areas or sprinkling the water on the Embankment through a truck mounted water tank sprinkling system. Use of hose pipes for water need to be avoided.
- (iii) If the soil is too wet, it shall be allowed to dry till the moisture content reaches acceptable level required for the compaction.
- (iv) Placement moisture content of soil should be decided based on the field trial and site conditions. The objective should be to compact near OMC to achieve uniform compaction with specified density in the most efficient manner.
- (v) Clods or hard lumps of soil of the borrow area shall be broken to 75 mm or lesser size before placing on Embankment.
- (vi) Each layer should be compacted with recommended type of roller upto required level of compaction, commencing from the sides, before putting the next upper layer.

- (vii) Extra embankment width of 500mm on either side shall be rolled/compacted to ensure proper compaction at the edges. The extra soil should be cut and dressed mechanically to achieve regular side slope and the slope shall be compacted with 6-8 passes of slope compactors (10-20 ton capacity). Details of some of the slope compactors are annexed at **Appendix-E**.
- (viii) Backfill behind abutments: To avoid differential settlement in the approaches of bridges, compaction should be carried out with the help of vibratory plate compactors.
- (ix) In areas susceptible to flooding, the sides of an Embankment (except approach bank of bridges) should be protected with a layer of rockfill or stones with an intermediate granular layer upto 1 m above HFL. For other conventional methods of Erosion Control of slopes in such cases, Para 8.3.1 of Chapter 8 of this document shall be referred to.

6.2.3 Compaction of Earthwork

Performance of the Embankment would depend to large extent on the quality of compaction done during execution.

A. Advantages of Compaction

- (i)** 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:
 - a) Helps soils to acquire increase in strength in both bearing resistance and shear strength.
 - b) Reduces compressibility, thus minimising uneven settlement during service.
 - c) Increases density and reduces permeability, thereby reducing susceptibility to change in moisture content.
 - d) Reduction in Erodibility.
 - e) Results in homogenous uniform soil mass of known properties.
 - f) Reduction in frost susceptibility in cold regions
- (ii)** However, 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 embankment or cutting:
 - a) Excessive creep or slipping of slopes.
 - b) Swelling and shrinkage characteristic of soils due to variation in moisture content because physio-chemical properties of a soil do not change on compaction.
 - c) Mud pumping at ballast - soil interface.
 - d) Settlements due to consolidation of embankment and subsoil that can occur even for a few years after construction of the embankment.

B. Factors Affecting Compaction in the Field

Compaction of a particular soil is affected by moisture content, compacting effort, type of roller etc as explained below:

- (i) Compacting Effort:** In modern construction projects, heavy compaction machinery is deployed to provide compaction energy. Types of machinery required are decided based on the type of soil to be compacted. The method of compaction is primarily of four types i.e. kneading compaction, static compaction, dynamic or impact compaction and vibratory compaction. Different type of actions is effective in different type of soils such as for cohesive soils, Sheepsfoot rollers or pneumatic rollers provide the kneading action. Silty soil can be effectively compacted by Sheepsfoot roller/pneumatic roller or smooth wheel roller. For compacting sandy and gravelly soil, vibratory rollers are most effective. If granular soil has some fines, both smooth wheeled and pneumatic rollers can be used.
- (ii) Moisture Control:** Proper control of moisture content in soil is necessary for achieving desired density. Maximum density with minimum compacting effort can be achieved by compaction of soil near its OMC (Optimum Moisture Content). If natural moisture content of the soil is less than the OMC, a calculated amount of water should be added with sprinkler attached to the water tanker and mixed with soil by motor grader for uniform moisture content. When soil is too wet it is required to be dried by aeration to reach up to OMC.
- (iii) Soil Type:** Type of soil has a great influence on its compaction characteristics. Normally, heavy clays, clays and silts offer higher resistance to compaction, whereas, sandy soils and coarse grained or gravelly soils are amenable for easy compaction. Coarse-grained soils yield higher densities in comparison to clay. A well-graded soil can be compacted to higher density.
- (iv) Thickness of Layer:** Suitable thickness of soil of each layer is necessary to achieve uniform compaction. Layer thickness depends upon type of soil involved and type of roller, its weight and contact pressure of its drums. Normally, 200 – 300 mm layer thickness is optimum in the field for achieving homogenous compaction.
- (v) Number of Passes:** Density of soil will increase with the number of passes of roller but after optimum number of passes, further increase in density is insignificant for additional number of passes. For determination of optimum number of passes for given type of roller and optimum thickness of layer at a predetermined moisture content, a field trial for compaction is necessary.

C. Field Compaction Trial

(i) General

Field compaction trial is carried out to optimize compaction efforts of earthwork while achieving desired level of density based on Lab tests (Heavy

compaction test, IS: 2720 (Part-8) and Relative Density Test, IS: 2720 (Part - 14). Type of roller to be used for compaction has to be decided depending on the type of soil to be compacted in execution of earthwork.

(ii) Determination of compaction efficiency

The increasing trend of density with increase in number of passes of a compactor tends to diminish gradually and a 'diminishing return stage' is reached. This will determine the type of compactor, optimum thickness of layer, corresponding water contents and number of roller passes.

(iii) Methodology for conducting field compaction trial includes following steps:

Step 1: Construct a test ramp about 20-30m long, 10-12m wide & 0.15m thick on one end & 0.55m on other end, preferably at the construction site, over a level ground surface clear of bushes, depressions etc. under nearly identical conditions as shown in **Appendix-D (Fig-D1)**.

Step 2: Divide the ramp equally into the desired number, say, four segments, longitudinally of about 2.5m width (more than width of roller). Each strip will be used for conducting trials at specific moisture content, viz. OMC (Lab test value), OMC $\pm 4\%$ and (PL - 2%) etc.

Note: *Experience shows that most suitable water content falls within a small range of 3% below to 1% above the OMC for most of the- soil.*

Step 3: Start a compaction trial on the first segment at a particular moisture content (Step 2).

Step 4: Fix four number sampling points on this strip at locations where layer thickness of about 225, 300, 375 & 450 mm are to be obtained after rolling. **Appendix-D (Table-D4)**.

Step 5: Collect samples around the sampling points (Step 4). Determine moisture content by any suitable standard method

Step 6: Compare the moisture content with that of the relevant desired moisture content (Step-3).

Step 7: Wait for natural drying if moisture content is on higher side or sprinkle appropriate amount of water uniformly followed by ploughing etc. and leave for 5 to 30 minutes depending on type of soil, in case the moisture content is on lower side (Step 3).

Step 8: Determine moisture content once again at sampling points before rolling. Observations of determination of moisture content are recorded as per **Appendix-D (Table – D2)**.

Step 9: Roll the strip and measure the dry density (by any standard method) of the soil after every two passes commencing from four roller passes. The observations are recorded as per **Appendix-D (Table–D3)**.

Note: *Measurement of dry density and moisture content are taken after removing the top 5 cm layer of earth with least possible disturbance. If the layer thickness is small, density ring should be used.*

Step 10: Carry out testing on each strip at different specific moisture content as for the first strip explained above. Compile the results of trial of all strips as per **Appendix-D (Table–D3)**.

Step 11: From these test results, two sets of graph are plotted:

First set of graphs: Dry density v/s number of roller passes for each water content and layer thickness. For each layer, there would be four (depending on range of moisture content chosen) curves for different moisture content. **Appendix-D (Fig-D2).**

Second set of graphs: Maximum dry density vs moisture content for each layer thickness. **Appendix-D (Fig-D3).**

Step 12: Second set of graphs will give field moisture content, maximum attainable field dry density and optimum layer thickness. From this field values minimum no. of passes of particular roller **Appendix-D (Fig-D2)** are read from the first set of graphs.

D. Compaction Procedures for Different Soils

The Embankments are constructed with locally available soils provided it fulfils the specified requirements. Procedure of compaction to be adopted will depend on the type of soil being used in construction. General guidelines to deal with compaction of various types of soils for attaining optimum dry density/relative density at minimum effort have been briefly given as under:

i) Compaction of Cohesionless Gravely and Sandy Soil

Sandy & gravely soils should be compacted with vibratory rollers. If fines are less in these types of soils, it can be compacted with minimum number of passes of vibratory rollers without strict control of moisture to achieve desired Relative Density. With higher percentage fines, sandy and gravely soils need to be brought to OMC level to get effective compaction. Uniformly graded sand and gravel are difficult to be compacted. Top layer of sand and gravel remains loose in vibrating compaction. Therefore, in final pass the roller should move smoothly without vibration. Dry densities obtained in field trials normally should be around MDD/ specified Relative Density as obtained from laboratory tests and should form the basis for specification and quality control.

ii) Compaction of Silty - Clayey Soils

Silty soil is a fine-grained soil. These can be plastic or non-plastic depending upon the clay content in it. Silts and fine sands with high water content have a tendency to undergo liquefaction under vibrating rolling due to the pore water pressure generated by mechanical work. Silty soils can be compacted satisfactorily near about OMC either with smooth rollers or vibratory rollers. Vibratory roller will give high degree of compaction and higher lift. Compaction of silty clays will have to be handled in a manner similar to clays.

iii) Compaction of Clays

a) Water content plays a very important role in compaction of clays. Main objective of compacting predominantly clays is to achieve uniform mass of soil with no voids between the lumps of clays. 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 rollers. Appropriate water content i.e. OMC of the soil is in the range of about plastic limit plus two percent. Sheep foot rollers are most effective in breaking the clods and filling large spaces.

- b) Thickness of layer should not be more than depth of feet of roller plus 50 mm.
- iv) In case of such soils, the MDD and OMC, as determined in the Laboratory may not be very relevant and therefore achievable MDD and practicable moisture content at which such soils can be compacted effectively should be determined by conducting field trials.
- v) **Selection of Compacting Equipment:** The performance of roller is dependent mainly on the type of soil used in construction. Guidelines on selection of compacting equipment are given in **Appendix-F**. Vibratory rollers which can be used in static as well as dynamic mode with plain & pad drum are now being manufactured by reputed Indian Companies also. Salient features of some of the models are given in **Appendix-E**.

vi) Use of Construction Equipments for Execution of Earthwork

Any manual methods of construction cannot achieve the desired quality of earthwork. It would be necessary to deploy modern equipment such as earthmover, motor graders, scraper, dumpers, mobile water sprinklers, vibratory rollers, sheep foot rollers etc. as per need, on all projects, so that the quality of work is as per laid down standards. It would be desirable to maintain records of work done by various equipment at a particular site to assess the output and quality control.

6.2.4 Sandwich Construction of Embankments with Cohesive Soils

Sandwich type of construction may be adopted for construction of Embankments with cohesive soils having very low permeability (less than or equal to 10^{-2} cm/sec.) (As given in Fig-6.1) and where height of the embankment is greater than 3m. In such situations, a layer of coarse sand ($C_u > 2$) of about 20 to 30 cm thick should be provided at embankment height intervals of 2 to 3m. **Fig-6.1** given below provides Guidelines for sandwich construction for different heights to improve the factor of safety against slope failure, drainage and dissipation of pore water pressure. It is desirable to have a bottom layer of coarse sand in all cases where soils of low permeability are used even for depths upto 3m. However, before adopting such construction, it may be necessary to carry out a detailed technical study along with economics of sandwich construction, depending on site conditions and availability of material, if required, in consultation with RDSO.

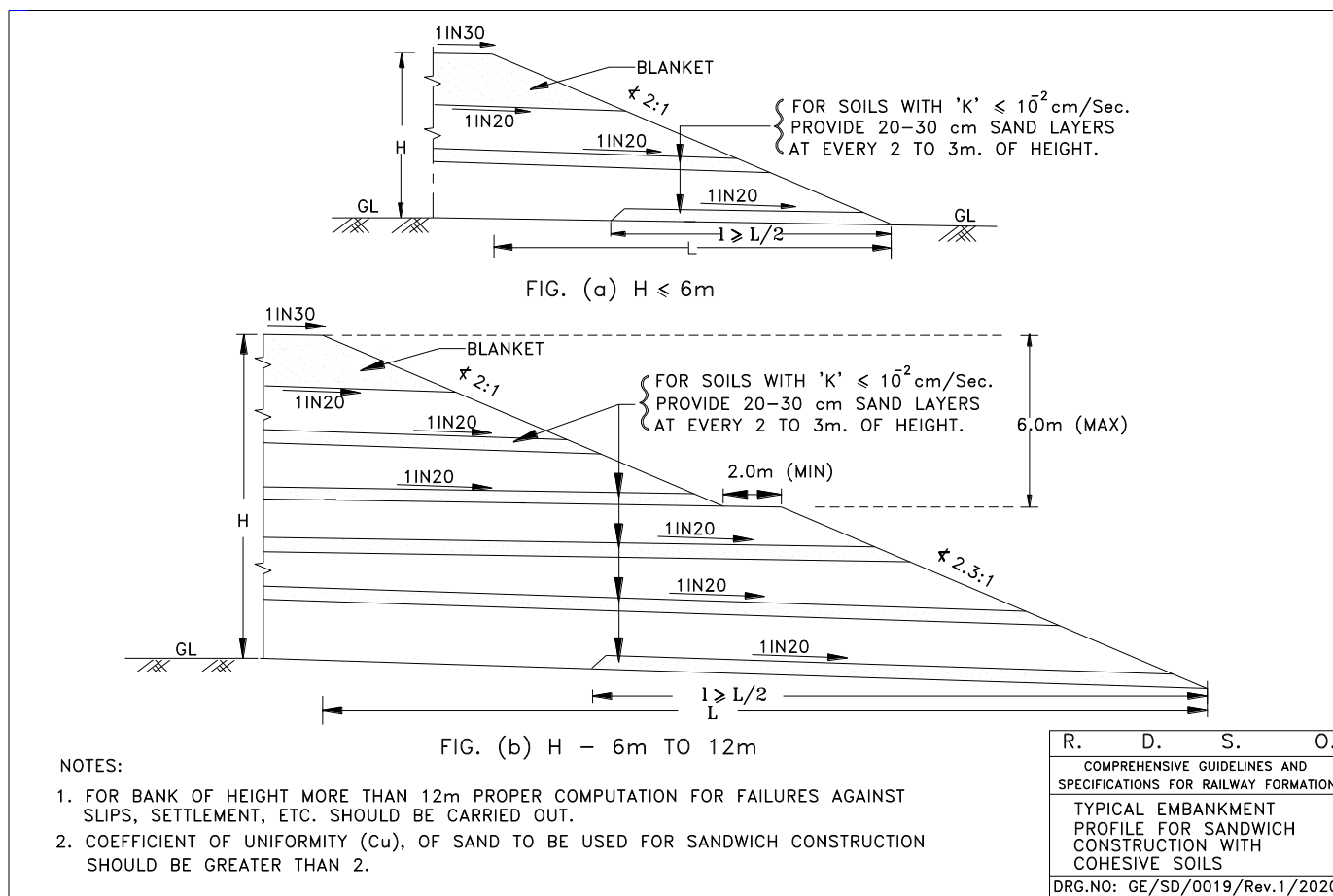


Fig-6.1 Typical embankment profile for sandwich construction with cohesive soil

6.2.5 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-a-vis, abutments, which rest on comparatively much stiffer bases. To avoid such differential settlements, while on one hand it is essential to compact the back fill in the properly laid layers of soil for Settlements within tolerable limits so that Coefficient of subgrade reaction should have gradual change from approach to the bridge.
- Back-fills on bridge approaches shall be placed in accordance to Para 7.5 of Bridge Substructure code (including latest correction slips). Sketch for details given in **Fig-6.2** below.

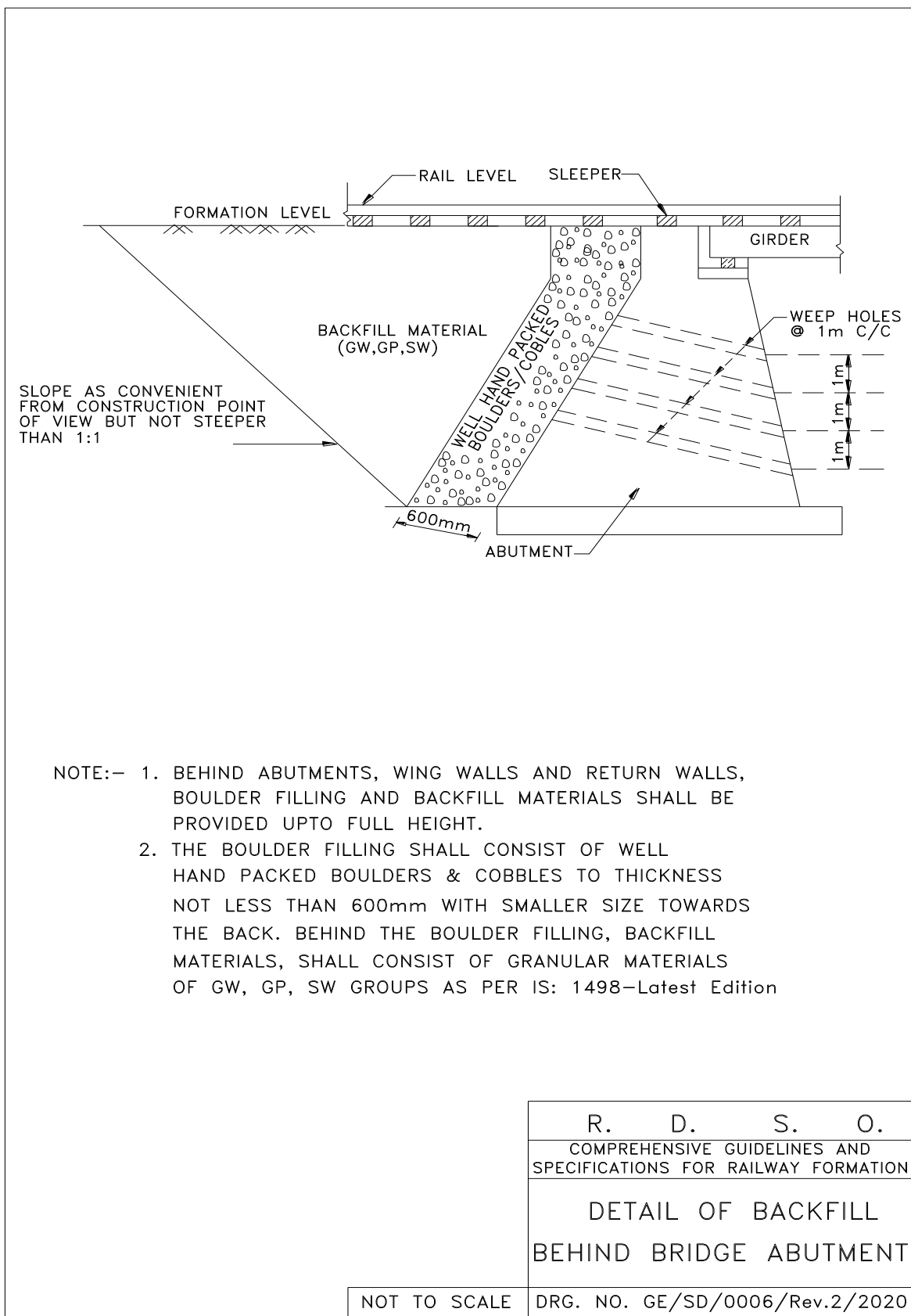


Fig-6.2 Details of backfill behind bridge abutment

- iii) Fill material being granular and sandy type soil, therefore need to be placed in 150mm or lesser thick layers and compacted with vibratory plate compactors.
- iv) While placing backfill material benching should be made in approach Embankment to provide proper bonding.
- v) Geocomposite drain (vertical) can replace the natural graded filters (consisting of 600mm thick boulders/cobbles etc. as shown in Fig 6.2 above), provided behind bridge abutment and/or retaining walls for drainage in places where availability of graded filters is matter of concern. Detailed elaboration is given in Appendix-C.

6.2.6 Drainage Arrangement in Embankments and Cuttings

Drainage is the most important factor in the stability of embankment/cutting in railway construction. Effective drainage of the rainwater in the monsoon season is very important to safeguard embankment/cutting from failure. Railway formation is designed for fully saturated soil condition. However, Stagnation of water for long time on formation is not desirable. Therefore, the drainage system should be efficient enough to prevent stagnation and allow quick flow of water. Some guidelines on this aspect are given as follows:

- i) Drainage of Embankment:** In embankment cross slope is provided to drain out surface water. Therefore, normally there is a need of side drains in case of embankment.

Top of formation should have a cross slope of 1 in 30 from centre of formation towards both sides for single line/multiple line in new construction. In case of doubling or multiple line construction work in existing lines, the cross slope of 1 in 30 should continue from the edge of existing formation towards cess/drain side (single slope) to avoid any stagnation of water between two tracks. However, if the cross slope of existing embankment is steeper than 1 in 30 due to any reason, the configuration of 1 in 30 cross slope shall be maintained in the new line while ensuring proper drainage conditions at the same time so as to avoid any stagnation of water in between tracks, by adopting various measures as per site conditions.

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

ii) Drainage in Cuttings

- a) 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 up to 4m), 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. A typical sketch of side drain and catch water drain is given in **Fig-6.3** below. It is to be noted that blanket material is to be placed like fill/embankment and top of side drains has to remain below the bottom of blanket material.

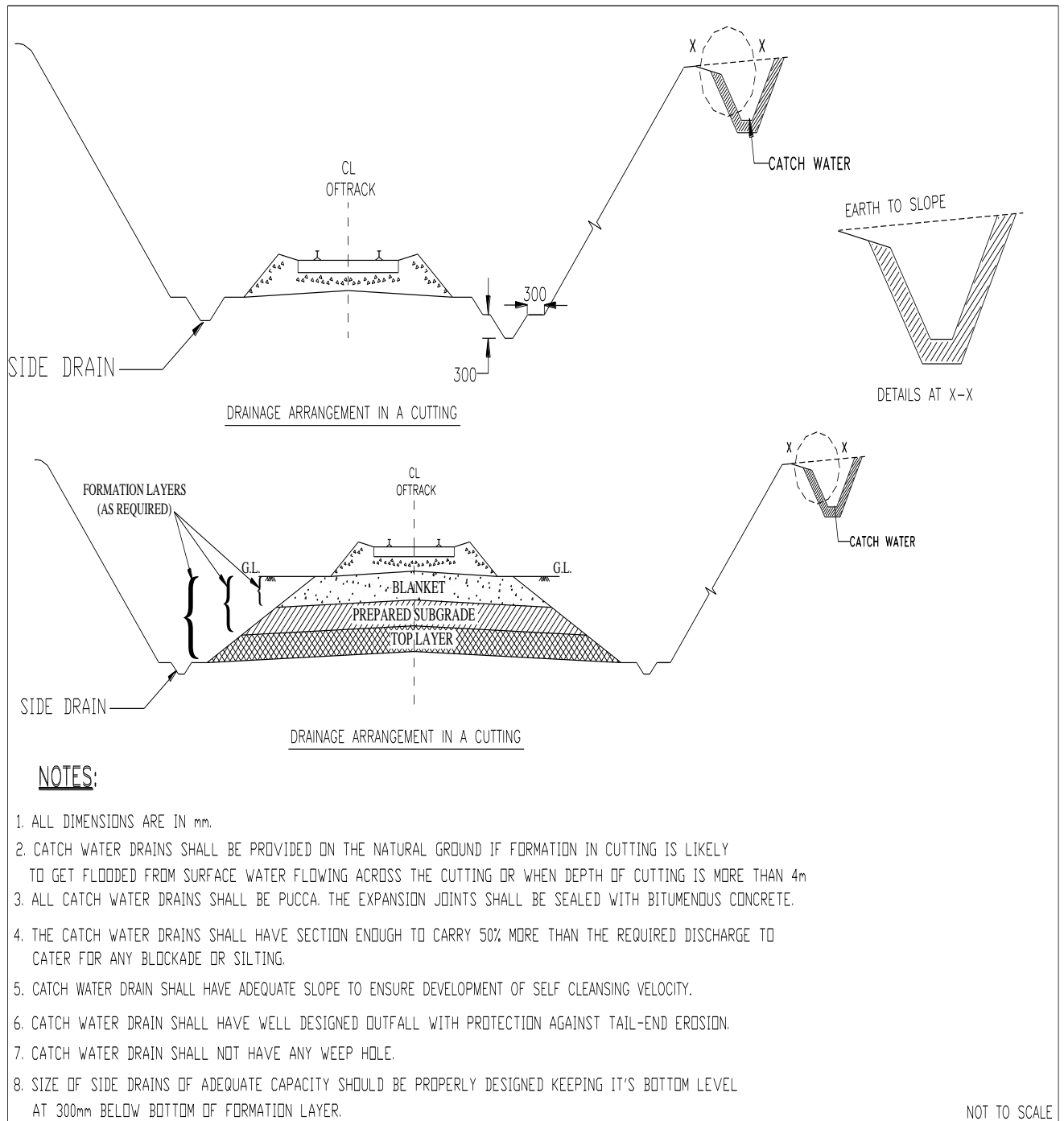


Fig-6.3: Arrangement of drainage in cutting

b) Catch Water Drains: Surface water flowing from top of hill slope towards the track in huge quantities needs to be controlled. It is also not possible to allow water from the hillside to flow into the side drains, which are not designed for carrying such huge quantity of water. Therefore, it is essential to intercept and divert the water coming from the hill slopes; accordingly, catch water drains are provided running almost parallel to the track. Depending on site condition, water from the catch water drains may require to be diverting by sloping drains and carrying across the track by means of culvert. In some of the situations, depending on topography of top of cutting, there may be requirement of construction of net of small catch water drains which are subsequently connected to main catch water drain so that there is no possibility of water stagnation/ponding upto distance approximately three times depth of cutting from its edge. Catch water drains should be made pucca/lined with impervious flexible material locally available.

c) Considerations in Design of 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 into instability in the cuttings. Catch water drains should be located slightly away (as per site conditions) from the top edge of 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:

- i) Catch water drains shall have adequate slope to ensure development of self- cleansing velocity.
- ii) Catch water drains shall not have any weep hole.
- iii) The expansion joints, if provided, shall be sealed with bituminous concrete.
- iv) Regular inspection and maintenance work, specially before onset of monsoon, should be carried out to plug seepage of water.
- v) Catch water drains shall have well designed out fall 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:

- i) Intensity and duration of rainfall.
- ii) Catchment area- shape, size, rate of infiltration etc.
- iii) **Velocity of flow which should satisfy the Manning's formula**
- iv) Minimum gradient of drain should be about 1 in 300.
- v) Normally catch water drains should be of trapezoidal cross section.
- vi) The catch water drain 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
- vii) Rugosity coefficient should be about 0.03.

-
- Diagram illustrating a cross-slope for a drainage ditch. The ditch has a 4:1V slope on the left and a cross-slope of 1:30 on the right. A water level is indicated by a horizontal line with an arrow pointing to the ditch bottom.

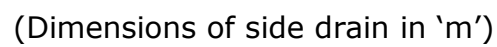


Fig-6.5: Sub-soil Longitudinal Drainage System

6.2.7 Finishing and Blanketing

- i) Providing Camber/Cross Slope below Blanketing: Top of the formation should be finished to desired cross slope of 1 in 30. Cross slope should be within 1 in 28 to 1 in 30. Camber may be checked at site through use of a cross-section camber board.
- ii) Once the top surface of the formation has been finished to proper slope and level, movement of material vehicle for transportation of ballast, sleepers etc. should be avoided, these movements will cause development of unevenness, ruts on the surface which will accumulate water and weaken the formation.
- iii) Provision of Blanket Layer: The specifications for the material to be used as Blanket and thickness of blanket layer shall be as per relevant provisions given in **Chapter 3**.

6.2.8 Setting up of GE lab at Construction Site

A well-equipped Geo-technical Engineering (GE) Field Laboratory shall be set up at all construction projects connected with new lines, doubling and gauge conversion works as well as, where rehabilitation of failing formation is being undertaken. Number of such GE labs to be established on a particular project/work site should be so decided that all quality control checks can be performed effectively. The field lab should be manned adequately by trained officials & staff capable of carrying out required investigation, soil testing and quality control at site.

- i) Aspects to be looked after by field GE lab are as under:
 - a) To ensure that the quality of supplied soil and blanket material conforms to the accepted limits of gradation, classification, plasticity, etc.
 - b) To evaluate methods of compaction by conducting tests in connection with field trials.
 - c) To exercise moisture and density control as the earthwork proceeds in layers rolled with the suitable equipment.
- ii) Field lab shall be equipped with minimum equipment as listed in **Appendix-K**, to facilitate the following minimum tests:
 - a) Gradation Analysis-Sieve and Hydrometer.
 - b) **Atterberg's Limits** - Liquid Limit & plastic Limit
 - c) Optimum Moisture Content (OMC), Maximum Dry Density (MDD) and Relative Density.
 - d) Placement moisture content & in-situ Density.
 - e) CBR test

6.2.9 Maintenance of Records

At the work site, details of works along with materials being used are to be properly recorded so that work of satisfactory quality can be achieved which can also be verified at later stage. Records are also required to develop completion drawings and other details, which would become permanent records of the section and could be helpful in future to plan developmental activities and remedial measures if need be.

CHAPTER-7

QUALITY CONTROL OF EARTHWORK

7.1 General

Quality of execution of formation earthwork shall be controlled through exercise of checks on the borrow material, blanket material, compaction process, drainage system, longitudinal & cross sectional profiles of the finished embankment. The details of quality control procedure are as follows:

7.2 Quality Control test on Construction Material

This is required to ascertain the suitability of the material for construction of Embankment and to decide the OMC/MDD and other relevant tests, which becomes the quality control inputs. Quality control tests are required to be conducted on borrow material as well as on blanket material.

7.3 Suitability tests at source

7.3.1 Borrow Material (Embankment fill as well as prepared subgrade)

a) Following specific tests to be conducted on borrow Material

- i) Sieve analysis
- ii) Hydrometer analysis
- iii) Consistency limits
- iv) CBR test
- v) Test for organic content in soil
- vi) Crumb test, double hydrometer test, pin hole & chemical test - for Dispersive soil only
- vii) OMC/MDD

Fill material proposed to be used either from Railway land or from outside would have to be assessed for its suitability as well as to decide thickness of the blanket layer after conducting soil classification and other relevant tests as per site requirement. On the basis of the tests, areas for borrow material, especially from outside the Railway land, need to be earmarked. Once the material has been found fit for use as fill material for Embankment, further lab tests, to assess OMC, MDD/ Relative Density, need to be conducted.

In case, slope stability analysis, as explained in **Chapter - 5** is required, triaxial shear test will also need to be done to find effective shear strength parameters.

- b) Frequency of Testing:** The frequency of testing before laying for borrow material should be as detailed in **table 7.2**.

Note: *It would be in the interest of the execution agency to have frequent tests conducted at source/manufacturing point on his own to judge the suitability of the material to avoid any complication at a later stage. However the final acceptance of the borrow material should be at the site before laying.*

7.3.2 Blanket Material: The source(s) of blanket material needs to be identified based on the final location survey report, tests & studies conducted and conformity to the Specification as stipulated in **Table 3.3 to 3.6**.

a) Method of Test: Blanket material should be tested as per IS: 2720 (Part 4) to plot particle size distribution curve, so as to assess its suitability. It would be necessary to carry out wet analysis to assess the actual percentage of fines.

b) Frequency of Tests: The frequency of testing at site before laying for blanket material should be as detailed in **Table 7.2**.

c) Following tests/checks are to be conducted

- i) Sieve analysis and hydrometer analysis to determine C_c , C_u & percentage fines
- ii) CBR test
- iii) Los Angeles Abrasion value,
- iv) Filter criteria, as required
- v) Gradation Analysis,
- vi) Check for conformity with enveloping curves

Note: *It would be in the interest of the execution agency to have frequent tests conducted at source/manufacturing point on his own to judge the suitability of the material to avoid any complication at a later stage. However the final acceptance of the blanket material should be at the site before laying.*

7.4 Quality Control Checks on Finished Earthwork

7.4.1 Compacted Earth: Degree of compaction of each layer of compacted soil should be ascertained by measurement of dry density/Relative Density of soil at locations selected in specified pattern. The method of sampling, frequency of tests, method of tests to be conducted and acceptance criteria to be adopted are as under

a) Method of Sampling

- i) Various methods of selection of sample points for checking the field dry density are in practice. These methods **are shown in Fig-7.1**. The sampling method should be such that the effectiveness of compaction for the entire area of compacted earthwork can be judged properly. The Engineer in-charge should specify the sampling method depending on the site conditions.
- ii) For each layer, a minimum of one sample at a predetermined interval along the centerline of the alignment would be taken in a staggered pattern so as to attain a minimum frequency of tests as given in the note below **table 7.2**. For subsequent layer, the stagger should be such that the point of sampling does not fall vertically on the earlier sampling points of the layer immediately below. The process of sampling is explained in **Fig-7.1** for guidance. Additional sampling points can be taken, as considered necessary.
- iii) In case of embankment widening, sampling should be done at an interval of minimum 200metres on the widened side(s) of Embankment.

- b) Methods of In-situ Dry Density Measurements:** Any of the following methods could be adopted as per the requirements at site.

Table-7.1

Method of measurement	Procedure of test	Parameters to be measured	Remarks
i) Sand Replacement Method	As per IS-2720 (Part 28) - latest version	In-situ Dry Density Moisture Content	May be adopted for all type of soils
ii) Core Cutter Method	As per IS-2720 (Part 29) - latest version	-do-	In some of the coarse-grained soils (with little fines) taking core cutter samples is difficult. In such cases, a sand replacement method may be used for density measurement.
iii) Nuclear Moisture Density Gauge	As per Appendix-H	a) Bulk density b) Moisture Content c) Dry density d) Degree of compaction	It is a faster Method and should be widely used for large construction projects.

c) Acceptance Criteria

- i) Coarse grained soils which contain fines passing 75 micron IS Sieve, upto 5 percent should have the Density Index (Relative Density) a minimum of 70% as obtained in accordance with IS: 2720 (Part 14) – 1983 (Reaffirmed 2015).
- ii) In field compaction trial, the maximum attainable dry density should not be less than 98% of MDD value as obtained by Heavy Compaction Test (IS: 2720 (Part 8) – (Reaffirmed 2015) in the laboratory. In case, there are difficulties in achieving 98% of the MDD values as obtained by Laboratory test, in the field trials, the same may be relaxed upto 95% of MDD with the specific approval of Chief Engineer/Construction, recording reasons for such relaxation. The level of compaction to be achieved in field, as a percentage of MDD value achieved in field compaction trial, for various layers shall be as per Table 3.3 to 3.6 of Chapter 3. In case of PSU, existing provision of Equivalent authority for acceptance criteria shall continue.
- iii) During widening of embankment in case of gauge conversion and rehabilitation of unstable formation, compaction of earthwork should be minimum 95% of MDD as obtained by Laboratory test as per Heavy Compaction Test (IS: 2720 Part 8 – 2013) or 70% Relative Density for

Coarse grained soils which contains fines (passing 75 micron IS Sieve) upto 5 percent (IS: 2720 (Part 14) –1983 (Reaffirmed 2015)).

7.4.2 Deformation Modulus (E_{v2}) measurement

It is a parameter expressing the deformation characteristics of a soil. It is calculated taking values from the load settlement curve obtained from the second cycle of loading in the Plate Load Test (Details given in **Appendix-H**). It is to be determined in the field on top of each formation layer i.e. at top of compacted Blanket layer/Prepared sub-grade/Subgrade- Top & Lower layer in accordance with DIN: 18134-2012.

7.4.3 Frequency of Tests

The frequency of testing at finished earthwork should be as specified in the Table **7.2** given below.

7.5 Qualifying and Quality assurance Tests

Qualifying tests as part of pre-selection of good earth for Blanket, Prepared sub-grade, Subgrade is required to be carried out. Also quality of execution of formation earthwork shall be controlled through exercise of checks on the borrow material, blanket material, compaction process to ensure good quality construction. The quality control procedures are summarised in **Table-7.2** below.

Table-7.2: Summary of quality control tests in Borrow material/ finished earth work

Item / Material	Parameters to be determined	Location of sampling for quality control	IS Code Ref. (Latest version)	Frequency of test	Acceptance Criteria		
(i) Borrow material							
(a) Subgrade/ Prepared Subgrade	(i) Soil classification	At site before laying	IS: 1498	At least one test at every change of subgrade/ prepared-subgrade material subject to minimum of one test for every 5000 cum.	Soil should not be "unsuitable type" as given in Para 3.7 and should conform to specification given in Para 3.10 for 25T/32.5T Axle load of Chapter 3		
	(ii) CBR		IS: 2720-Part-16				
	(iii) Plasticity Index (Prepared Subgrade)		IS: 2720- Part-5				
	(iv) OMC & MDD		IS: 2720 – Part-8				
(b) Blanket material	(i) Gradation	At site before laying	IS: 2720-Part-4	Minimum one test for every 500 cum or part thereof			
	(ii) Cc & Cu						
	(iii) Fines (passing 75 μ)		IS: 2386 – Part-4				
	(iv) Abrasion value						
	(v) CBR		IS: 2720-Part-				

			16		
	(vi) Filter criteria		IS: 2720 – Part-4		
	(vii) OMC & MDD		IS: 2720 – Part-8		
	(viii) Y_{max} & Y_{min} (Determined in Relative Density test If fines are upto 5%)		IS: 2720-Part-14		
(ii) Finished earthwork					
(Subgrade /Prepared Subgrade/ Blanket)	(i) E_v	Top of final finished surface of Blanket/ Prepared subgrade & Subgrade	DIN 18134 – 2012	One test per Km (*)	Acceptance Criteria as specified in Para 3.10 of Chapter 3
	(ii) Compaction	Every compacted layer	IS: 2720 (Part-28/29) or NMDG(as per Procedure issued by RDSO)	As per note given below	
	(iii) Density Index (Relative Density if fines are upto 5%)	Every compacted layer	IS: 2720 – Part-14		Minimum 70%

** Additionally this test can also be done by third party (i.e. IIT, NIT, Govt. Labs or any NABL approved Lab) having testing facilities, to cross check the results achieved at site. Frequency of testing in this case shall be decided/approved at the level of Chief Engineer (Con). In PSUs, frequency of such tests shall be decided as per existing delegations for testing.*

Note: Frequency of Tests: Density check would be done for every layer of compacted fill/blanket material as per following minimum frequency:

- At least one density check for every 30 m length for blanket layers and top one metre of prepared subgrade/subgrade along the alignment in a staggered pattern of each compacted layer.
- At least one density check for layers other than as specified in(i) above, every 500 m² or 75 m c/c whichever occurs earlier along the alignment in a staggered pattern of each compacted layer.
- In case of important bridge approaches (100 m length on either side), at least one density check for every 25 m length shall be adopted.

7.6 Formation Level: Finished top of sub-grade level may have variation from design level by ± 25 mm and finished top of blanket layer may also be permitted to have variation from design level by plus 25 mm only. The ballast should be placed only on level formation without ruts or low pockets.

7.7 Cross Slope: Cross slope should be within 1 in 28 to 1 in 30.

7.8 Side Slopes: Side slope should be 2H: 1V or flatter as per design.

7.9 Formation Width: Formation width should not be less than the specified width.

7.10 Quality Control Records: At least, following records of quality control as per proforma given in **Appendix- D & G** needs to be maintained.

- i) Characteristics of borrow materials as per proforma **No. G-1.**
- ii) Quality of blanket materials as per proforma **No. G-2.**
- iii) Field compaction trial computation sheet details as per **Table D-4** of **Appendix-D.**
- iv) Quality of compaction of earthwork including blanket material as per proforma no. **G-3** for core cutter method & proforma no. **G-4** for sand replacement method.
- v) Quality of material and its compaction for backfill behind bridge approaches etc. as per proforma no. **G1, G2, G3 & G4.**
- vi) Details of machineries engaged in execution of earth work including its output as per proforma decided by field engineers.

7.11 Setting up of GE Lab at Construction/Rehabilitation Site

A well-equipped Geo-technical Engineering (GE) Field Laboratory shall be set up at all construction projects connected with new lines, doubling and gauge conversion works as well as, where rehabilitation of failing formation is being undertaken. (Details are given in Para 6.2.8 of Chapter 6).

7.12 Certification for quality of earthwork

Certification for quality of earthwork in formation in respect of new lines, Gauge Conversion and Doubling projects etc. will be done by Executive authority at SAG level (i.e. CE/Con of respective projects). CE/Con will submit details for certification of quality of earthwork to CRS as per RDSO checklist.

7.13 Checklist for certification of quality of earthwork

Checklist for certification of quality of earthwork in Railway projects was issued by RDSO vide letter no RS/G/95/Main, dated: 11.06.2004. This Checklist has been revised and placed at Appendix –M.

7.14 Special design problems related with construction of formations

Any special design problems related with construction of formations may be referred to RDSO for guidance and advice, if required.

CHAPTER-8

EROSION CONTROL OF SLOPES

8.1 General

Exposed sloping surface of embankment/cutting experiences surficial erosion caused due to the action of exogenous wind and water resulting into loss of soil, leading to development of cuts, rills/gullies adversely affecting the cess width, soil matrix, steepening of slopes etc. which depends on type of soil, climatic condition topography of area etc.

8.2 Selection of Erosion control method

The following points may be considered while adopting suitable method for erosion control on soil slopes:

- i) Developing vegetation cover would be the best method to prevent soil erosion. This may be attempted by using 'Simple Turfing Method'.
- ii) At locations where a simple turfing method cannot ensure vegetation cover, natural fibre based netting can be adopted to support vegetation growth.

When the site is located in a drought prone area and it is difficult to sustain green cover throughout the year, geogrids can be adopted to provide long term protection.

- iii) Where vegetation cover alone is insufficient and soil surface needs to be protected in the absence of vegetation cover in certain patches, root reinforcing geosynthetic systems (3-D mats) can be used. Depending upon the duration for which protection needed (short term - 2 to 3 years or for longer term), either natural fibre based or polymer based 3-D mats can be adopted. For slope heights more than 5 m, root reinforcing systems would be better suited.
- iv) Organic mulch application (either manually or by using hydro seeding/hydro-mulching) can be adopted to aid simple vegetative turfing. By using hydro seeding/hydro-mulching method, inaccessible and near vertical slopes can be successfully vegetated and hydro seeding method can be used in combination with nettings/ mats to make them even more effective.

8.3 Erosion control method

The Erosion Control methods which have been suggested below are for guidance purpose and application of these methods depends on techno-economic, topographical, climatic and other considerations.

Erosion control measures are commonly classified in following categories:

- i) Conventional non-agronomical system,
- ii) Bio-technical system,
- iii) Engineering system, and
- iv) Non- conventional hydro-seeding/hydro-mulching system.

Most common methods used are the Bio-technical and Engineering System. However, appropriate method needs to be decided depending on site conditions.

8.3.1 Conventional Non-agronomical System

This method is best utilized against seepage, erosion by wave action etc. Soil bank or slopes exposed to constant concentrated flows, currents or waves does not support vegetation and needs to be protected by this system. For the slopes having inundation or continuous flooding for many days, slope protection system as indicated can be adopted as per site condition.

- i) Stone pitching on the slope to be protected.
- ii) Retaining walls, toe-walls or break walls and sheet piles that are placed in such a way to form a barrier between the shore and the waterfront.
- iii) Gabion & revet mattresses, manufactured as per IS 16014, filled with stones of specified size and provided on slopes.
- iv) Geotextile Bags - Bags made from geotextile material, which are filled with sand/suitable type of soil and are kept on the slopes in place of stone pitching.

With this system in place, water can seep in and out of the bank or slope, but the force of water is resisted by the non-agronomical system in place discussed above. To prevent possibility of any piping action in this system, traditionally a graded filter layer between bank soil and non-agronomical system is used. Geotextile can also be used in place of traditional filter layer with specific hydraulic and soil retention properties. (Chapter-5 in 'IRC: 56- For Different Methods to Prevent Soil Erosion' may be referred to.)

Note: *The sides of an Embankment (except approach bank of bridges) shall be protected upto 1 m above HFL (except for case-ii). For approach bank of bridges, 'Indian Railways Bridge Manual' shall be followed.*

8.3.2 Bio- Technical Solution

In this system, vegetation is provided on exposed slopes. It is suited for soil with some clay fraction. It consists of preparing a slope area by grading it for sowing seeds or planting root strips of locally available creeping grass. The root goes upto 50 to 75mm deep into the slopes serving as a soil anchor and offering added resistance to erosion.

This technique has some limitations such as in case of highly erodible soil or in case of infertile soil or in case soil having absence of initial binding in such cases help from botanists/agronomists may be sought for developing vegetation.

However, some typical deep rooted species of grasses and shrubs suited to different topographical area of our country are given under (table 8.1, 8.2 & 8.3) based on altitude of area and type of soil in (Reference: Recommended Practices Treatment of Embankment and Roadside slopes for Erosion Control, IRC: 56- latest version).

Table 8.1 Plains (including altitude upto 1500 m above sea level)

Grasses and Shrubs	
1.	Horticulture grass <i>Cynodon dactylon</i>
2.	<i>Cynodon plectostyrum</i>
3.	<i>Chloris gayana</i>
4.	<i>Saccharum spontaneum</i> Tall Pernicious Deep rooted Perennial
5.	<i>Sachharum munja</i> (Sarkanda)

6.	Ipomea carnea (Bacharum Booti)
7.	Lantana species
8.	Agave Americana
9.	Erythrina indica
10.	Prosopis species
11.	Casuarina species
12.	Goat foot creepers
13.	Vetiver grass (vetiveriazizanioides)

Table 8.2 Hills

Grasses and Shrubs	
1	Eragrostis curvula Love Grass (Kumaon -Central Himalaya)
2	Eragrostis superva (Locally known as Babia in Kumaon -Central Himalayas)
3	Chrysopogon mountanus - Central Himalayas
4	Pennisetum orientale - Central Himalayas
5	Lolium perenne (Rai Grass - H.P. & Kumaon)
6	Poa pratensis (above 1800 m)
7	Imperata cylindrica
8	Robinia pseudoaccadia Cuttings as well as plants
9	Kudzu vine all over upto 2400 m (Pueraria thungbergia)
10	Kikuyu (Pennisetum clandestinum)
11	Jatropha curcas
12	Ficus caric
13	Philendus cuttings
14	Lemon grass (Cymbopogon flexuosus) for use in elevations around 1900 m)

**Table 8.3 Selection of species vegetation based on soil type
(As per IS 15869)**

SL	Name of Species	Suited for
1	Cyanodon dactylon	For sandy soil
2	Cenchrus ciliaris	Can be used for most type of soil
3	Dichanthium annulatum	For alluvial soil
4	Pennisetum pedicellatum	Sandy loam soil
5	Rochela glabra	Laterite semi-arid soil
6	Stylosanthis gracilis	Alluvial soils having less moisture
7	Pueraria hirsute	Suited to alluvial soils and for the hills in humid climate
8	Pennisetum purpureum	For hill slopes

8.3.3 Engineering System

In this system, following methods discussed below are normally used. Help from botanists/agronomists may be sought for developing vegetation & determining requirements of soil cover, nutrients or other aspects, wherever required.

i) Jute netting for erosion control:

In this system Geojute is used for erosion problems. Geojute is eco-friendly

material made of jute yarn with a coarse open mesh structure and is biodegradable. By using Geojute netting for erosion control the soil particles, seed, grass root slips are held securely in their original locations without being dislodged.

Jute netting is having high water absorbing capacity, which gives full benefit of moisture for growth of vegetation. After the first rainy season, the seeded and sprigged vegetation develops in the entire surface thus, protecting the slopes against erosion. Jute netting has been observed to have a life of about 1 to 2 years in the field, which is sufficient for fully promoting the growth of vegetation cover on the denuded slopes.

Once vegetation growth has been established the purpose of providing jute netting is accomplished. As jute netting is biodegradable, after the end of its life it decomposes and, in the process, adds nutrients to the soil.

For laying, Geojute roll is unrolled loosely and evenly on slope and then anchored at shoulder i.e. at the top and at the toe i.e. at bottom. It shall be ensured that there is proper contact between the jute mat and surface of the slope by use of steel nails or other appropriate anchorage pins on slope surface at suitable distance, to secure it against displacement. Watering facilities should be ensured during the initial period of sowing if the work is undertaken during non-monsoon period.

For details about use of Jute Geo-textiles (JGT), their technical specifications and laying methodology etc., RDSO Guidelines titled "Guidelines for application of Jute Geo-textiles in Railway Embankment and Hill Slopes" No. RDSO/2007/GE: G-0008, Feb-2007 may be referred.

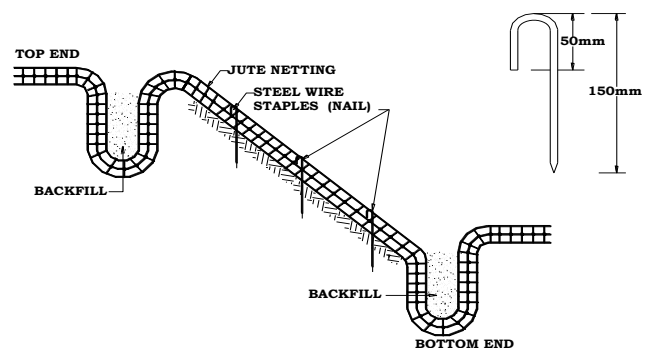
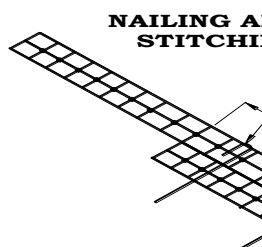


Fig- 8.1: (b) Overlapping Of Jute Netting

Fig- 8.1(c) Placement of Jute Netting

ii) Coir netting for erosion control

Coir netting (also known as 'Coir Bhoovastra') is another type of biodegradable material which can be effectively used in a manner similar to jute netting. Coir nettings degrade much slower than jute nettings (expected field life of about 2 to 3 years) and **thus** provide protection to the slopes for a longer time than jute nettings.

Coir is also resistant to saline water and provides an ecological niche for a rapid re-establishment of the vegetation cover. Coir resembles natural soil in its capacity to absorb solar radiation. This means that there is no risk of excessive heating. In a manner similar to jute nettings, coir netting also breaks up runoff from heavy rains and dissipates the energy of flowing water. Coir also promotes the growth of new vegetation by absorbing water and preventing the top soil from drying out. In coir mats also, proper contact between the mat and surface of the slope by use of steel nails or appropriate anchorage pins on slope surface at suitable distance, to be secured against displacement

However, compared to Jute nettings, drapability of coir netting is lesser and their water absorption capability is also lower than jute nettings. The length of the rolls would be 50 m and width can be between 1 to 4 m. For more details, IS: 15869 'Open weave coir Bhoovastra-Specification' and IS 15872 'Application of Coir Geotextiles (coir woven Bhoovastra) for Rainwater Erosion Control in Roads, Railway Embankments and Hill Slopes-Guidelines' and IRC: 56-latest version may be referred to.



Fig- 8.2 Coir Netting

iii) Erosion Control Using Geogrids Mesh/Netting

Under unfavorable soil & erratic weather conditions, prolonged drought in particular area, where vegetation growth is difficult and ordinary turfing as well as agro based nettings may fail to provide erosion prevention, use of geogrid mesh provides a permanent protection as it is not biodegradable.

A synthetic root reinforcement vegetation system using geogrids can achieve high density of grass growth as it reduces the velocity of surface runoff.

For laying geogrid mesh for erosion control, slope area should be dressed with filling of cavities and potholes if any by light ramming. The net should be unrolled ensuring uniform surface contact. Geogrid ends at top and bottom of slopes should be suitably anchored by MS pins & soil filled back, this will act as anchorage. With watering and implementation of grass seed/turf, the roots establish quickly. For more details IRC: 56-latest version may be referred to.

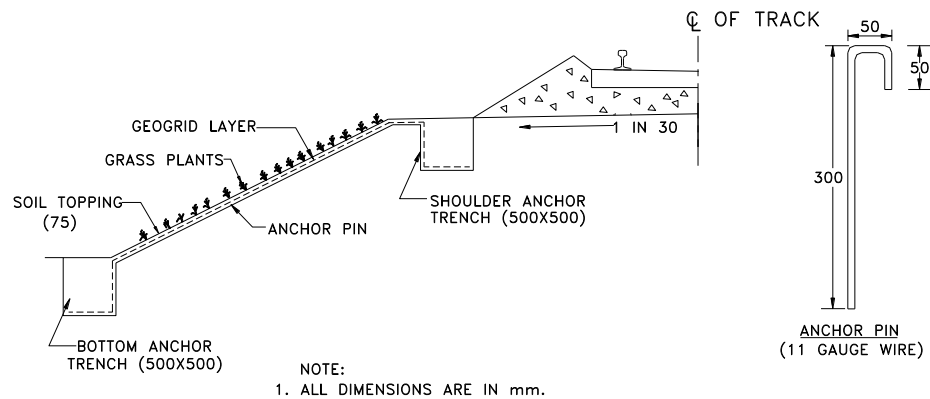


Fig- 8.3 Installation of Geogrid Mesh

iv) Erosion Control Mat/Rolled Erosion Control Products

Relying upon vegetation growth alone may be sometimes very unpredictable and unreliable as it may be extremely difficult to achieve 100 percent vegetation coverage, leaving exposed areas vulnerable to erosion. Furthermore, vegetation may sometimes dry up or become diseased, reducing its erosion control capability. Reinforced vegetation using three-dimensional erosion control Mat/rolled Erosion Control Products is another method that is being practiced for enhancing slope stability and erosion control.

The 3-D mat increases the soil's resistance to erosion by providing an environment that enhances the growth of vegetation through the mat. Initially the mat works to shield the soil from washing out before the vegetation has a chance to become established. Then as the vegetation matures, the roots anchor the mat to the soil to provide superior soil reinforcement strength, capable of handling greater volumes of runoff water and higher flow velocities.

These three-dimensional mats, being multi-filamented materials, have specified thickness. 3-D Mats can also be made using biodegradable natural fibers such as straw, jute, coir or wood shavings (used individually or in combination) stuffed into polymeric or organic nettings on either side to form a mat or blanket-like structure.

Mats which are made using natural fibres are biodegradable due to which they don't provide everlasting protection. Such Mats are used in combination with seed beds to enhance the growth of vegetation.

When geosynthetic mattings (3-D Mats) are made exclusively from polymeric substances, they consist of UV stabilised synthetic fibres and filaments processed into permanent, high strength, three dimensional (3-D) matrices. These products are long lasting. Steel wire mesh is sometimes included in these mats optionally where these mats are required to possess more strength against erosive forces, like steeper slopes or in heavy rainfall areas. For more details IRC: 56-latest version may be referred to.

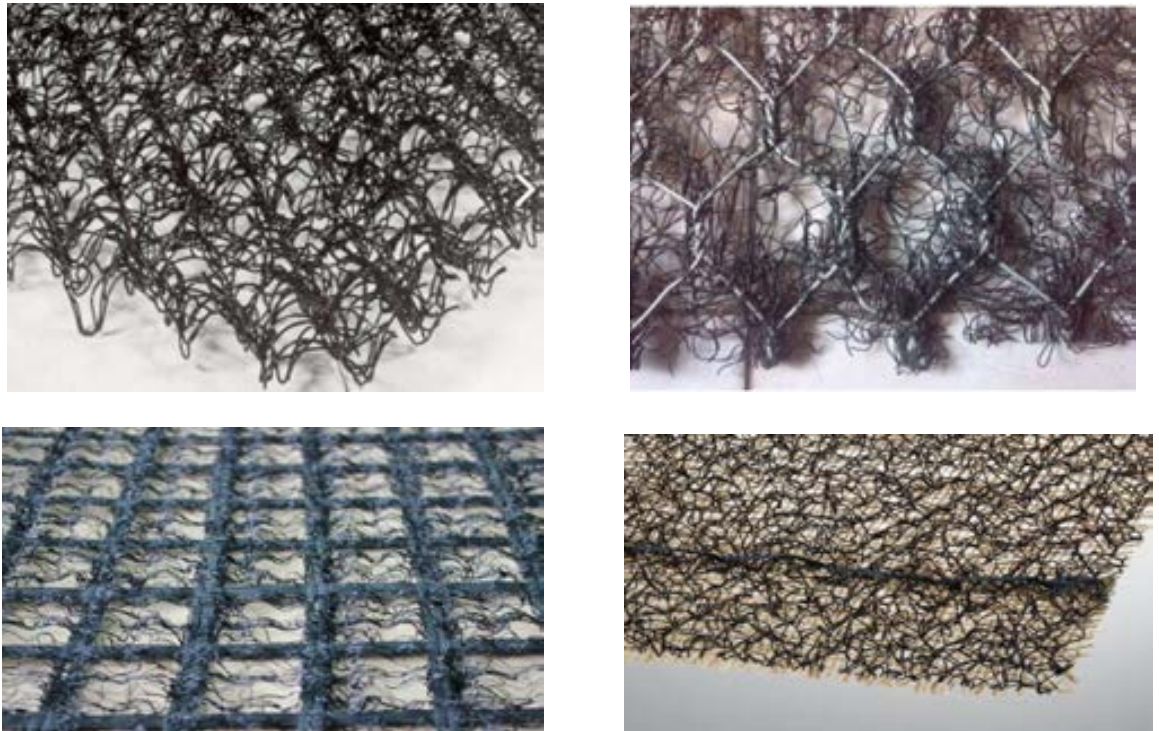


Fig- 8.4 Three Dimensional Erosion Control Mat

v) Non- conventional hydro-seeding/hydro-mulching system

Hydro-seeding/hydro-mulching is a process which can be considered as alternative to sodding. It involves seed application in water-based slurry via a high pressure pump and hoses or a spray gun. The basic ingredients used in this process are water, seeds, fertilizer, mulch, tackifier and bio-stimulant.

Mulch can be made from recycled paper or shredded wood or a mixture of both - wooden mulch breathes while paper mulch forms a protective cover.

Chopped straw cut to a length of 10 to 20 mm can also be used as mulch. Tackifier is required to make this mulch and seed stick to the soil surface to which it is being applied.

Mulch protects the slope until the seed germinates and provides organic nutrients as the vegetation grows. These mixed ingredients are stored in a tank and applied using a pressure pump, on a barren land surface on which vegetation is to be promoted.

Hydro-seeding/hydro-mulching method is especially suited for vertical or near vertical soil slopes (steep slopes) on which 'simple vegetative turfing' or manual application of mulch would not be successful. Hydro-seeding/hydro-mulching jobs are specialised and expensive but for some inaccessible slopes, it offers the only practical method. For more details IRC: 56-latest version may be referred to.



Fig-8.5 Figure showing Hydro-seeding/hydro-mulching on slope

8.4 Protection of Slopes in Cutting

The causes and manifestations of surficial erosion of slopes of embankments and cuttings with soil are almost similar hence erosion control measures can be adopted same as that for embankment. For cuttings in rocks, slope protection measures to be taken as per site condition. **RDSO "Guidelines for cuttings In Railway formations"** Guidelines No. GE: G-2 (April-2005) may be referred to.

CHAPTER-9

WIDENING OF EMBANKMENT AND RAISING OF FORMATION, INCLUDING CESS REPAIR

9.1 Widening of Embankment

9.1.1 Widening of Embankment for Gauge conversion

- Before taking up widening of Embankment for gauge conversion, it should be ensured that remedial measures for unstable formation have been taken.
- All vegetation shall be uprooted and taken away from the site of work. The loose materials removed from the slope should be dumped to form the bottom most layer on the ground in the width to be widened. If required, it shall be supplemented with local granular soil.
- Starting from the toe, benching on the slope at every 30cm height shall be provided on the slope surface as shown in **Fig-9.1** below so as to provide proper amalgamation between the old and new earthwork.

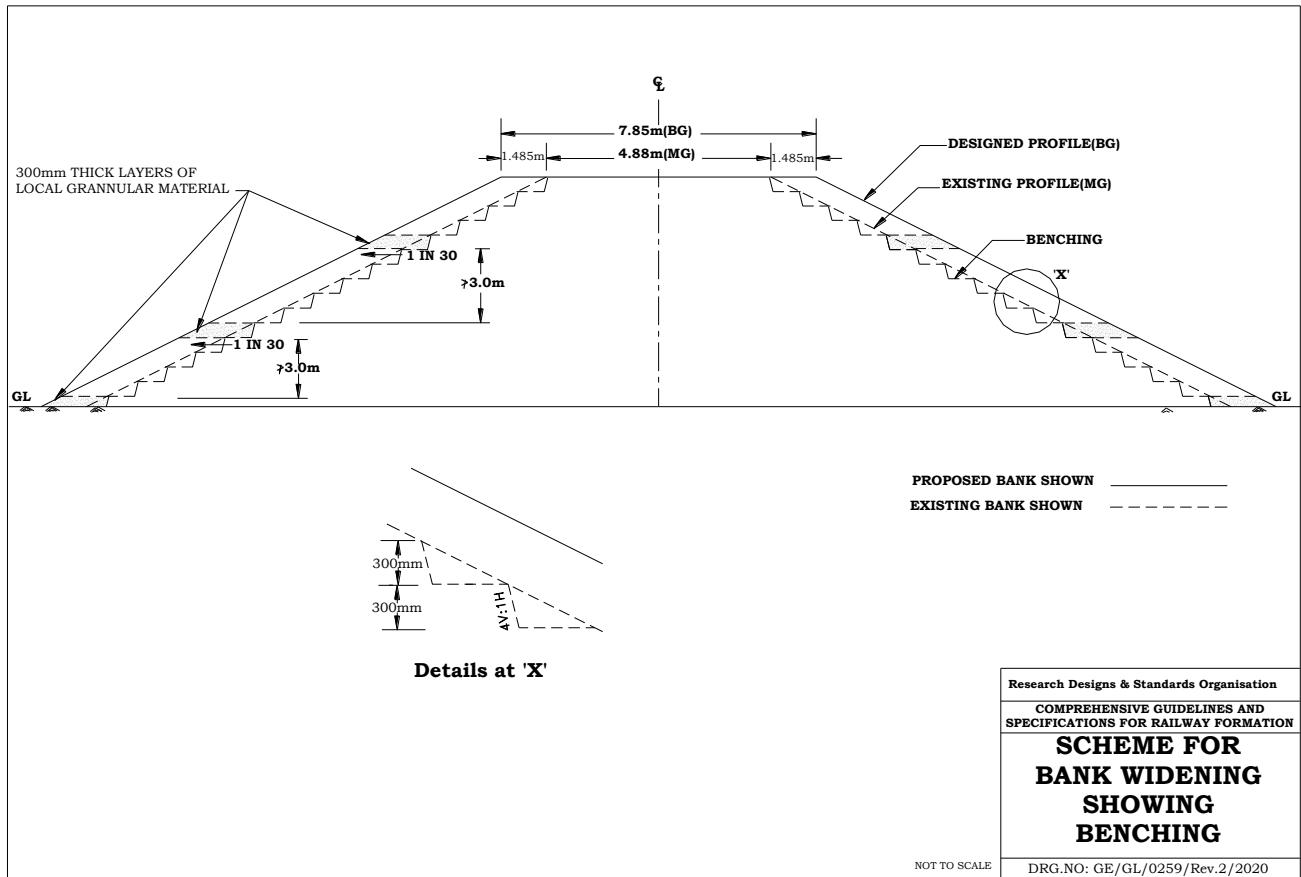


Fig-9.1: Scheme for bank widening showing benching

Earthwork shall be carried out in layers, each layer sloping out 1:30 and compacting it mechanically using vibratory rollers of around 0.9m width (which are available in the market); 6 to 8 passes of such rollers shall usually suffice to provide the

compaction to the specified level. Compaction on slope shall be ensured by using slope vibratory roller of 10-20t. Preferably, this should be a separately payable item.

- iv) The width of each layer of earthwork shall be in excess by 300mm of the designed profile to enable compaction near the edges. The excess width, thereafter, be cut and dressed, so as to achieve the required embankment profile.

In case of widening for gauge conversion, Earthwork shall be completed upto design formation level with due allowance of provision of blanket (as per RDSO specification) on entire formation width i.e. extended portion as well as in existing formation. If blanket layer does not exist on the existing formation, top layer of existing embankment shall be replaced with required depth of blanket layer in pursuance to guideline for fitment of existing formation for running of 25T axle load at 100 kmph (as per details given in **Appendix-I**).

9.1.2 Widening of Embankment for doubling

- i) Before taking up widening of Embankment for doubling, it should be ensured that remedial measures for existing unstable formation have been taken.
- ii) All vegetation shall be uprooted and taken away from the site of work. The loose materials removed from the slope should be dumped to form the bottom most layer on the ground in the width to be widened. If required, it shall be supplemented with local granular soil.
- iii) Starting from the toe, benching on the slope at every 30cm height shall be provided on the slope surface as given in **fig. 9.2**, so as to provide proper amalgamation between the old and new earthwork.

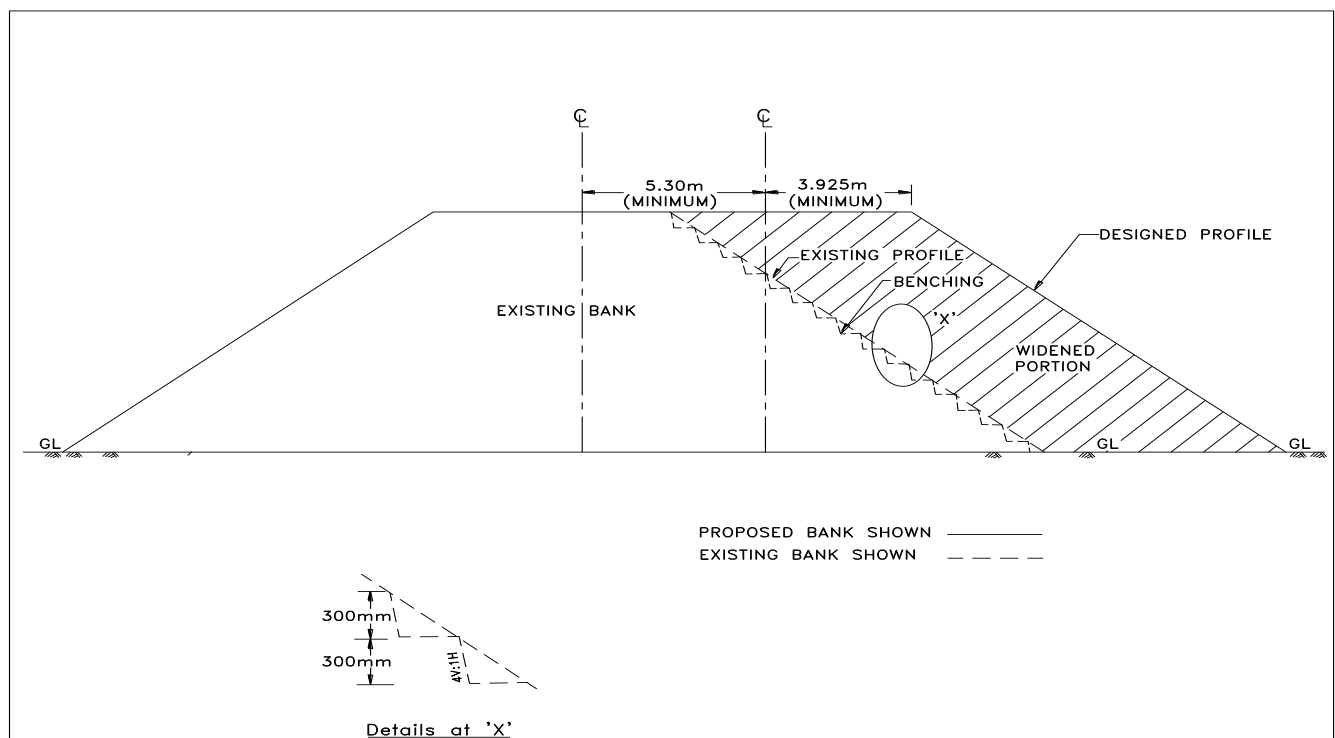


Fig-9.2: Widening of Embankment for doubling

Note 1- In case of existing formation is of minimum 7.85m width, widening is to be done only on one side as indicated in sketch above.

Note 2- In case of widening of existing formation (formation width 6.85 m or below as per previous provisions of IRSOD), the requirement of minimum formation width of 13.16 m & minimum cess width of 900 mm may not be fulfilled on other side of existing embankment which is not widened. In that case, cess width of existing track is to be increased on programmed basis as stipulated in para 9.2. The total formation width i.e. existing plus widened of minimum 13.16m shall have to be ensured as per latest provisions of IRSOD.

Note 3- Additional width of formation on curves should also be accounted for as per relevant provisions of IRSOD/IRPWM.

- iv) In case of doubling with widening of existing embankment, various provisions & methodology for new construction as stipulated in **Chapter 3 & 6**, shall be followed.

Note: Design and construction of any detours (for easing out of existing sharp curves, rebuilding of important bridges etc.) shall be carried out in accordance with provisions of new construction as stipulated in Chapter 3 (Table 3.1 to 3.6).

- v) In case, height of embankment (as per required top level of formation) is less than the required depth of formation layers (Blanket/Prepared sub-grade/Top layer of sub-grade), then also provision as stipulated for formation layer shall have to be ensured for effective stress dispersal. If required, excavation below ground level will have to be done as given in **Para 3.11 of Chapter 3 & Appendix-B.**
- vi) Suitable drainage arrangement as given in **Chapter 6-Execution of Earthwork** is to be provided.

9.1.3 Raising of Existing Formation

After widening of the embankment to the level of the existing formation, raising shall be done as under:

- i) Raising less than 150mm shall be done with ballast, restricting total ballast cushion to 350mm.
- ii) Raising from 150mm to 1000mm: The existing ballast shall be taken out under suitable speed restriction and raising should be done in suitable steps with the material as per specification of blanket material. After raising to the desired level, clean ballast shall be inserted. Limiting value of 1000mm may be reduced depending on the site conditions.
- iii) Raising of more than 1000mm, shall be done by laying temporary diversion for passage of traffic.

9.2 Widening/Repair of Cess for Open Line maintenance

9.2.1 Introduction

Adequate formation width, ballast profile and cess width/height are required to maintain desired track geometry. Minimum width of cess is needed for following purposes: -

- i) To provide adequate confinement and to minimize track settlement.
- ii) For efficient and safe execution of track maintenance/renewal activities like casual renewal of rails/sleepers
- iii) Welding of rails
- iv) De-stressing of LWR/CWR
- v) Operation/placement/movement of Small track machines.
- vi) Unloading/loading of free rails/rail panels/sleepers and placing them on cess before and after the renewal.

9.2.2 Preliminary works

The work of cess repairs may be planned when the distance of edge of formation, from center of track, becomes less than 3300 mm and the cess width should be made minimum 1200mm during the cess repair work. Cess width for new construction with formation width of 7.85m (single line) is around 1100mm, hence considering additional extra margin for any shrinkage/settlement, 1200mm cess width is required to be provided during cess repair works.

Before undertaking the cess repair work, a detailed field survey should be carried out to plot the existing profile of track including embankment, identification of suitable earth for carrying out cess repair and fixing Targeted Theoretical Profile (TTP) of cess for proposed work. The TTP should include cess width to be made up, proposed raising of cess if any and flattening of side slopes.

(i) Field survey to plot existing profile of track including embankment

- a) Longitudinal level of rail at every 30m interval should be recorded along with existing cess level.
- b) Cross sectional profile including that of existing embankment should be taken at every 30m. The distinctive points of reference in cross section are rail level, toe of ballast, edge of cess and level at every 50cm interval (vertical height) of slope of embankment.

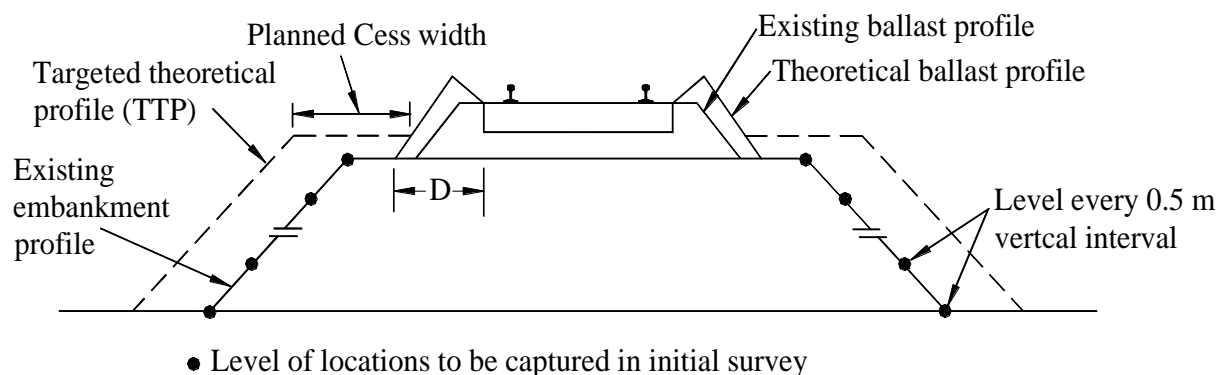


Fig-9.3

- c) The TTP with required longitudinal level of rail and cess at every 30m and also cross section as mentioned in above para should also be plotted. These levels should be recorded by SSE/SE and got approved by ADEN.
- d) In case of existence of level crossings, bridges or any other prominent track features, additional cross sections should be drawn based on site specific requirements.
- e) Location of Trolley Refuges etc. should also be identified and levels at these locations should be taken in sufficient detail to work out the quantity of earth required.
- f) To the extent possible, railway earth if found suitable may be used for cess repairs. The borrow pits should be dug along the edge of the railway boundary, duly ensuring that no borrow pits are dug within (H+3) m distance from the toe of the embankment, where "H" is the height of embankment. In case of non-availability of railway earth, suitable contractor's earth may be used.

(ii) Identification of suitable earth

Soils which are normally unsuitable for construction are stipulated in Para 3.7 of Chapter-3. Barring these, locally available soils of adequate strength can be used.

(iii) Targeted Theoretical Profile (TTP)

- a) In case, track renewal, deep screening, track lifting works are sanctioned, targeted theoretical profile should be finalized taking into account proposed longitudinal level of rail & cess, additional cess width required and sub bank if any required.
- b) Proposed TTP should be drawn for longitudinal levels of Rail/Cess and at every cross section as taken in Para 9.2.2(i) above should be fixed.
- c) Proposed rail level, cess level, edge of cess and level at every 50cm vertical interval on slope for TTP should be calculated and plotted.
- d) Due care should be taken while fixing TTP and must take into account any future proposed lifting to improve track geometry.
- e) On bridge approaches (up to the length of 50m on either side) where height of bank is more than 3m, extra 300mm cess width should be provided in addition to calculated above for cess repaired.
- f) The TTP should also include any additional width of cess or milder slope of embankment or sub-bank requirement based on site conditions and specific requirements with approval of Sr. DEN/DEN in charge of section.

9.2.3 Execution

- a) During earthwork on slopes, benching at the interval of 0.3m (vertical height must be done).

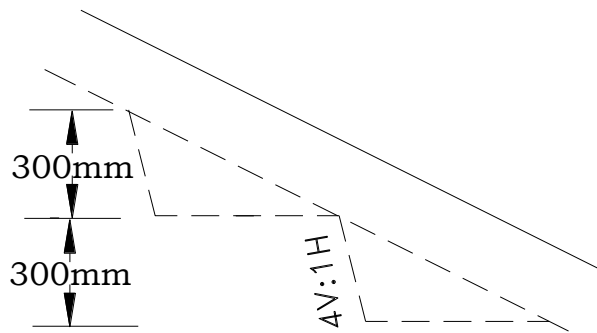


Fig-9.4

- b) Moisture to be added in the earth, to bring it near the Optimum Moisture Content value, shall be calculated and added to the soil. The moisture shall be mixed thoroughly using suitable means.
- c) After the final **layer's compaction**, the surface of earthwork executed must be as **per desired level and slope to the satisfaction of the engineer in charge's** representative.
- d) The earthwork shall be done in layers, compacting each layer with 10 passes of small width vibratory rollers. In top layers, where the working of rollers is not practical, suitable plate compactor may be used. After completing the earthwork of full height, the slope may be dressed and compacted with 10 passes of slope vibratory roller/compactor. The compaction on cess and slopes shall be kept as a separately payable item.
- e) For the repair work done on slope(s) of the embankment, suitable erosion control measures shall be adopted.
- f) Levels should be recorded at 30m length after completion of cess repair work **and "as done" profiles** should be plotted on the same sheets. Payment of cess repairs shall be based on the quantities worked out from the cross sectional calculations.
- g) Any excess repair work done beyond 10 cm of the TTP shall not be paid.
- h) In cess repair work, field measurement of compaction such as density and moisture content may not be insisted upon. Instead, record of compaction done, with machinery used & number of passes shall be maintained for each layer of earthwork done by concerned SSE, duly checked by ADEN/AXEN.