International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 18 (2015) pp 39408-39412

Design of high level railway embankment under constrain site conditions

Rakesh Kumar
Assistant Professor, Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, M.P. (India) rakesh20777@gmail.com

Pradeep K. Jain
Professor, Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, M.P. (India) pkjain10@rediffmail.com

Pratik Parmar
M.Tech Student, Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, M.P. (India) pratik.parmar@gmail.com

Abstract
The paper discusses the analysis of a high level railway embankment under a few limitations of in-situ soil, embankment material and the availability of land in transverse direction of the track alignment. A case of 20m high embankment is considered and the analysis is made for different conditions considering the guide lines given by Indian railways. The effect of water table rise on the stability of the embankment is studied. It is found that in situations where both the natural soil and the embankment soil have low shear strength parameters a wide expansion of side slope on either side of the alignment is needed. To overcome this problem, retaining wall at the toe of slope could be made. The rise of water table at the ground surface or above further complicates the situation. The factor of safety reduces by the rise of the water table above the ground level. To make the slope safe under raised water table condition, the analysis is made with enhanced shear parameters of sub soil. This could be possible by sub soil improvement using ground improvement techniques.

Keywords: Bishop's method, Factor of safety, Slope stability analysis, high level railway embankment, GeoStudio2004.

Introduction
Indian Railways is an Indian state-owned enterprise, owned and operated by the Government of India through the Ministry of Railways. It is one of the world's largest railway networks comprising 115,000 km (71,000 mi) of track over a route of 65,436 km (40,660 mi) and 7,172 stations (http://en.wikipedia.org/wiki/Indian_Railways Date 28/07/14). Such a large rail network passes from different terrain and soil profiles. In hilly terrain or waterlogged area, railway line is normally raised onto an embankment made of earth to avoid a change in level required by the terrain. When a track passes from poor soils, such as the clays or silts of high plasticity and compressibility, a flat slope is needed. In this paper, analysis of a 20m high embankment under following situations is discussed (1) natural soil is highly plastic having poor strength parameters (2) both natural soil and the embankment soil are plastic, having poor strength parameters. In both the cases, the effect of water table on stability of the slope is considered. (3) Further, if there is land restriction in transverse direction of track, particularly in case (2), the probable solution by providing retaining wall and the analysis of stability in this case is presented.

Railway guidelines for design and construction of slope
A few commonly used terms used in railways are mentioned through Fig.1.

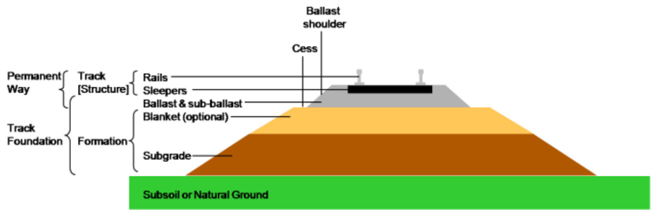

Fig.1. Typical Cross-section representing Formation Components (http://en.wikipedia.org/wiki/Track_bed)

RDSO Guidelines for embankment construction, useful in present discussion and analysis, are briefly mentioned below.

i) The soils unsuitable for embankment construction are Organic clays, organic silts, peat, chalks, dispersive soils, poorly graded gravel and sand with uniformity coefficient less than 2,

ii) Clays and silts of high plasticity (CH and MH) in top 3m of embankment are not suitable.

iii) The poor sub soils are those which have undrained shear strength less than 25 kPa, loose sand strata having N value less than 5, and Ev2 (Elastic Modulus of 2nd plate load test) less than 20MPa.

iv) Removal and replacement of weak soil if undrained shear strength is less than 20 kPa or CBR<3. Removal of unsuitable material and replacement with suitable fill, preferably well compacted coarse-grained/ sandy soil, may be carried out.

v) Change the alignment from poor soil site is a most economical option. If it is not possible, then if natural soil of shallow depth is poor, so replacement is better option rather than improvement of soil.

vi) A few of the techniques to improve the engineering properties of the soft subsoil are as follow - (a) Preloading, (b) Vertical drain, (c) Stone column,(d) Geosynthetics, (e) Dynamic consolidation.

vii) Material for construction: Construction of embankment is to be carried out normally with soil available in nearby area, if required soil properties are not available then Mixed Type of Soils may be used. Different types of fill materials, if used; they should be deposited and thoroughly mixed to get approximately homogeneous character of sub-grade. Soils for construction of embankment consist of cobbles, boulders, rock or waste fragments etc., largest size of material should normally not be greater than 2/3rd of the loose layer thickness. However, it should be ensured that after every one to three meter of such construction, a 30 cm layer of properly compacted soil (other than soils in unsuitable category) be provided.

viii) Formation Width: Currently, the standard width of formation of embankment is 6.85 m for single BG line (Fig.2). However, for new BG track recommended width is 8.5 m for single line and minimum 13.5m for double line tracks.

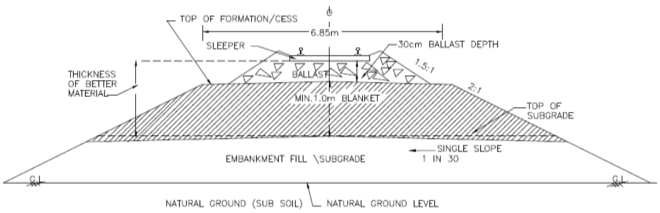

Fig. 2.Typical cross section of Current permanent way

ix) Blanket layer and sand layer: Blanket layer should be coarse, granular, and well graded material with uniformity coefficient Cu > 4 (preferably > 7) and coefficient of curvature Cc should be within 1 and 3 used in top 1m of embankment. Sand layer of 20 to 30cm at every 2 to 3m for soil having permeability coefficient, K value less than or equal to 10-2 cm/Sec are used with slope of 1in 20 in transverse direction of track as shown in Fig. 3.a and b as per GE: G-1, 2003.

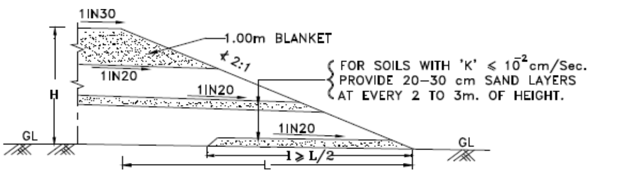

Fig. 3.a. Typical Embankment profile for sandwich construction with cohesive soil for height up to 6m and 6 to 12m.

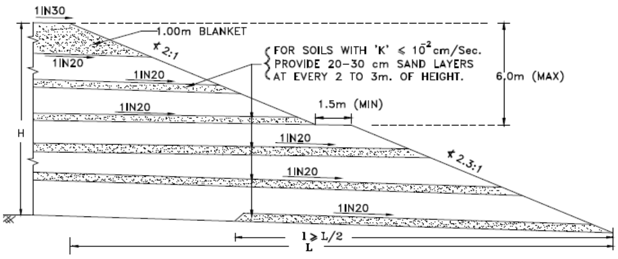

Fig. 3.b. Typical Embankment profile for sandwich construc -tion with cohesive soil for height up to 6m and 6 to 12m.

x) Protection of slope: For banks higher than 4.5 meters, suitable slope stability analysis, reinforcement of slopes, plantation of deep root grass and toe wall construction shall be suitably adopted.

In case of high bank on soft sub-soil, flatter slope with berm/sub-bank should be provided after slope stability analysis. Adequate erosion control measures on slopes of bank and cutting should be ensured by vegetation on slopes with deep-rooted Vetiver grass and geo-jute textile, if necessary.

In areas susceptible to flooding, the sides of an embankment should be protected with a layer of rock fill or stones with an intermediate granular layer up to 1 m above HFL.

At locations, where water table is high and fill-soil is fine-grained, it may be desirable to provide a granular layer of about 30 cm thickness at the base, above sub-soil across the full width of formation. Boulder pitching should be done on embankment slope

xi) Design of Side Slope of Embankment: As per GE: G-1, 2003, for construction on poor subsoil/with poor soil, slope-stability analysis has to be carried out in detail in following cases.

a) When subsoil is soft, compressible and 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.

c) In situations where mixed type of soil has been used.

Slope stability analysis should be carried out to design stable slopes for the embankment. Usually, slopes of 1V :2H of embankment up to height of 6.0 m would be safe for most of the soils. However, stability analysis has to be carried out for above 6.0m height in detail.

The analyses should be carried out with Bishop's simplified method, using shear strength parameters. preferably with Slope 'W' Software (RDSO, GE: G-6).

xii) Pressure on Formation and sub-soil: The maximum pressure on formation at bottom of sub-soil should not generally exceed 0.1MN/m2 or 1 kg/cm2, as per RDSO GE: 0014, 2007 shown in Fig.4. below:

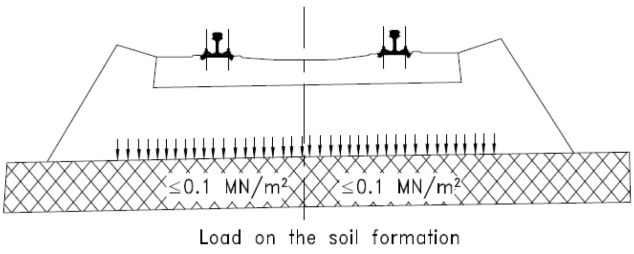

Fig. 4. Pressure on formation

xiii) Factor of safety: As per GE: G1, 2003 factor of safety of 1.4 should normally be adopted against slope failure. 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. Moving train loads need not be considered in the slope stability analysis for embankments. Overstressing zones in soil mass due to live loads would affect the slope stability adversely because 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 up to 4m.

Design of 20m high embankment under constrain situation

CASE (1) natural soil is highly plastic having poor strength parameters and good soil is available for construction

Considering railway guideline that pressure on formation should not exceed 0.1MN/m2 means the soil below ballast and sub ballast (Fig.1) should be strong enough to bear a pressure of 0.1MN/m2 i.e. 100kN/m2. Corresponding to this value of safe pressure, the ultimate pressure on formation material /sub grade soil should be nearly 300kN/m2.

The poor sub soil/ natural soil is considered to have safe bearing pressure of 100kN/m2, a value considered as low and can be assigned to the soils such as the poor black cotton soil.

Considering above, for analysis following values of input parameters are taken.

Formation soil: Assuming good soil is available with Effective cohesion, C=100kPa, Effective ϕ=20°, γ=20kN/m3

Subsoil: Effective cohesion, C=50kPa, Effective ϕ=05°, γ=20kN/m3

Height of bank (H) = 20m

Let us try, slope at top 2m depth is 1:2, next 2m to 8m 1:2.3, next 8m to 14m 1:2.3, next 14m to 20m is 1:2.3 (refer Fig. 3). The berm of 2.5m is provided at every 6m from N.G.L.

From the GeoStudio2004 by Bishop's method, the slip surface and F.O.S is determined. Fig.5, shows the slip surface with minimum F.O.S. =1.517>1.4, hence O.K.

With the above provisions the bottom width i.e. lateral spread of land from either side of c/L of track comes out to be 112.5/2=56.25m i.e. nearly 60m.

Considering effect of water table the F.O.S. is calculated and given in Table I.

Table I: Effect of water Table on slope stability: Case I

Position of Water Table, w.r.t. NGL, m	F.O.S.	Position of Water Table, w.r.t. NGL, m	F.O.S.
-2.0	1.435	6.0	1.327
0.0	1.412	12.0	1.218
2.0	1.385	18.0	1.092

From Table I, it is concluded that the embankment may be considered safe till the water table rises up to 12m above N. G.L. (minimum F.O.S. 1.2 permissible for short duration)

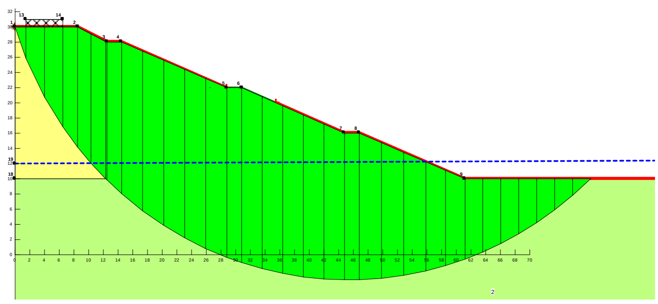

Fig. 5. 20m high slope on poor sub soil

CASE (2) natural soil is highly plastic and embankment soil is also poor

In this case following values of input parameters are taken.

Formation soil: Assuming soil of moderate strength with Effective cohesion, C=67kPa, Effective ϕ=10°, γ=20kN/m3

Subsoil: Poor soil with Effective cohesion, C=50kPa, Effective ϕ=05°, γ=20kN/m3

Height of bank (H) = 20m

With same configuration of embankment as shown in Fig. 5, F.O.S. =1.327<1.4 hence not satisfactory.

Therefore, slope is revised and made as top 2m is 1:2, next 2m to 8m 1:2.3, next 8m to 14m 1:3.1, next 14m to 20m is 1:5. With the above, F.O.S.=1.516>1.4, O.K.

With the above provisions the bottom width i.e. lateral spread of land from either side of c/L of track comes out to be 154.5/2=77.25m i.e. nearly 80m.

Considering effect of water table the F.O.S. is calculated and given in Table II.

Table II: Effect of water Table on slope stability: Case 2

Position of Water Table, w.r.t. NGL, m	F.O.S.	Position of Water Table, w.r.t. NGL, m	F.O.S.
-2.0	1.433	6.0	1.326
0.0	1.409	12.0	1.228
2.0	1.384	18.0	1.12

From Table II, it is concluded that the embankment may be considered safe till the water table rises up to 12m above N. G.L. (minimum F.O.S. 1.2 permissible for short duration). However, if chances of water table rise above this level is expected, the subsoil improvement may be considered to bring the F.O.S. to acceptable value.

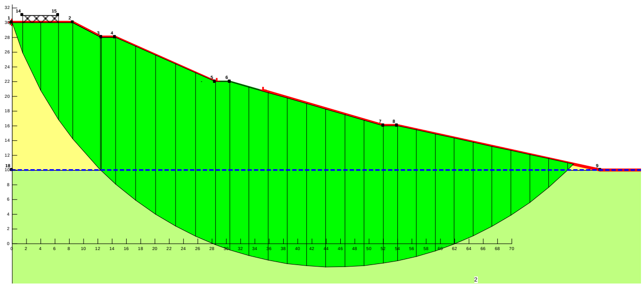

Fig. 6. 20m high slope on poor sub soil and embankment soil

CASE (3) Land restriction in transverse direction with poor sub soil and moderate embankment soil situation

With the land restriction along with the poor soil availability at site, it is attempted to overcome this constraint. Considering that land is available only up to 55m from c/L on either side of alignment i.e. comparable to case 1, the analysis is made with inserting a retaining wall at the toe of the embankment, 1.5m high at the boundary of the land with the provisions of the slope as were made in case 2 i.e. top 2m is 1:2, next 2m to 8m 1:2.3, next 8m to 14m 1:3.1, next 14m to retaing wall is 1:5.

Adopting following values of input parameters.

Formation soil: Assuming C-ϕ soil with Effective cohesion, C=67kPa, Effective ϕ=10°, γ=20kN/m3 as in Case 2.

Subsoil: Effective cohesion, C=50kPa, Effective ϕ=07°, γ=20kN/m3 (improve the soil by any ground improvement technique such as mixing of coarse soil to increase ϕ by 05° to 07°)

Height of bank (H) = 20m

Height of Retaining wall above N.G.L = 1.5m

With the above, F.O.S.=1.414>1.4, but the failure takes place from the base of retaining wall (Fig. 7, top sketch). Therefore, slope is revised and made as top 2m with 1:2.62. With the above, F.O.S.=1.474>1.4, and the failure plane just at the top of retaining wall, hence acceptable.

Considering effect of water table, the F.O.S. is calculated and given in Table III.'

Table III: Effect of water table on FOS in Case 3

Position of Water Table, w.r.t. NGL, m	F.O.S.	Position of Water Table, w.r.t. NGL, m	F.O.S.
-2.0	1.357	6.0	1.213
0.0	1.331	12.0	1.101
2.0	1.281	18.0	0.978

From Table III, it is concluded that the embankment may be considered safe till the water table rises up to 6m above N. G.L. In order to improve F.O.S., the properties of sub soil and embankment soil needs to be improved. By changing shear parameters of formation soil and the sub soil it is noted that slight change in subsoil properties has relatively large influence on F.O.S. than that of the formations soil. Hence attempts should be made to modify it so that it behaves as hard/ medium dense material. If sub soil is soft clay, the technique of stone column can also be used.

Conclusions

The analysis of a high level railway embankment under limitations of in-situ poor soil, availability of good soil for construction and land in transverse direction of the track alignment has been discussed. A 20m high embankment design is made for three different situations. If good earth is available then slopes with 1V:2.3H can suffice, however, in moderate embankment material case, flat slope up to 1V: 5H in some portion may be required. This will necessitate more land for lateral spread of the embankment. To construct the embankment under constraint land situation, two modifications are suggested

i) sub soil improvement and

ii) provision of retaining wall. In case 3 discussed in the paper the above has been tried and found successful with a few trials of slope change in comparison to unrestricted land case 2.

The effect of rise of the water table on FOS was studied and it is concluded that the properties of subsoil has marked influence on FOS than that of the formation soils. Hence, efforts should be made to either replace the poor soil or adopt ground improvement techniques.

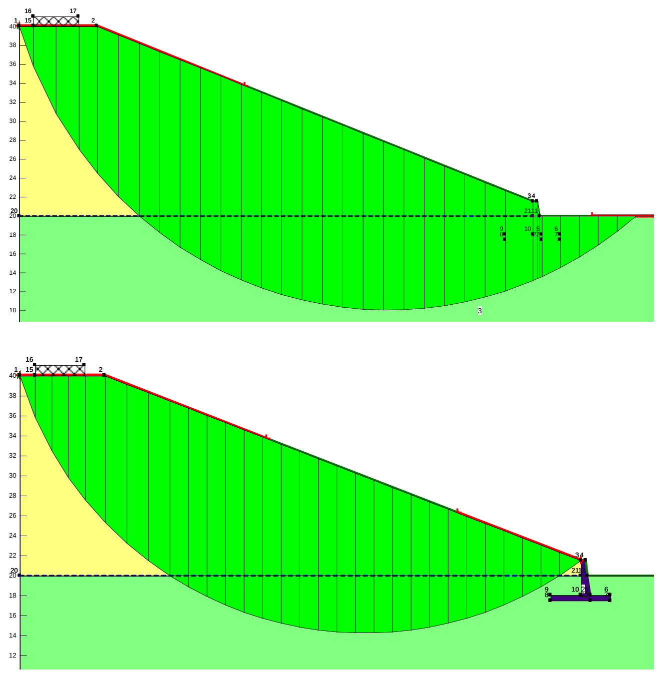

Fig. 7. 20m high slope with retaining wall (failure along R.Wall base, FOS=1.414 and just at the top of R. Wall FOS=1.474)

References

[1] A. W. Bishop, “The Use of the Slip Circle in the Stability Analysis of Slopes”, Geotechnique, Vol. 5, No. 1, PP. 7-17, 1955.

[2] A.W. Bishop and N. Morgeustern, “ Stability Coefficients for Earth Slopes”, Geotechnique Vol. X, Dec. No. 4 pp 129 – 150, 1960.

[3] R. F. Craig, “Soil Mechanics”, Padstow Ltd., Cornwall, Great Britain, 1990.

[4] RDSO, “Civil Engineering Report no: 157 “ Compaction Characteristics of Black Cotton Soils” 1977

[5] RDSO Guideline No. GE: G-1, – “ Guidelines for Earthwork in Railway Project” 2003

[6] RDSO Specifications GE: 0014, – “Specifications for Heavy Axle Load” 2009

[7] RDSO Guidelines GE: G-5, - "Guideline on Soft soil : Stage construction method"2005

[8] RDSO Consultancy Report No. RDSO/2011/GE-CR0149 on Rehabilitation of Unstable Formation, Lumbding Division, NF Rly.2011

[9] RDSO Consultancy Report No. RDSO/2009/GE-CR135 on Rehabilitation of Unstable Formation, Sonpur Division, EC Rly. 2009

[10] RDSO Consultancy Report No. GE-CR-0157 on Rehabilitation of Unstable Formation, Malda Division, E Rly.