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GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

COMPREHENSIVE GUIDELINES AND SPECIFICATIONS FOR RAILWAY FORMATION

Specification No. RDSO/2020/GE: IRS-0004

September - 2020

Geo-technical Engineering Directorate,
Research Designs and Standards Organisation
Manak Nagar, Lucknow – 226011

FOREWORD

The Railway Track System is an important part of the transportation infra-structure of the country as the Railway plays an important role in the economic growth of the country. Indian Railways has planned to carry higher axle loads as well as higher speeds for increasing through put.

Indian Railway has already decided in 2009 to construct formations for 25T axle load. Further, formation in Dedicated Freight Corridors is being constructed to cater higher axle load of 32.5T. Feeder routes to DFCs are also being strengthened for 25T axle load.

RDSO has been involved with research and standardization of track structure including formation and issued various guidelines on earthwork for railway projects and formation design for heavy axle load i.e., GE:G-1 in July 2003, GE:G-14 in Nov 2009 and other guidelines from time to time covering various geotechnical aspects of track formations. However due to variations in practice in the field over Indian Railways and many changes taken place over a period of time, there is need for comprehensive unified instructions for construction of Railway formation for present and future needs of the traffic. With this view, Railway Board directed RDSO vide letter dated 01.03.2018 & 28.01.2019 to prepare Comprehensive Guidelines covering newly developed aspects like Geo-synthetics, Ground improvement, quality assurance tests, provisions to assess suitability of existing formation for running of 25T axle load and passenger load at 160 kmph of construction/maintenance practices. These Comprehensive Guidelines also cover the latest parameters adopted as per UIC-719 for construction of new formation to meet the requirements of 25 T loading at 100 kmph for goods traffic and 160 kmph speed for passenger traffic.

I am happy to see that after tremendous efforts of Geotechnical Engineering Directorate of RDSO, this "**Comprehensive Guidelines and Specifications for Railway Formation**" could be framed and Railway Board has approved this for implementation on Indian Railways. I am sure that implementation of these guidelines and specifications on Zonal Railways will result in stable and better quality formations fit for running of higher axle load with higher speed viz. 25t & 32.5T axle load and passenger train at 160 kmph. It is particularly appreciable to see the right emphasis on quality control aspects, use of new materials for Railway formation, new field tests to help accelerated construction of formation, check lists and formats through which quality of work can be monitored by Railway field engineers at different levels and will enable engineers to achieve quality of earthwork.

I am sure this "**Comprehensive Guidelines and Specifications for Railway Formation**" will be found very much useful by all sections of Civil Engineers on Indian Railways. Your feedback may be sent directly to PED/ED/GE/RDSO and PED/CE(P)/Railway Board who will be glad to take care of your doubts and suggestions.

(Sudhir Agarwal)
Spl. Director General (Engg.)
RDSO

Lucknow,
September, 2020

PREAMBLE

The existing formation for most of the routes of Indian Railways was constructed by conventional methods and meant to carry lighter axle load with less number of trains and lower speed, as compared to present scenario. Over the years, increase in axle load, speeds and traffic have placed a greater demand on the formation. Unlike replacement of track components and ballast, the rehabilitation /improvement of formation is costly, time consuming and causes traffic disruption. As a result, lot of stretches are continuing under severe speed restrictions over the years.

With an aim to construct the formation for future needs, it was decided in 2009, that the formation on Indian Railways will be constructed for 25T axle load.

Guidelines for earth work in Railway Projects No.GE: G-1, July 2003 and Guidelines & Specifications for design of formation for Heavy Axle Load GE: G-14, November 2009, cater for construction of formation along with other Guidelines i.e. erosion control, widening of formation in gauge conversion etc. Guidelines GE: G-1 were issued for 22.5T axle load mainly, whereas Guidelines GE: G-14 caters for the specification for top layers of the formation for 25T, 30T and 32.5T axle load. There are over-lapping provisions in these two Guidelines and 30T axle load is not envisaged for the future, as 32.5T axle load trains are planned to be run on DFC routes. Thus there was a need for comprehensive unified instructions for construction of Railway Formation for the present and future needs of the traffic.

In view of above, Railway Board vide letter No.2011/CE-II/Form/Spec. dated 01.03.2018 instructed to prepare comprehensive guidelines by merging various existing guidelines regarding earthwork issued from time to time by RDSO and updating with latest technical developments in the related areas with following terms of reference:

i. To prepare comprehensive Specifications for construction of Railway Formation covering all aspects of execution of earthwork in Construction and Open Line. Various guidelines related to earthwork issued by RDSO should be incorporated as appendices to the specifications.

ii. The present Guidelines i.e. GE:G-14 contains Guidelines for Construction of Formation for 30T Axle Load in addition to 25T Axle Load and 32.5T Axle Load. The new specifications should contain Provisions for Construction of Formation for 25T and 32.5T Axle Load only as further Standards/Operation are not being contemplated for 30T Axle Load on projects.

iii. The specification should contain provisions for widening of Formation such as in Doubling and Gauge Conversion projects.

iv. The specifications should contain methodology for repair of cess, widening of cess/formation in open line maintenance.

v. The specifications should cover guidelines for formation treatment for existing formation.

vi. The specifications should contain fitness of type of formation w.r.t. speed.

vii. The details of modern equipments required for construction and testing of formation in large projects should be incorporated as appendix.

viii. The testing methodology to adjudge suitability of soil for formation and quality of construction should be incorporated in the specifications.

In addition, there is a need to judge the suitability of existing formation for running of 25T axle load as well as increasing speed of Mail/Express trains to 160 kmph.

Further, as per the instructions of Railway Board vide letter dated 28.01.2019, preparation of this guidelines & specifications was divided into two phases:

First Phase: Specification of Geotextile and Geo-composite drain and Rationalization of Formation Layer thickness

Second Phase: Specification of Geogrid and All the balance items of the comprehensive specification for construction, repairs and rehabilitation of formation.

Specifications for Geotextile, Geogrid, Geocomposite Drain and document on Rationalistion of formation layer thickness have already been issued by RDSO and also incorporated in this Document.

This document apart from covering various aspects for execution of earthwork in Indian Railway Formation, also includes other relevant features such as slope stability analysis, application of Geo-synthetics in formation, ground improvement techniques, quality assurance tests viz. CBR values of subgrade soil, Elastic modulus of compacted layer (Ev_2) etc. It also covers provisions to judge the suitability of existing formation for running of 25T axle load as well as increasing speed of mail/express trains speed upto 160 kmph.

This comprehensive Guidelines & Specifications supersedes all earlier guidelines/instructions for Earthwork issued by RDSO i.e. Guidelines for Earthwork in Railway Project GE: G-1, July 2003, Guidelines and Specifications for Design of Formation for Heavy Axle Load GE: G-0014 Nov 2009, RDSO letter no. RS/G/108/Heavy Axle Load dated 26.10.16 and Rationalisation of Formation Layer Thickness on Indian Railway Track Specification No. RDSO/2018/GE: IRS-0004(D) Part-IV dated: 25.07.2019.

Vide letter no. 2011/CE-II/Form/Spec dated 14.09.2020, Railway Board has approved this document with minor modifications which have been incorporated in this document.

Following officers of RDSO (including GE staff as mentioned in the Acknowledgement) have contributed significantly in preparation of the Guidelines:

1. Shri Ashok Kumar, Executive Director/Geotechnical Engineering/RDSO
2. Shri Sameer Singh, Joint Director/Geotechnical Engineering /RDSO
3. Shri S. K. Awasthi, Jt. Director/ Geotechnical Engineering /RDSO
4. Shri S. K. Ojha, Asstt. Research Engineer/ Geotechnical Engineering /RDSO

Valuable suggestions were also received from Shri R. K. Shekhawat, Sr. Professor/IRICEN, Pune on various issues covered in this guideline and incorporating these has led to further improvement of the guidelines.

17/09/2020

Lucknow
September, 2020

(Ashok Kumar)
Exe.Director/Geo-tech.Engg.

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Terminology

Commonly used terms in context of the subject and in this document, with their specific meanings are mentioned as under:

1.0 **Formation**: In a general way, collectively refers to the layers comprising blanket, prepared subgrade/Subgrade.

2.0 **Formation Top:** Boundary (interface) between ballast and top of blanket or prepared subgrade/Subgrade (where blanket layer is not provided).

3.0 **Track Foundation:** Constitutes ballast, blanket, Prepared subgrade/Subgrade, which is placed / exist below track structure to transmit load to subsoil.

4.0 **Cess:** Portion at top of formation level, extending from toe of ballast to edge of formation.

5.0 **Ballast:** Crushed stones with desired specifications placed directly below the sleepers.

6.0 **Blanket:** Blanket is a layer of coarse, granular material of designed thickness & specification provided over full width of formation between subgrade and ballast.

7.0 **Prepared Subgrade:** In case of two layer system, it is provided over the subgrade and below the blanket layer with a view to economise the thickness of blanket layer.

8.0 **Sub-grade:** It is the upper part of Railway Embankment constructed by borrowed soil of suitable quality upto bottom of blanket/prepared subgrade. It is divided into top layer and lower layer (fill).

9.0 **Subsoil:** The existing soil below natural ground level.

10.0 **Cohesive Subgrade:** Subgrade constructed with soils having cohesive behaviour i.e., shear strength is predominantly derived from cohesion of the soil is termed as cohesive subgrade. Normally, soils having particles finer than 75 micron exceeding 12% exhibit cohesive behaviour.

11.0 **Cohesionless Subgrade**: Subgrade constructed with cohesion-less, coarse-grained soils i.e., shear strength is predominantly derived from internal friction of the soil are termed as cohesion-less subgrade. Normally, soils having particles finer than 75 micron less than 5% exhibit cohesion-less behaviour.

12.0 **Dispersive Soil:** Dispersive soils are those, which normally deflocculate when exposed to water of low salt content. Generally, dispersive soils are clays which are highly erosive and have high shrink and swell potential. These soils can be identified by Crumb, Double Hydrometer, Pin Hole and Chemical Tests.

13.0 **Unstable Formation:** It is yielding formation with continued settlement including slope failure, which requires excessive maintenance efforts.

14.0 **Shear Strength:** Shear strength of soil is its ability to resist shearing at a shearing surface (plane) under direct stress (vertical pressure).

15.0 **Soil Pressure Units,** equivalence: 1 Pascal (Pa) = 1 N/m^2 and 1 Mega Pascal (MPa) = 1 N/mm^2

100 kPa = 10 t/m^2 = 1 Kg/cm^2 = 1/10 N/mm^2 = 1/10 MPa

16.0 Deformation Modulus (Ev_2) : It is modulus of elasticity (also deformation) in the second cycle of loading in the cyclic plate load test. It is determined by cyclic Plate Load Test on top of compacted blanket layer/prepared subgrade/Embankment fill in accordance with DIN:18134-2012 (Ref :Appendix-H).

17.0 Geosynthetic: A planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a man-made project, structure, or system.

18.0 Geogrid: Geogrid is a planar, polymeric structure consisting of a regular open network of integrally connected tensile elements, which may be linked by extrusion, bonding or interlacing. They have open grid like configuration with large apertures between individual ribs.

19.0 Geotextile: Geotextiles are planar and permeable members which are used in contact with soil/rock and/or any other geotechnical material for civil engineering applications. They are basically textiles manufactured from synthetic fibers.

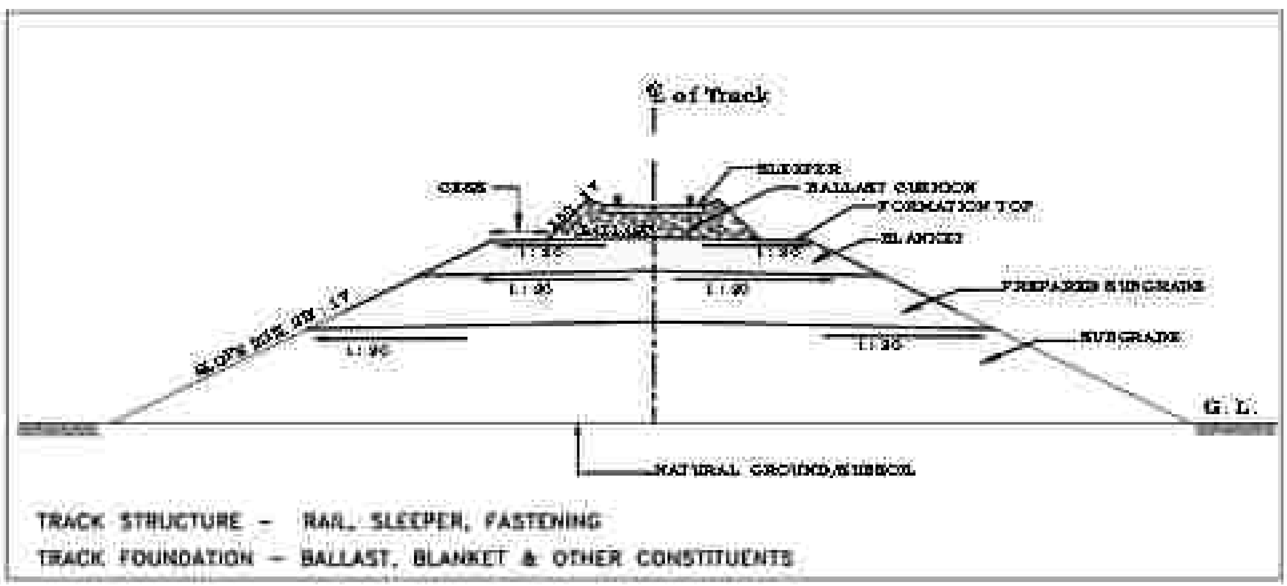
20.0 Geonet: A geosynthetic consisting of integrally connected parallel sets of ribs overlying similar sets at various angles for planar drainage of liquids or gases.

21.0 Geocomposite Drain: Geocomposite drains, consisting of a geonet bonded with non-woven geotextile layer(s) on one or both sides are used for drainage.

22.0 Pre-Fabricated Vertical Drain (PVD): A geocomposite consisting of geotextile cover and drainage core installed vertically into soil to provide drainage for accelerating consolidation of soils. Also known as band or wick drain.

23.0 Formation components:

Formation comprises of granular layer (blanket) over prepared subgrade and subgrade. General profile of formation given below.



Typical cross-section representing formation component

CHAPTER-1

SOIL EXPLORATION & SURVEY

Objectives of constructing a stable formation can only be achieved if soil exploration, as envisaged in **"Indian Railways Code For The Engineering Department"** (Engineering Code) Paras 409, 425 and 528, is undertaken in right earnest and precautions are taken to design embankment & cutting against likely causes which could render it troublesome during service. Adequate provision for soil surveys & explorations at different stages, as per requirements of the terrain, should be made in the project estimates to cover the cost for this activity.

1.1 Objectives of Soil Exploration:

Main objectives of soil survey and exploration work are:

a) To determine soil type with a view to identify their suitability for earthwork and to design the foundation for other structures.
b) To avoid known troublesome spots, unstable hill sides, swampy areas, soft rock areas, peat lands, etc.
c) To determine method of handling and compaction of subgrade.
d) To identify suitable alignment for Embankment and cutting from stability, safety, economy in construction and maintenance considerations.
e) To identify suitable borrow areas for desired quality and quantity of subgrade and blanket material.
f) To determine depth of various strata of sub-soil and bedrock level.
g) To determine ground water table position and its seasonal variation and general hydrology of the area such as flood plains, river streams, etc.
h) To determine behaviour of existing track or road structure nature and causes of geo-technical problems in them, if any.

1.2 Soil survey and exploration/investigation for construction projects should be carried out in following three stages:

1.2.1 During Reconnaissance Survey

a) The main objective of soil survey during Reconnaissance is to collect maximum surface and sub-surface information without drilling exploratory boring/ test pits to avoid obviously weak locations such as unstable hillsides, talus formation/scree (accumulation of broken rock debris, as at the base of a cliff or other high place), swampy areas, peat grounds, very soft rocks or highly weathered rocks, etc.
b) At the reconnaissance stage, available data from geological and topological maps and other soil surveys done in the past, existing soil profiles in nearby cuts, quarries are scrutinized. Water table is recorded from local observation and inquiry. The involved soils are classified by visual examination and if necessary, few field/ laboratory tests are conducted for this purpose.

c) Survey reports available from other Departments/Agencies such as Geological Survey of India, Ministry of Road Transport and Highways, Central Board of Irrigation and Power, CPWD, State Irrigation, PWD, etc. can be acquired to obtain information on the accessibility, geology and soils, subsurface information, etc.

d) Areas of prospective borrow soil and blanket material should also be surveyed to give idea of quality and quantity of materials to be used for construction of Railway Embankment.

e) Above collection of data should be incorporated in the Feasibility Report required to be submitted as per "Indian Railways Code For The Engineering Department" (Engineering Code) Paras 555 and 576 in chapter of Project Engineering under heading of formation (para 528 of Engineering Code).

f) The data and information collected during survey should be presented in suitable format such as graphs, bar charts or in tabular or statement form.

1.2.2 During Preliminary Survey

a) Primary objective of preliminary exploration is to obtain sufficient subsurface data to permit selection of the type, location and principal dimensions of all major structures and estimation of earthwork and design of formation. The scope of preliminary survey is restricted to determination of depths, thickness and composition of each soil stratum, location of rock and ground water and also to obtain appropriate information regarding strength and compressibility characteristics of various soil strata.

b) As stated in Para 409 of "Indian Railways Code For The Engineering Department", the field work in Preliminary Survey includes a compass traverse along one or more routes with transverse and longitudinal levels to prepare an L- section of routes proposed. This fieldwork shall also cover a soil survey by sampling at suitable intervals in order to obtain a fair idea of the soil classification and characteristics of soils on proposed routes. Testing of disturbed soil samples is usually adequate; however core drilling will be necessary in rocks. This will help in determining the thickness of the blanket layer on different sections and total quantity of blanket material to be required.

c) Exploratory boring with hand/ auger samplers and soil sampling should be undertaken along the alignment and soil samples also should be collected from borrow pit area, at an interval of 500 meter or at a closer interval, wherever change of soil strata occurs. The boring should be done upto 1.5 to 2.0 m depth below existing ground level. In case of Embankments more than 4m height and embankments with problematic substrata, the boring should be taken down to a depth equal to twice the height of Embankment. Samples should be collected from each stratum found in each boring.

d) Bore logs are prepared based on laboratory test results of disturbed samples obtained by auguring or split spoon sampler. Particle size distribution, soil classification and index properties of the soils are determined from laboratory tests.

e) In case of soft clays and sensitive clays, in-situ vane shear tests should be conducted to determine its shear strength and depth of underlying compressible clay layer. Undisturbed samples should also be collected to know actual moisture content, natural dry density and shear and consolidation parameters of the soil.

f) Geo-physical investigations for bedrock profile, sub-surface strata and soil properties are required to be carried out for foundation of major structures such as bridges. Methods such as Seismic Refraction Method (IS: 1892-1979) (Reaffirmed 2016), Standard Penetration Test (IS: 2131- 1981) (Reaffirmed 2016), Dynamic Cone Penetration Test (IS: 4968-1976) (Reaffirmed 2016) etc., will be required to be carried out to ascertain constituents of substrata and their properties and design foundation of such structures. In alluvial strata, deep auger boring upto 6m may be deployed for subsurface exploration and sampling.

g) The data and information collected during survey should be presented in suitable format such as graphs, bar charts or in tabular or statement form.

1.2.3 During Final Location Survey

a) During Final Location survey, detailed investigations are done at locations where important structures viz. high embankment, deep cuttings, major bridges etc. are to be located and where weak sub-soil, swampy ground, marshy land exist. Undisturbed soil samples with the help of deep auger sampler or Split spoon samplers are collected for conducting detailed tests viz. shear strength tests & consolidation test to design safe and economical structure and predict settlements. However, if some tests during preliminary survey are deficient, the same should also be covered.

b) Assistance may be taken from Geologists, in case of rocky strata, known unstable hill slopes, earthquake prone area and geological fault.

c) Detailed subsoil exploration is necessary to check stability of structures against failure and to predict anticipated settlement. Bores are made along alignment normally at 200 m to 300m apart in case of uniform type of soil and closely spaced in critical zones. Soil samples within the boreholes are obtained at every change of stratum and interval not exceeding 1.5 m. In case of sandy and gravely soils, Standard Penetration Test may be adequate, as taking out samples in these types of strata is difficult.

d) Besides classification tests, soil samples should be tested for shear strength and consolidation properties. In case of very soft clays, vane shear test should be conducted for each boring site. Free swell index test should also be carried out in case of expansive soil and organic contents of soil should be determined if soil is suspected to be having large organic contents.

e) Availability of naturally occurring source of blanket material conforming to the laid down specification shall be explored during the survey. Sources of blanket material of specified quality and its availability around the project site needs to be located to assess its realistic costs for inclusion in project estimates. The source identification should cover various logistics involved in its utilization.

f) The data and information collected during survey should be presented in suitable format such as graphs, bar charts or in tabular or statement form.

1.2.4 The availability of borrow soil sources shall be explored during the survey. As formation design will primarily depend upon the type of the soil being used in construction, it is essential that soil classification and assessment of bearing capacity is done during soil exploration.

The results of soil exploration shall be reviewed and finally approved at the level of the CAO/Construction as this will be the basis of further design. In case of PSUs the powers of PCE/CAO shall be exercised at appropriate level of authority as nominated by CMD/MD of the PSU.

1.3 Soil Survey & Exploration for Gauge Conversion, Doubling & Rehabilitation Work

For these projects, additional information required will be as follows:

1.3.1 A statement listing out problematic stretches on existing track should be prepared/obtained after scrutiny of gang charts for identifying locations requiring frequent attention, having unsatisfactory TRC results, past history of stretches having failure like slips, subsidence, pre-mature ballast recoupment, ballast penetration etc.

1.3.2 Failure of existing formation is accompanied by signs of distress/instability. The identified and suspected locations shall be subjected to detailed examination as per symptoms of failures. Recommended scheme of soil exploration and testing is given in table 1.1 below:

Table: 1.1 Recommended Scheme for soil exploration and data collection & testing

S. No.	Symptoms	Type of failure	Recommended Scheme for soil exploration and data collection	Soil testing
1	2	3	4	5
1	i) Embankment settlement - loss of longitudinal profile ii) Heaving of soil beyond toe iii) Leaning of telegraph posts, trees, etc. on the embankment and at the toe	Base failure	i) Recording of embankment profiles and ballast profile in x-section ii) Undisturbed sampling iii) Field tests- Vane shear DCP/SPT	i) Classification tests ii) Consolidation tests iii) Natural moisture content and Natural dry density tests. iv) Peak and residual shear strength tests
2	i) Flattening of Embankment/ slope ii) Bulging of slope	Slope failure	i) Recording of embankment profile and x-section of ballast profile.	i) Classification and swell tests ii) Peak and Residual Shear

	surface. iii) Longitudinal cracks on cess/slopes iv) Leaning of OHE masts		ii) Survey and recording of surface cracks iii) Undisturbed sampling	strength tests iii) Natural moisture content and Natural dry density tests.
3.	i) Soil heaving on cess and on slopes ii) Ballast penetration exceeding 30 cm below formation iii) Excessive – cross level variations	Subgrade failure (by shear)	i) Recording of embankment profile and ballast penetration profiles inside subgrade ii) Collection of data a. Track geometry variations b. Excessive maintenance inputs c. Quantum of ballast recoupment d. Speed restrictions imposed iii) Undisturbed and Disturbed soil samples below the ballast penetration	i) Classification and swell tests ii) Shear strength tests iii) Natural Moisture content and Natural Dry Density tests iv) CBR test
4	i) Fouling of ballast with subgrade fines ii) Ballast penetration below formation – 30 cm or less iii) Impaired drainage iv) Excessive cross level variations in Monsoon v) Hard running during summer	Subgrade failure (by mud pumping)	i) Recording of embankment profile and ballast penetration inside subgrade ii) Collection of data – a. Track geometry variations b. Excessive maintenance inputs c. Speed restrictions imposed iii) Undisturbed & Disturbed soil samples from below the ballast penetration	i) Classification and swell tests ii) Shear tests iii) Natural Moisture Content and Natural Dry Density tests iv) CBR Test
5	i) Reduced cess & denuded slopes- loss of soil/absence of vegetation. ii) Formation of	Erosion failure of Slopes leading to ballast penetration	i) Recording of embankment profile ii) Undisturbed soil samples	i) Classification tests ii) Field crumb test for soil dispersivity iii) Pinhole test

	rills/ gullies and pot holes on slopes & on cess	and slope Failure		iv) Double hydrometer tests v) Natural Moisture Content and Natural Dry Density tests
6	i) Cut slope failures ii) Choked side drains iii) Seepage of water iv) Saturated subgrade	Failure of Cuttings	i) Recording of profile side slope, longitudinal drain sections, HFL and Ground water table ii) Cross-section and Ballast penetration profile iii) Undisturbed soil sample	i) Classification of soils ii) Natural Moisture Content and Natural Dry Density tests iii) Lab. Shear tests

Note: a) In practice generally more than one type of failure is encountered.
b) Recommended scheme and soil tests are for general guidance.

1.3.3 Frequency of soil sampling shall depend on the extent and type of problems in the troublesome stretches. However, samples should be taken at 500m intervals for determination of natural dry density and soil type only where no formation problem is reported.

1.3.4 In order to ensure proper bonding of earthwork and soil compatibility behaviour of old and new earthwork, samples of soils from mid-slope of existing bank at about 1 m depth and 500m length or closer intervals should be collected and tested for particle size, natural moisture content, natural dry density and consistency limits.

1.3.5 In case of doubling, where existing formation is troublesome as described in Para 1.3.2 above, soil investigation shall be planned for remedial measures to be undertaken before execution of doubling work and additional possibility of construction of new line away from centre line of the existing track may also be explored in such cases.

1.4 Soil Classification system as per Indian Standard 1498 is also explained in brief in Appendix: L for reference.

CHAPTER-2

SUITABILITY OF SUBSOIL & GROUND IMPROVEMENT TECHNIQUES

2.1 General

Field tests are required to be conducted on sub-soil strata, i.e. Plate load test for determination of Elastic Modulus in second cycle of loading (Ev_2), Standard Penetration test to determine N-value, and Unconfined Compression Test or Vane Shear Test to determine unconfined compressive strength or undrained cohesion, c_u. If any of these parameters, as specified in following para do not meet with specified requirement then ground improvement needs to be undertaken.

2.2 Suitability of sub-soil

Strengthening of sub soil, including in cutting shall be required when;

(i) E_{v2} value less than 20 MPa, or

(ii) Undrained cohesion (c_u) < 25 kPa, only for soils having particles finer than 75 microns exceeding 12%, or

(iii) N-value < 5,

In such cases Ground Improvement Techniques mentioned below can be adopted. However, these are suggestive in nature and depend on site conditions before implementing these techniques, proper planning and investigation is required.

2.3 Ground Improvement Techniques/ Methods for Soft soil

Soil at a construction site may not always be totally suitable for supporting structures in its natural state. In such a case, the soil needs to be improved to increase its bearing capacity and decrease the expected settlement. These techniques can be adopted to improve the ground strength on which the Embankment/fills is constructed.

2.3.1 Removal and replacement of weak sub-soil

Soil replacement is one of the oldest and simplest methods for Ground improvement. The foundation condition can be improved by replacing poor soil (e.g. organic soils and medium or soft clay) with more competent materials which can improve the bearing capacity of subsoil.

The removal and replacement may be required even in 'cutting' areas where the naturally occurring soils are found to be of low shear strength. Subsurface drainage may have to be introduced in most of such areas. Excavation and replacement can be carried out for soft soil up to the depth of 1.5 to 2 m as per site condition.

2.3.2 Preloading

The preloading technique is a simple and economical method for accelerating consolidation railway fills on soft clays, since; the material can stay in place and need not be relocated. Preloading is especially attractive when fill material is subsequently used on the same project for site preparation.

For low Embankment over soft compressible soil where the poor ground is of limited thickness (short drainage path) or is capable of compressing rapidly under the load of excess preload fill due to presence of sand lenses, preloading may be resorted. Preloading of soft soils is based on the consolidation concepts, whereby pore water is squeezed from the voids until the water content and the volume of the soil are in equilibrium under the loading stresses imposed by the surcharge. This is usually accompanied by gain in shear strength of soil. To a certain extent, the primary consolidation under final loading can be achieved during construction and hence post construction settlement reduces.

The pre-loading technique takes two forms:

i) Overloading
ii) Stage construction

(i) Overloading

In the overloading process, a surcharge (overload) is placed temporarily on the ground and after a pre-determined time lapse, the intended structure can be built with occurrence of little or no additional settlement. The ratio of surcharge load to design load is known as overload coefficient. The charge is normally a uniformly distributed surface load which is placed prior to the construction of the intended structure. A part or the entire surcharge may be removed before the construction commences, depending on the requirements. The magnitude of the surcharge load and its duration of application are determined by the conventional settlement calculations. The settlement which occur under overloading results in an increase in the undrained shear strength of the clay. The principle of overloading method is shown in fig-2.1.

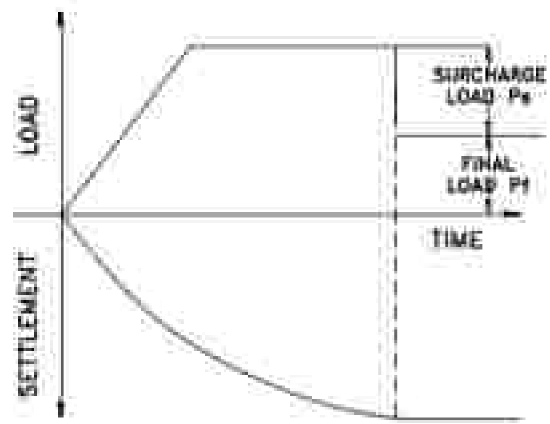


Fig-2.1: Principle of overloading

(ii) Stage Construction (Improvement of Shear Parameters)

This technique enhances the bearing capacity of the sub-soil and provides the site for construction of Embankment up to the design height in the phases/stages, with a designed strength of the soil & calculated waiting period for the next loading after the previous loading.

Stage construction is employed mainly as a means of gradually increasing the shear strength of soft clay which would otherwise be inadequate to carry the intended Embankment load. In stage construction, advantage of increase in shear strength of sub-soil strata due to consolidation by surcharge load of Embankment is taken into account. Work on next stage filling can be permitted only after it is ascertained that the strength gain needed for building the next stage has been reached. The principle of stage construction method is shown in Fig-2.2 below-

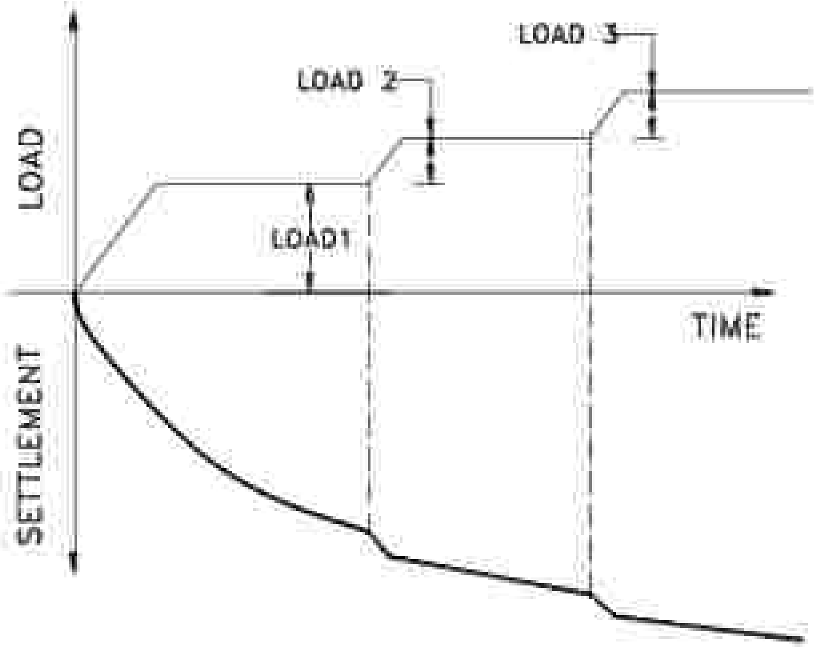


Fig-2.2: stage construction method

Theoretical basis of design using stage construction method, solved practical examples and instrumentation scheme for monitoring the behavior of Embankment on soft soil are covered in "RDSO Guidelines on Soft Soils-Stage Construction Method (Guideline No: GE:G-5)-April 2005".

2.3.3 Ground improvement using Vertical drains

Because of low permeability the consolidation settlement of soft clay takes long time to complete. Wherever in such case if preloading is not sufficient, to shorten the consolidation time vertical drain are installed together with preloading. Vertical drain are artificially created drainage path which are inserted in soft clay in order to accelerate the process of consolidation settlement for the construction of structure.

The Sand drain is one of such method being used for this purpose.

Sand drains (Fig-2.3) are constructed by driving down casing or hollow mandrels in to the soil and then the holes are filled with sand and casing is taken out. When the surcharge is applied on the ground surface the pore water pressure in the soil increases and the drainage in vertical and horizontal direction starts. Process of dissipation of excess pore water pressure created by loading is accelerated and hence the settlement rate. Top of sand drain are connected to granular sand blanket to allow the pore water to flow out.

Now days mostly **PVD** are being used for this purpose as they are easy to install and less time consuming. PVD have been explained in para 2.4 Stabilization & Ground Improvement Methods Using Geosynthetics of this chapter.

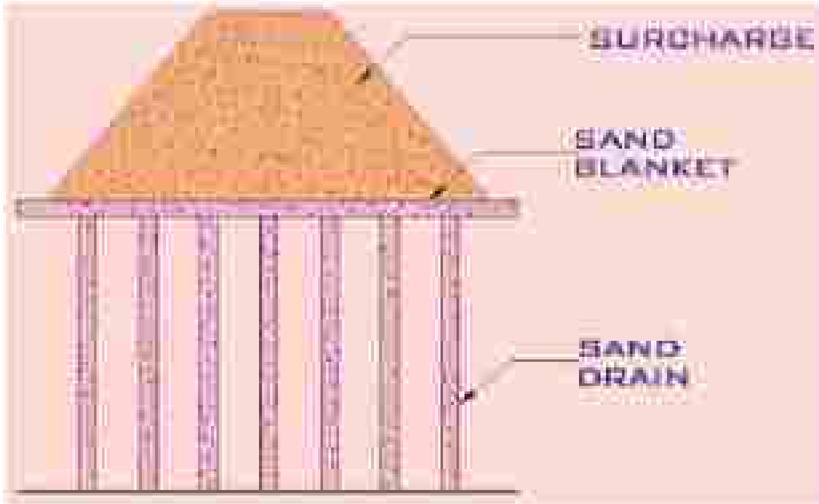


Fig-2.3 Ground improvements using sand drain

2.3.4 Ground improvement using Stone Columns

Stone column method of ground improvement is an efficient method of improving the strength parameter like bearing capacity and it also reduces the consolidation settlement time. Stone column consist of compacted crushed stone or well graded gravel of 75 mm to 2mm size and can be extended through the most compressible strata that contribute the settlement to foundation. The stone should be chemically inert, hard and resistant to breakage.

Stone column will transmit some load to soil by shear stress and end bearing but the predominant load transfer mechanism is due to the lateral bulging into the surrounding soil. Generally, column bulging will be closer to the top of column where the over burden pressure is lowest thus distributes the stresses at the upper portion of the soil profile rather than transferring the stresses in to the deeper layer, thus causing the soil to support it. Along with this rapid consolidation due to accelerated dissipation of pore water pressure into the drainage path formed by stone column. Due to this combined effect construction can be started soon after instillation of stone column completed.

Stone column provides rapid consolidation and immediate increase in shear strength hence there is no waiting period is required (such as in case of ground improvement by PVD/sand drain) and construction of embankment can be begin soon after the installation up to full height with non-compressible fill without further stage construction.

Subsurface conditions for which stone columns are generally not suited include sensitive clays and silts (sensitivity is > 4) which lose strength when vibrated and also where suitable bearing strata for resting the toe of the column are not available under the weak strata.

Stone column can be installed by Non-Displacement method (Fig-2.4) or by Displacement method. In case of displacement installation, the soil is laterally displaced while making the hole due to driving of tube or a casing, while in case of non-displacement method soil is taken out during boring. Compacted crushed coarse aggregate of various sizes fed in to the hole created and on top of stone column a clean medium to coarse sand layer is laid; it should be exposed to atmosphere at its periphery for dissipation of pore water pressure.

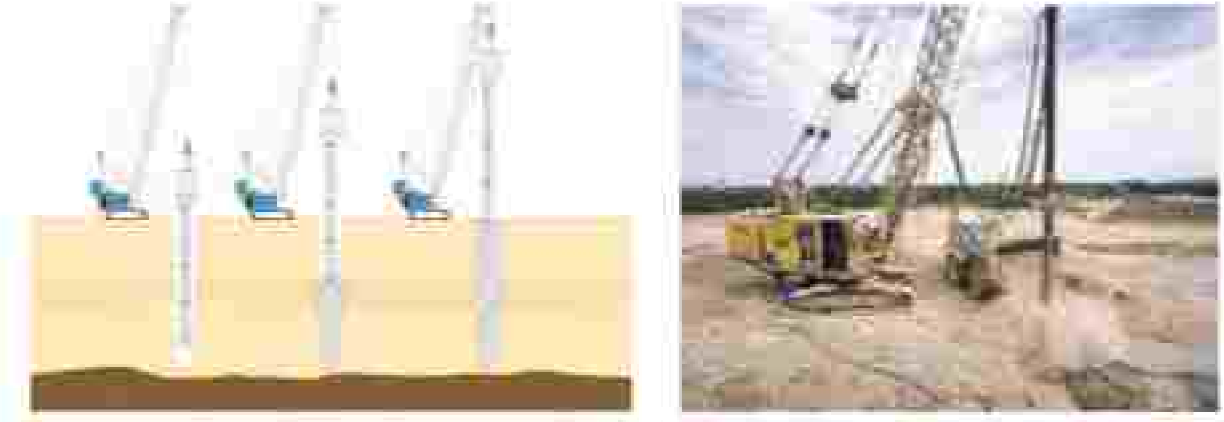


Fig- 2.4: Ground improvement using stone column

2.3.5 Ground Improvement for expansive soils using CNS material

Using a layer of Cohesive Non-Swelling soil (CNS) is one of the effective methods of ground improvement in expansive soils area. CNS layer shall be provided below the bottom layer of Embankment fill in case of Embankment and below subgrade/prepared subgrade level in case of cuttings, of suitably designed thickness and width, compacted to 97% of MDD at optimum moisture content (OMC).The width of treatment should be extended minimum 3.0m beyond the toe line on both sides.
The CNS material possesses the property of cohesion of varying degree and non-expanding type clay minerals such as illite and kaolinite, having low plasticity with liquid limit not exceeding 50 percent.

The properties of CNS material are defined below (Ref- IS 9451: 1994):

Grain Size Distribution
Clay (less than 2 micron) : 15-20 %
Silt (0.06 mm to 0.002 mm) : 30-40 %
Sand (2 mm to 0.06 mm) : 30-40%
Gravel (greater than 2 mm) : 0-10%

Liquid Limit : >30 but less than 50
Plasticity Index : >15 but less than 30
Swelling Pressure : <10kN/m2
Unconfined Compression strength : >10kN/m2

The thickness of CNS materials required for balancing the different swelling pressures are as follows:

Table-1

Swelling Pressure of Soil (KN/m2)	Thickness of CNS Materials (cm) (Min)
50 to 150	75
150 to 300	85
300 to 500	100

In case naturally occurring, soil do not meet the parameters of CNS soil, same can be produced by blending suitable combination of locally available materials. Such artificial CNS should satisfy all the parameters of CNS soil.

2.4 Stabilization & Ground Improvement Methods Using Geo-synthetics

Some of the ground improvement methods (list is not exhaustive), wherein geo-synthetics are used, are as under:

2.4.1 Use of Geo-composite drain for Construction of new embankment over soft subsoil

In case of embankments over weak/fine grained sub-soils (which are mostly soft clays) and having water table at higher level (shallow depth), it is a good practice to provide a "separator-cum-drainage layer" of Geo-composite drain layer, sandwiched between two layers of sand of about 75mm thickness **(Fig-2.5)**, at the ground level to provide adequate drainage path for the water coming from sub-soil (reducing excess pore water pressure in embankment and thereby increasing its' stability) and to prevent fouling of subgrade by the fine grained subsoil. Alternatively, a 1000mm thick sand layer can be provided. Its thickness may be varied depending on the bank height, characteristics of sub-soil and water table. The sand layer to be used in both the cases should be clean medium to coarse sand with minimum permeability of the order of 10^{-5} m/second.

Specification for Geo-composite drains to be used at the base of the Embankment for Railway Formation, for Embankment height upto 8m (Specification No. RDSO/2018/GE: IRS-0004-Part-II) is given in **APPENDIX-C.** These specifications have been issued to Zonal Railway/PSU's initially for trial purpose. On satisfactory performance report from the field, the mandating of its usage will be decided.

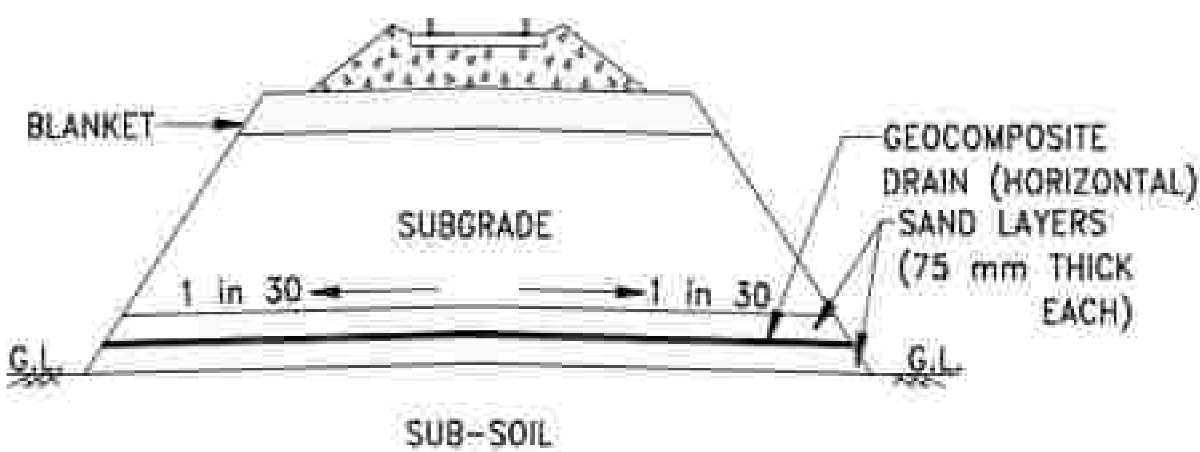


Fig- 2.5: Use of Geo-Composite Drain in bank over soft subsoil

2.4.2 Use of Geocell

Geocell is another form of Geosynthetics used as basal mattress in embankments for ground improvement [Fig-2.6(a)].

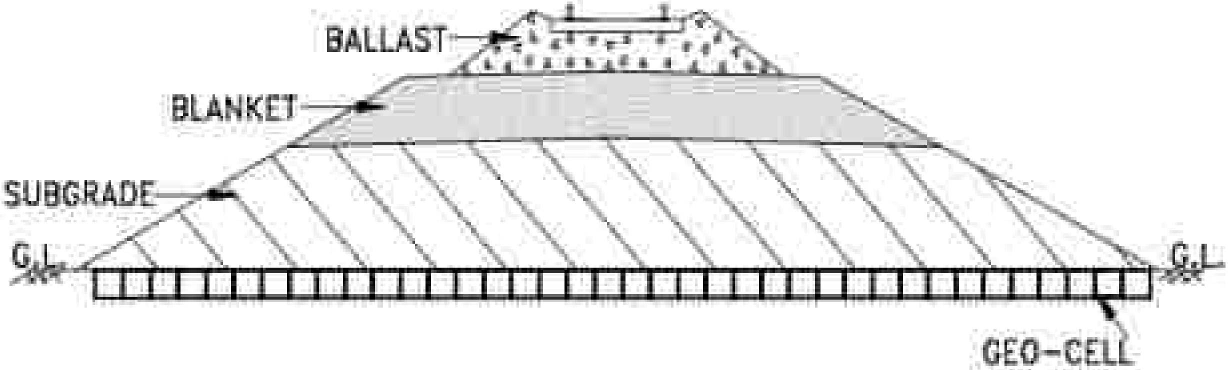


Fig-2.6(a): Application of Geocell for ground improvement

Fig-2.6(b): Geocell and it's applications

Geocell is a three dimensional honeycomb like cellular structure, consisting of a regular open network of synthetic strips, linked by extrusion or adhesion or other methods [Fig-2.6(b)].On site, the Geocell sections are fastened together and placed directly on the subsoil or on a Non-woven Geotextile filter placed on the subgrade surface and propped open in an accordion-like fashion with an external stretcher assembly.

They are then filled with various infill materials, such as soil, sand, aggregate or recycled materials and then compacted using vibratory compactors.

When the soil contained within Geocell is subjected to pressure, it causes lateral stresses on cell perimeter walls. The 3D zone of confinement reduces the lateral movement of soil particles while vertical loading on the contained infill results in high lateral stress and resistance on the cell-soil interface. This increases the shear strength of the confined soil, which creates a stiff mattress/slab to distribute the load over a wider area, reduces punching of soft soil, increases shear resistance and bearing capacity and decreases deformation. Confinement from adjacent cells provides additional resistance against the loaded cell through passive resistance, while lateral expansion of the infill is restricted by high hoop strength. Compaction is maintained by the confinement, resulting in long-term reinforcement.

In Railway Embankment applications, Geocell can improve the load support capacity of soft subsoil. It is often recommended for swampy conditions where the ground water is close to the surface.

2.4.3 Use of Prefabricated vertical drain (PVD):

Prefabricated vertical drains consist of channeled synthetics core wrapped in Non-woven geotextile fabric known as filter (Fig-2.7). Prefabricated Vertical drains are used where preloading alone is not sufficient.

Prefabricated Vertical drains in soft clay accelerate the primary consolidation of clay since they bring about rapid dissipation of excess pore water pressure. Therefore, the structures or Embankments can be put to use earlier than it would be possible otherwise. The accelerated rate of gain in shear strength of clay enables the loads to be applied more rapidly than would otherwise be possible.

The effectiveness of Prefabricated Vertical drains depends mainly on the engineering properties of soils, namely, soil permeability and coefficient of consolidation and their variations in space and time. They are, however, ineffective in organic soils and highly stratified soils.

For installation, PVD is placed into steel mandrel and the mandrel is pushed into the ground to the determined depth with a mast mounted on back hoe. Anchor plate is attached to the wick material to hold it in place as mandrel is removed. Then the PVD is cut off a little above the ground (Fig-2.7). Top of PVD drain are connected to granular sand blanket to allow the pore water to flow out.

Fig-2.7: PVDs and their Installation

2.4.4 Geosynthetic encapsulated Stone column:

When stone columns are installed in soft clays, over a period of time, the gaps in the stones are filled by soft clays which decrease the load carrying capacity and lead to increase in the vertical deformation. Also, soft clay can provide a limited lateral pressure. To overcome this problem, the idea of placing a Geosynthetic (geotextile/geogrid) encasement around the granular material has been developed recently. By this, the granular material that wants to expand sideways is not only restricted by the cohesive soil, but also by the Geosynthetic reinforcement (Fig-2.8). The encapsulation in geosynthetics makes stone column more ductile than normal stone column. The specifications of geogrid and geotextile included in Appendix-C will not be applicable in this case. It can be suitably designed with suitable type of geosynthetics.

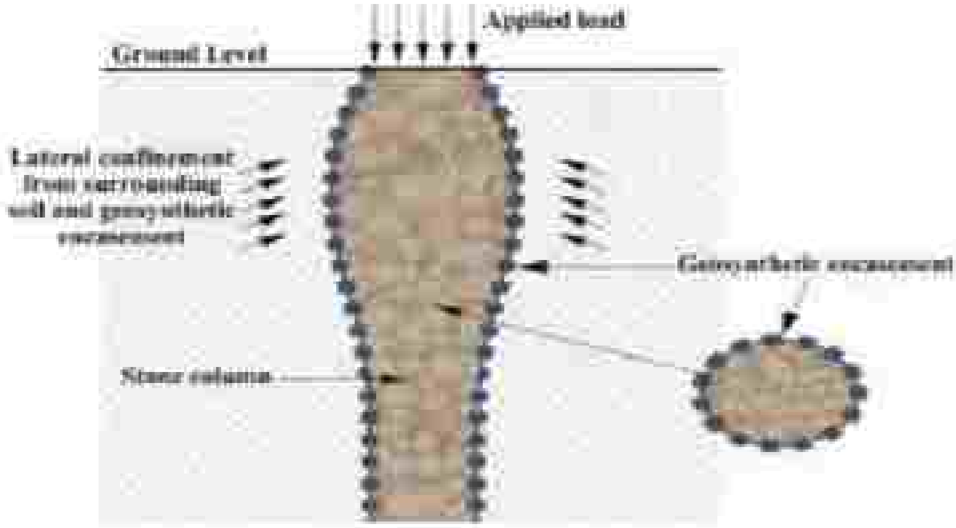


Fig-2.8: Geosynthetics Encapsulated Stone column

Note: All the above methods are suggestive in nature and final methodology to be adopted will depends on site condition and topography, soil type, drainage condition etc.

CHAPTER-3

DESIGN OF FORMATION & SPECIFICATIONS FOR FORMATION LAYERS

3.1 General

Formation comprises of Blanket and, Prepared subgrade/Subgrade. Depending upon techno-economic considerations, it can be Single layer or Two-layer construction as shown in Fig-**3.1 & 3.2** below. For construction of a new line, it is important to ensure that the track bed layers (Blanket/Prepared subgrade/Subgrade) have the appropriate mechanical characteristics and are of adequate thickness. For Indian Railway Formation, it has been stipulated & described in detail in Para 3.10 of this Chapter.

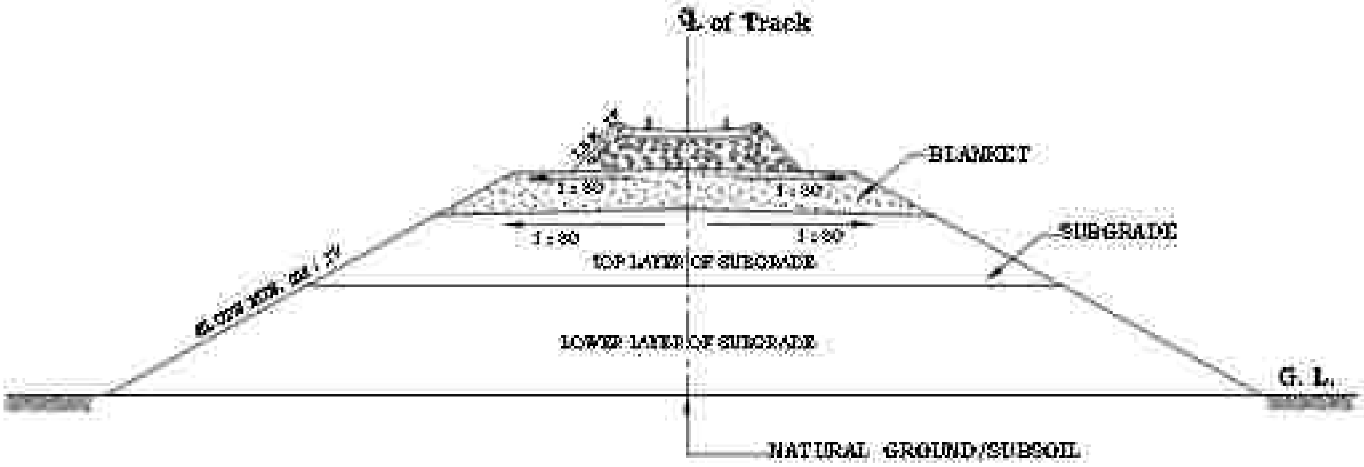


Fig-3.1: Single layer construction

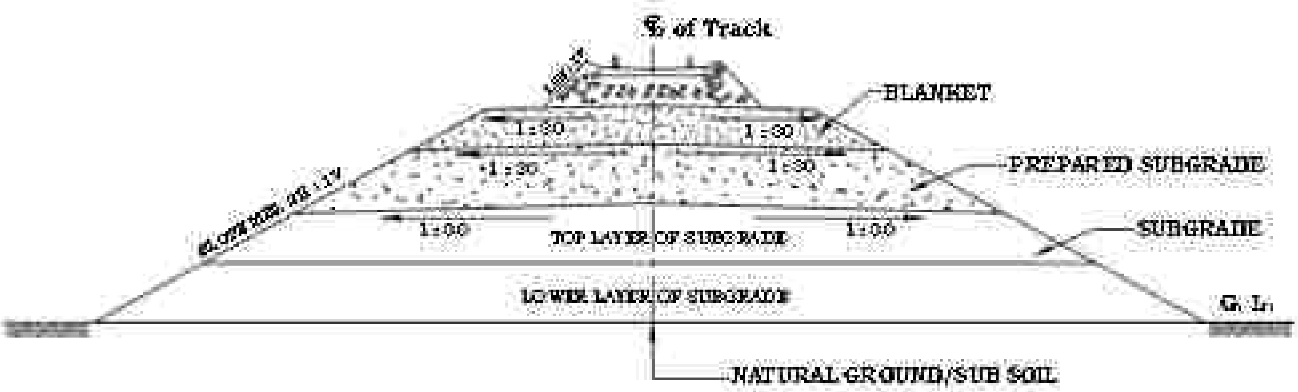


Fig-3.2: Two layer construction

3.2. Pressure on Formation and sub-soil

As good design practice, typical values for the maximum pressure on formation at bottom of ballast should not exceed 0.3MN/m^2 or 3 kg/cm^2, and the pressure on sub-soil should not exceed 0.1MN/m^2 or 1 kg/cm^2 generally.

3.3 Top Width of Formation

a) It should be adequate enough to accommodate tracks laid with concrete sleepers and standard ballast section (minimum 35cm depth) and have minimum cess width of 90cm on either side.

b) Additional Width of formation will have to be provided to cater for increase in extra widening of ballast shoulder and extra clearances required on curves.

It shall be regulated/provided in accordance with extant instructions as per Indian Railway Schedule of Dimensions (IRSOD) & Indian Railway permanent Way manual (IRPWM).

3.4 Cross Slope of Formation

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 appropriate measures as per site conditions.

Further elaboration on drainage is given **in Chapter 6 for Execution of Earthwork.**

3.5 Erosion Control System

The design should provide for a suitable and cost-effective erosion control system considering soil matrix, topography and hydrological conditions. Further elaborations given in **chapter-8 (Erosion control of slopes).**

3.6 Borrow Pits

It will be necessary to keep borrow pits sufficiently away from the toe of the embankments as far as possible at the extreme of Railway land but normally not less than 3m plus height of the embankment to prevent base failures due to lateral escapement of the soil. Existing borrow pits, close to the toe of bank may be filled or its depth should be taken into account in analysing slope stability of the bank.

3.7 Soils to be normally avoided

a) There are some soils, which are normally unsuitable for construction of formation as listed below:

i) Organic clays, organic silts, peat, chalks, marl, dispersive soils and soil containing soluble material (e.g. rock salt or gypsum).

ii) Poorly graded sand and gravel with $Cu < 2.0$, should not be used to safeguard against liquefaction. Generally, most liquefiable soils as falling in gradation zone as indicated in the Fig-L1 of Appendix-L & having coefficient of uniformity, $Cu < 2$ shall not be used. (Reference Sketch given in Appendix-L).

iii) Clays and Silts of high plasticity (CH & MH) in top 3m of Embankment.

iv) Shales and soft rocks which become muddy after coming into contact with water.

b) There may be some typical situations in construction of formation & cuttings, where it is not possible to avoid conditions as given below, for economical or any other reason, then Railway may decide special investigations and other measures to formulate suitable scheme of construction.

i) Cuttings passing through unsuitable soils as defined in para 3.7 (a).

ii) Construction of embankment on subsoil of unsuitable types of soils.

3.8 Blanket Layer

3.8.1 Need and functions of Blanket Layer

a) It reduces traffic-induced stresses to a tolerable limit (i.e. threshold stress) on the top of subgrade, thereby, prevents subgrade failures.

b) It prevents penetration of ballast into the subgrade and also prevents upward migration of fine particles from subgrade into the ballast under adverse conditions, during service. This prevents mud pumping by separating the ballast and subgrade soil.

c) It results in increased track modulus and thereby reduces the track stresses & deformations.

d) It facilitates drainage of surface water and reduces moisture variations in subgrade, thereby reducing track maintenance problems.

e) It facilitates dissipation of excess pore water pressure developed in subgrade on account of cyclic loading and leads to increase in shear strength of subgrade soil.

3.8.2 Blanketing Material

It is difficult to get natural blanket material. Normally, the blanket material shall be produced mechanically by crushing the stones and/or by mixing, naturally available materials using suitable equipment/plants like pug mill, wet mix plant, crusher etc. However, if naturally available material conforms to the specifications, the same can also be used. The type of blanket material to be used whether natural or manufactured (mechanical crushing and/or blending) may be indicated clearly before start of the work and should be indicated in tender document. Some Typical methods used for mechanised production of blanket material are given in **Appendix-A.**

Decisions to use natural blanket material or manufactured blanket material shall be taken on the basis of site conditions or final location survey report.

3.8.3 Requirement of Blanket Layer

a) The provision of blanket layer shall not be needed when formation/earth fill embankment have:

i) Rocky beds except those, which are very susceptible to weathering e.g. rocks consisting of shale and other soft rocks, which become muddy after coming into contact with water.

(ii) Soils conforming to specifications of Blanket layer as given in Table 3.3 to 3.6.

b) For other conditions, the system of layered construction of embankment (Single layer/ Two layer) shall normally be followed.

3.9 Soil Quality

For Design of Railway Formation, the soils for their use in Indian Railway Embankment have been grouped based on percentage of fines present in the soil, as given below:

Description of Soil Quality Class

Description w.r.t. Fine-Particles (size less than 75 micron)	Soil Quality Class,
Soils containing fines > 50 %	SQ1
Soils containing fines from 12% to 50%	SQ2
Soils containing fines < 12%	SQ3

3.10 Specifications and Thickness of Formation Layers:

(A) The Railway Formation may be constructed with Single Layer System or Two Layer System based on availability of local soils/materials and on economic considerations. The thickness of the prepared sub-grade and blanket layer has been rationalized based on UIC-719R calculation for ballast cushion of 350 mm. The specifications and thickness of Blanket layer, Prepared subgrade, Subgrade (Top Layer & Lower layer) and Sub-Soil are tabulated for Single layer system and Two-layer system for 25T and 32.5T Axle load as below: -

Table-3.1: For 25 T Axle Load

S. No.	Soil type Category in Sub-grade	Prepared Sub-grade		Recommended Blanket Thickness (mm)	Remarks
		Soil Type	Thickness (mm)		
1.	SQ1	SQ1*	--	550	Single layer
2.	SQ1	SQ2	500	400	Two layer
3.	SQ1	SQ3	500	300	Two layer
4.	SQ2	SQ2*	--	400	Single layer
5.	SQ2	SQ3	350	300	Two layer
6.	SQ3	SQ3*	--	300	Single layer

* Subgrade soil is continued upto blanket layer

Table-3.2: For 32.5 T Axle Load

S. No.	Soil type Category in Sub-grade	Prepared Sub-grade		Recommended Blanket Thickness (mm)	Remarks
		Soil Type	Thickness (mm)		
1.	SQ1	SQ1*	--	700	Single layer
2.	SQ1	SQ2	500	550	Two layer
3.	SQ1	SQ3	500	450	Two layer
4.	SQ2	SQ2*	--	550	Single layer
5.	SQ2	SQ3	350	450	Two layer
6.	SQ3	SQ3*	--	450	Single layer

* Subgrade soil is continued upto blanket layer

(B) Formation for 25T axle load

Table 3.3: Specification and Thickness of Formation Layers for 25T axle load: Single layer system

Layers	Specification	Thickness
Blanket	i) C_U> 7 and C_C between 1 and 3. ii) Fines (passing 75 microns) :3% to 10% iii) Minimum soaked CBR value ≥ 25, (Soil compacted at 100% of MDD * in Lab) iv) Los Angeles Abrasion value < 40% v) Field Compaction :Min. 100% of MDD * in field trial vi) Minimum Ev_2 **= 100 MPa vii) Size gradation – within specified range (as table-3.7) or should lie more or less within enveloping curves (as Fig-3.8) viii) Filter criteria **(***Optional)** should be satisfied with sub-grade layer as given below: Criteria-1: D_{15} (blanket) < 5xD_{85} (sub-grade) Criteria-2: D_{15} (blanket) > 4 to 5xD_{15} (sub-grade) Criteria-3: D_{50} (blanket) < 25xD_{50} (sub-grade)	**30 cm** over SQ3 sub-grade **40 cm** over SQ2 sub-grade **55 cm** over SQ1 sub-grade
Sub-grade Top Layer	SQ1/SQ2/SQ3 soil SQ1 soils (To be used only with dispensation of PCE/ CAO) i) For SQ2/SQ3 soil, CBR ≥6 (soil compacted at 98% of MDD *) ii) For SQ1 soil, CBR ≥4 soil compacted at 98% of MDD*	100 cm

Lower layer (fill)	iii) Field Compaction : Min. 98% of MDD * iv) Minimum Ev_2 = 45 MPa (for SQ1) 60 MPa (for SQ2/SQ3) SQ1/SQ2/SQ3 soil (+) i) CBR≥ 3 (soil compacted at 97% of MDD *) ii) Field Compaction :Min. 97% of MDD *	As per Embankment height
Ground Soil/Sub-soil Strata	i) Undrained Cohesion of soil (c_u) ≥ 25 KPa (only for soils having particles finer than 75 micron exceeding 12%) ii) Ev_2 (determined from PLT) ≥ 20 MPa iii) N (determined from SPT) ≥ 5 Ground Improvement is required, if any of the above parameters not complied with	--

* MDD mentioned in the above table

(a) For determination of CBR - MDD achieved in Lab

(b) For field compaction - MDD achieved in field compaction trials which should not be less than 98% of MDD in lab.

Ev_2 is Modulus of deformation **(Para 2.0 of Appendix-H)

*** With the application of Non-woven Geotextile as a separator layer below the blanket, filter criteria will not be required or mandatory.

+ No dispensation of PCE/CAO required for use of SQ1 soil in Lower layer (fill) of Subgrade.

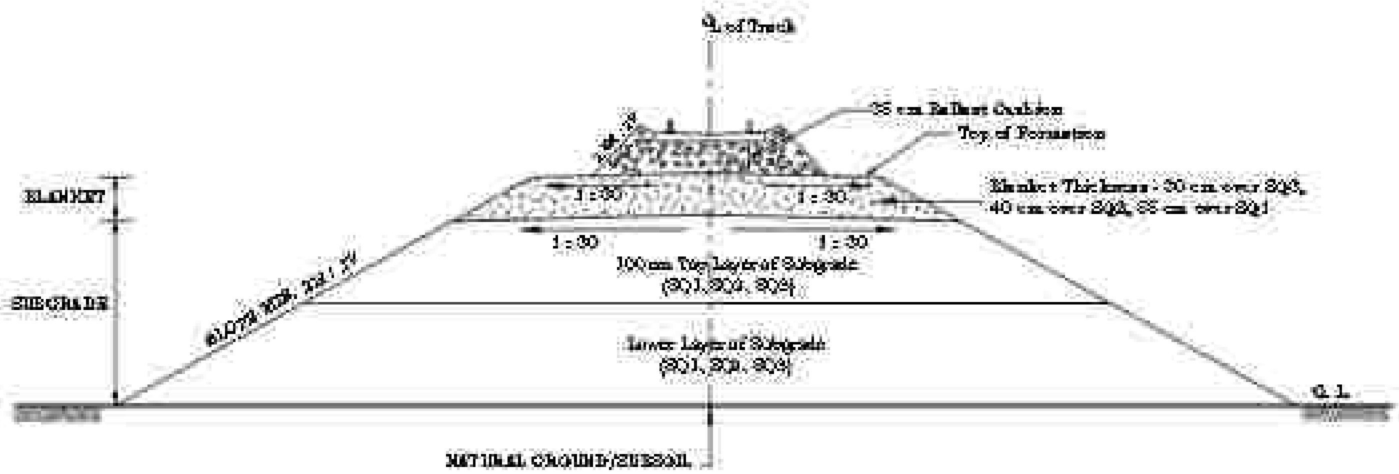


Fig-3.4: Track Formation for 25 T Axle Load (Single layer system)

Table 3.4: Specification and Thickness of Formation Layers for 25T axle load: Two layer system

Layers	Specification	Thickness
Blanket	i) $C_U > 7$ and C_C between 1 and 3. ii) Fines (passing 75 microns) : 3% to 10% iii) Los Angeles Abrasion value < 40% iv) Minimum soaked CBR value ≥ 25, (soil compacted at 100% of MDD * in lab) v) Field compaction: 100% of MDD* in field trial vi) Minimum Ev_2 **= 100 MPa vii) Size gradation – within specified range (as table-3.7) or should lie more or less within enveloping curves (as fig.-3.8) viii) Filter criteria **(***Optional)** should be satisfied with prepared sub-grade layer as given below: Criteria-1: D_{15} (blanket)<5xD_{85} (prepared sub-grade) Criteria-2: D_{15} (blanket) > 4 to 5xD_{15} (prepared sub-grade) Criteria-3: D_{50} (blanket) < 25xD_{50} (prepared sub-grade)	**30 cm** over SQ3 Prepared Sub-grade **40 cm** over SQ2 Prepared Sub-grade
Prepared Subgrade	SQ2/SQ3 i) CBR ≥ 8 (soil compacted upto 98% of MDD *) ii) Plasticity Index ≤ 12 iii) Field Compaction :Min. 98% of MDD * iv) Minimum Ev_2 = 60 MPa	**50 cm** over SQ1 fill **35 cm** over SQ2 fill
Subgrade Top Layer	SQ1/SQ2/SQ3 (SQ1 soils (To be used only with dispensation of PCE/ CAO) i) CBR ≥ 5 (soil compacted at 97% of MDD *) for SQ2/SQ3 soils ii) For SQ1 soil, CBR ≥ 4 (soil compacted at 97% of MDD *) iii) Field Compaction : Min. 97% of MDD * iv) Minimum Ev_2 = 30 MPa (for SQ1) 45 MPa (for SQ2/SQ3)	**50 cm**
Lower layer (fill)	SQ1/SQ2/SQ3 soil (+) i) CBR≥ 3 (soil compacted at 97% of MDD *) ii) Field Compaction :Min. 97% of MDD *	As per Embankment height

Ground Soil/Sub-soil Strata	i) Undrained Cohesion of soil (c_u) ≥ 25 KPa (only for soils having particles finer than 75 micron exceeding 12%) ii) Ev_2 (determined from PLT) ≥ 20 MPa iii) N (determined from SPT) ≥ 5 Ground Improvement is required, if any of the above parameters not complied with	--

* MDD mentioned in above table

a) For determination of CBR - MDD achieved in Lab,

b) For field compaction - MDD achieved in field compaction trials which should not be less than 98% of MDD in lab.

Ev_2 is Modulus of deformation **(Para 2.0 of Appendix-H)

*** With the application of Non-woven Geotextile as a separator layer below the blanket, filter criteria will not be required or mandatory.

+ No dispensation of PCE/CAO required for use of SQ1 soil in Lower layer (fill) of Subgrade.

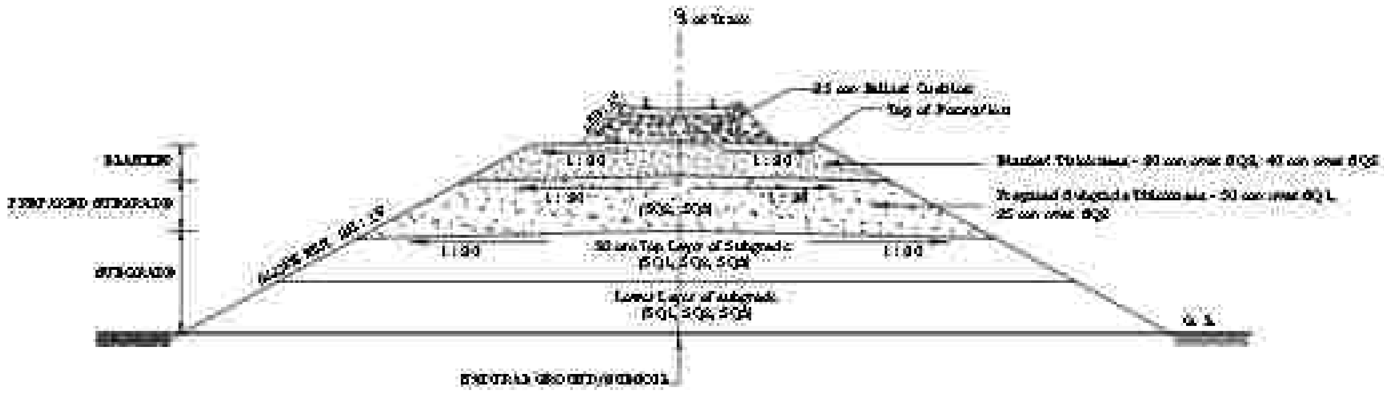


Fig-3.5: Track Formation for Two layer system (for 25 T Axle load)

(C) Formation for 32.5T Axle load

Table 3.5: Specification and Thickness of Formation Layers for 32.5T axle load: Single layer system

Layers	Specification	Thickness
Blanket	i) C_U> 7 and C_C between 1 and 3. ii) Fines (passing 75 microns) :3% to 10% iii) Size gradation within specified range as specified in Table 3.7 or should lie within enveloping curves given in fig 3.8. iv) Los Angeles Abrasion value< 40% (v) Minimum CBR value ≥ 25 (Soil compacted at 100%	**45cm** over SQ3 sub-grade **55cm** over SQ2 sub-grade **70cm**over SQ1 sub-grade

	of MDD* in Lab.) (vi) Field Compaction: 100% of MDD * in field trial (vii) Minimum E_{v2} ** = 120Mpa (viii) Filter Criteria **(***Optional)** should be satisfied with subgrade layer, as given below : Criteria-1: D_{15} (blanket) $< 5 \times D_{85}$ (sub-grade) Criteria-2: D_{15}(blanket) $>$4to5 D_{15}(sub-grade) Criteria-3: D_{50}(blanket) $< 25 \times D_{50}$ (sub-grade)	
<u>Subgrade</u> Top Layer	SQ1/SQ2/SQ3 soil (SQ1 soils (To be used only with dispensation of PCE/ CAO) i) CBR ≥ 6, for SQ2/SQ3 soil compacted at 98% of MDD*) ii) CBR≥ 4, for SQ1 (soil compacted at 98% of MDD*) iii) Field Compaction : Min. 98% of MDD* iv) Minimum Ev_2 ** = 45 MPa (for SQ1 soil) 60 MPa (for SQ2/SQ3)	**100 cm**
Lower layer (fill)	SQ1/SQ2/SQ3 soil (+) i) CBR ≥ 3 (soil compacted at 97% of MDD*) ii) Field Compaction: min 97% of MDD*	As per Embankment height
Ground Soil/Sub-soil	i) Undrained Cohesion of soil (c_u) ≥ 25 KPa (only for soils having particles finer than 75 micron exceeding 12%) ii) Ev_2 (determined from PLT) ≥ 20 MPa iii) N (determined from SPT) ≥ 5 Ground Improvement is required, if any of the above parameters not complied with	--

* MDD mentioned in above table

a) For determination of CBR - MDD achieved in Lab,

b) For field compaction - MDD achieved in field compaction trials which should not be less than 98% of MDD in lab.

** Ev2 is Modulus of deformation (**Para 2.0 of Appendix-H**)

*** With the application of Non-woven Geotextile as a separator layer below the blanket, filter criteria will not be required or mandatory.

\+ No dispensation of PCE/CAO required for use of SQ1 soil in Lower layer (fill) of Subgrade.

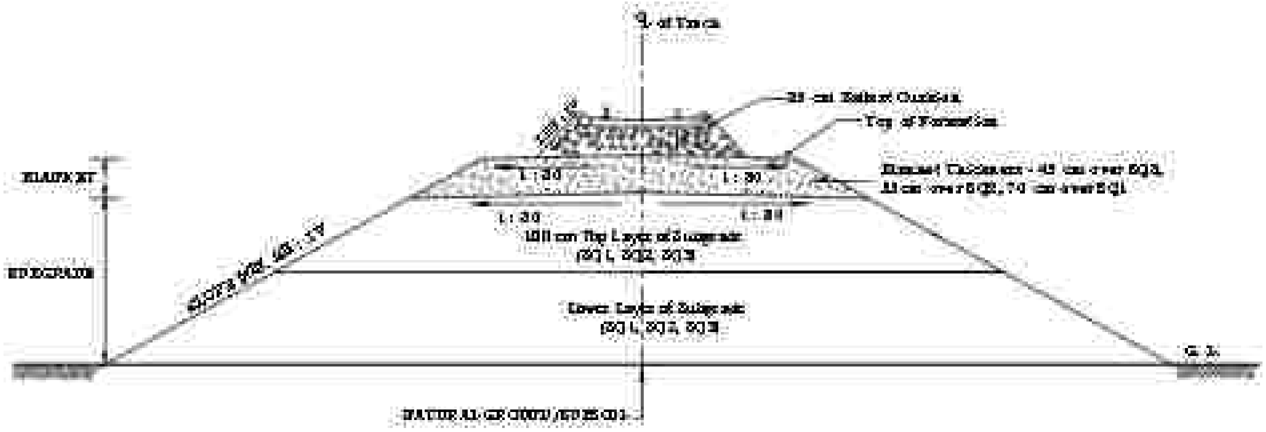


Fig-3.6: Track Formation for single layer system (for 32.5 T Axle load)

Table 3.6: Specification and Thickness of Formation Layers for 32.5T axle load: Two layer system

Layers	Specification	Thickness
Blanket	i) C_U> 7 and C_C between 1 and 3. ii)Fines (passing 75 microns) :3% to 10% iii) Size gradation – within specified range as given in Table 3.7or should lie within enveloping curves as given in Fig. 3.8 iv) Los Angeles Abrasion value< 40% (v) Minimum soaked CBR value ≥ 25 (Soil compacted at 100% of MDD* in Lab.) (vi) Field Compaction: 100% of MDD* in field trial (vii) Minimum E_{V2} ** = 120MPa (viii) Filter Criteria **(***Optional)** should be satisfied with subgrade layer, as given below : Criteria–1: D_{15} (blanket) <5xD_{85} (prepared sub-grade) Criteria–2: D_{15}(blanket) >4 to 5 D_{15} (prepared sub-grade) Criteria–3: D_{50}(blanket) <25xD_{50} (prepared sub-grade)	**45cm** over SQ3 prepared subgrade **55cm** over SQ2 prepared subgrade
Prepared Subgrade	SQ2/SQ3 Soil i) CBR ≥ 8 (soil compacted at 98% of MDD*) ii) Field Compaction :Min. 98% of MDD* iii) Plasticity Index ≤ 12 iv) Minimum E_{V2} = 60 MPa	**50 cm** over SQ1 fill **35 cm** over SQ2 fill
Subgrade Top layer	SQ1/SQ2/SQ3 Soil (SQ1 soils (To be used only with dispensation	**50 cm**

Lower layer (fill)	of PCE/ CAO) i) CBR ≥ 5 (soil compacted at 97% of MDD *) for SQ2/SQ3 soil ii) CBR≥ 4, for SQ1 (soil compacted at 97% of MDD *) iii) Field Compaction : Min. 97% of MDD* iv) Minimum Ev_2** = 30 MPa (for SQ1 soil) 45 MPa (for SQ2/SQ3) SQ1/SQ2/SQ3 Soil (+) i) CBR ≥ 3, (soil compacted at 97% of MDD*) ii) Field Compaction : Min. 97% of MDD*	As per Embankment height
Ground Soil/Sub-soil Strata	i) Undrained Cohesion of soil (c_u) ≥ 25 KPa (only for soils having particles finer than 75 micron exceeding 12%) ii) Ev_2 (determined from PLT) ≥ 20 MPa iii) N (determined from SPT) ≥ 5 Ground Improvement is required, if any of the above parameters not complied with	--

* MDD mentioned in above table

a) For determination of CBR - MDD achieved in Lab,

b) For field compaction - MDD achieved in field compaction trials which should not be less than 98% of MDD in lab.

** Ev2 is Modulus of deformation **(Para 2.0 of Appendix-H)**

*** With the application of Non-woven Geotextile as a separator layer below the blanket, filter criteria will not be required or mandatory.

\+ No dispensation of PCE/CAO required for use of SQ1 soil in Lower layer (fill) of Subgrade.

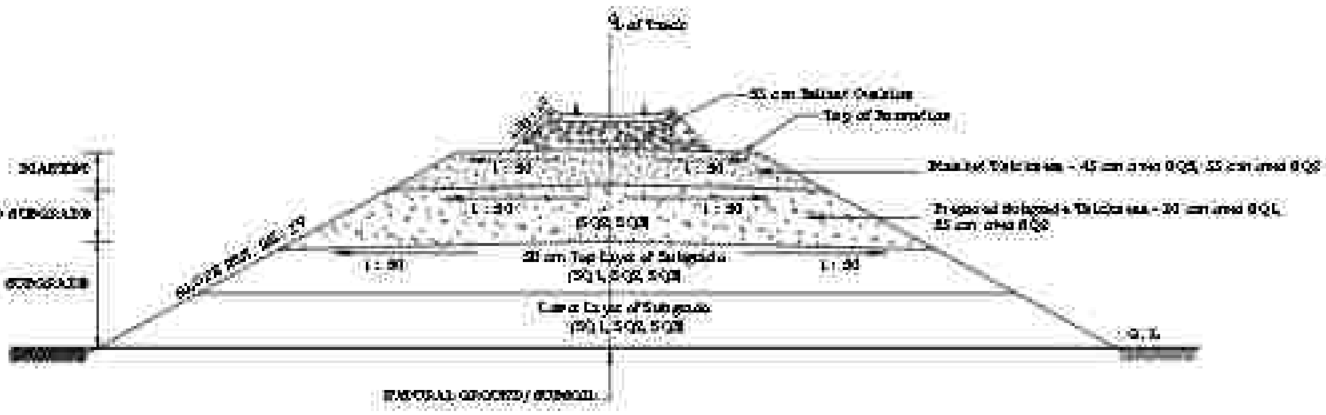


Fig-3.7: Track Formation for Two layer system (for 32.5 T Axle load)

Table-3.7: Gradation Percentage of Blanket Material

SL	IS Sieve Size	Percent Passing (by weight)
1.	40 mm	100
2.	20 mm	80 - 100
3.	10 mm	63 - 85
4.	4.75 mm	42 - 68
5.	2 mm	27 - 52
6.	600 micron	13 - 35
7.	425 micron	10 - 32
8.	212 micron	6 - 22
9.	75 micron	3 - 10

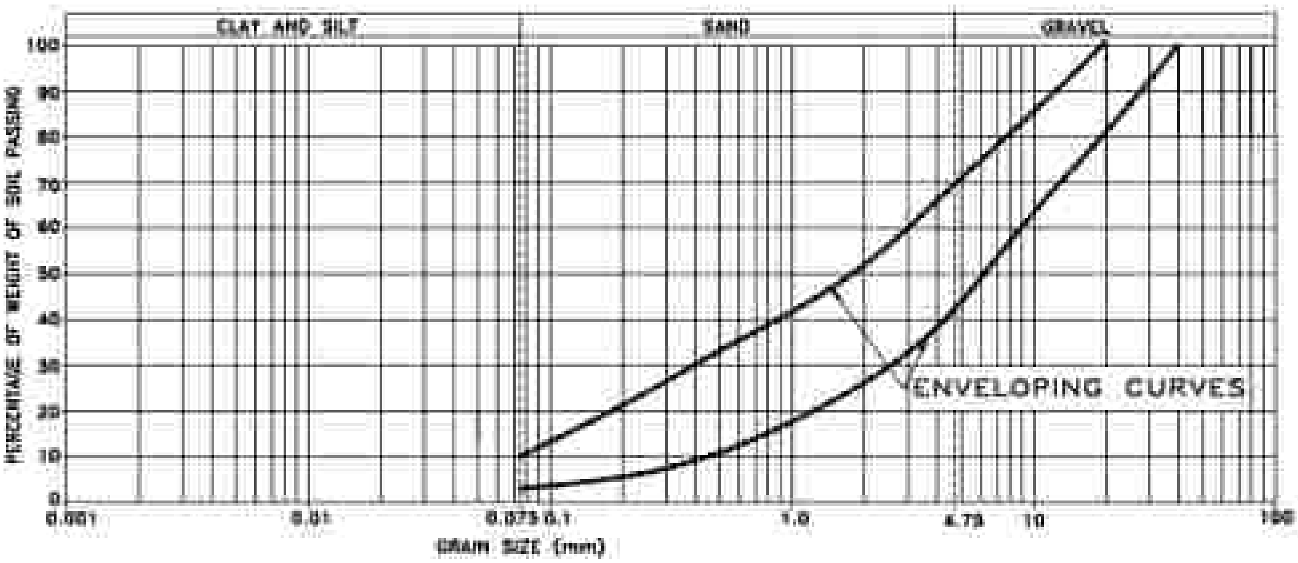


Fig-3.8: Enveloping Curves for Blanket Material

(D) When the subgrade/prepared subgrade is of SQ1 or SQ2 category soil (in table 3.3 to 3.6), a suitable non-woven geo-textile layer may be used as "separator layer" on the top of subgrade to prevent upward migration of the fines from subgrade/prepared subgrade causing contamination of blanket layer on top of it and also to prevent penetration of coarse particles of layer on top of subgrade into soft/fine grained particles of sub-grade below. Specifications of Non-Woven Geotextile to be used as "separator layer" given in APPENDIX-C.

(E) Design of formation, including adoption of single layer or two layer system, and use of SQ1 soil (in top layer of subgrade) as given in above paras shall be decided by PCE/CAO (Con) on the basis of soil investigation.

In case of the projects being executed by PSUs, the powers of PCE/CAO shall be exercised at appropriate level of authority as nominated by CMD/MD of the PSU.

(F) In case of cutting also, blanketing shall be provided as required & as specified in this Para 3.10, based on the type of soil just below the blanket.

3.11 Height of Embankment and Formation Layer thickness:

i) Minimum height of embankment above ground level or highest flood level (HFL) whichever is higher should not be less than **one meter** to ensure proper drainage and avoid trespassing.

ii) Total required thickness of formation layers as specified in **Para 3.10** for blanket, prepared sub-grade & Subgrade-Top Layer, should be provided/ensured uniformly in embankment/cutting for effective stress dispersal.

iii) The specification of soil strata below the ground level (GL) must be ascertained from the results of soil exploration.

iv) For effective stress dispersal, required total uniform thickness of formation layer (Blanket, Prepared sub-grade & Subgrade/Top Layer) shall be ensured in cuttings as well as in embankments, even where embankment height is less than about 1.5m or total uniform required thickness. It is further explained as below:

a) For Embankment (where height of embankment is less than required total uniform thickness): If the specification of sub-soil meets the required specification of blanket/prepared subgrade/subgrade-top layer, upto required total depth of uniform thickness below ground level, then there will be no need of excavation, else the excavations will be done below ground level as per the requirement, to satisfy the provision of total uniform thickness for effective stress dispersal. Detailed description & few examples are as given in **APPENDIX-B.**

b) For Cutting: If the specification of sub-soil does not meet the required specification of blanket/prepared subgrade/subgrade-top layer i.e. total required uniform thickness, below the proposed level of excavation in cuttings, the excavation level for cuttings shall be enhanced to the level so as to satisfy the total required uniform thickness requirement. Detailed description & few examples are as given in **APPENDIX-B.**

v) Suitable drainage arrangement shall be ensured.

CHAPTER-4

APPLICATIONS OF GEOSYNTHETICS IN RAILWAY FORMATION

4.1 General

Geo-synthetic is a generic term which includes different synthetic products used in Geotechnical Engineering applications. Geo-synthetics are available in a wide range of forms and materials.

They can be utilized to solve various issues related to railway roadbed stabilization, like drainage, filtration, reinforcement, separation, erosion control etc. The raw materials used in the manufacturing of Geosynthetics are polymers, which are non-biodegradable.

4.2 Functions of Geo-synthetics

A properly designed Geosynthetic can serve various functions; some of them are as given below:

4.2.1 Separation

A Geosynthetic placed at the interface between two dissimilar geotechnical materials (fine and coarse grained soils) functions as a Separator when it prevents intermixing of two soil types to maintain integrity of each material under the applied loads (**Fig-4.1**). Non-woven geotextile layer is commonly used for separation, in Railway formations, and it provides filtration and drainage also.

Fig-4.1: Separation

4.2.2 Filtration

In this function, the geosynthetics allows passage of fluids from the soil in either direction while simultaneously prevents the uncontrolled passage of soil particles (**Fig-4.2**)The pore size of the geosynthetic (mostly non-woven geotextile) is chosen to aid against their blocking, binding and clogging. Non-woven geotextile layer is commonly used for filtration in Railway formations and it normally partnered with Separation.

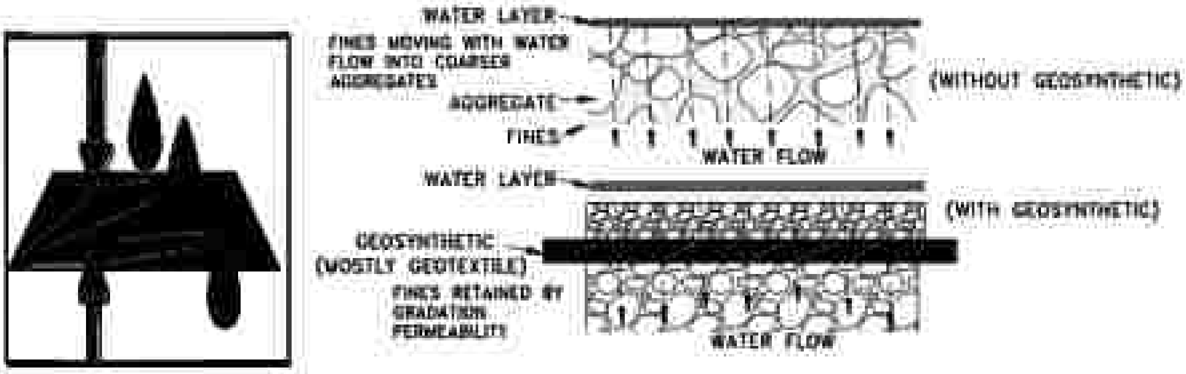


Fig-4.2: Filtration

4.2.3 Drainage

In this function, the Geosynthetic collects the fluid and transports it in its own plane **[Fig-4.3 (a) & (b)].** This function is facilitated due to in-plane permeability of the geosynthetic (called "transmissivity") being far more than permeability across the plane (called "permittivity"). Non-woven geotextile or Geocomsposite drains are commonly used for drainage in Railway formations.

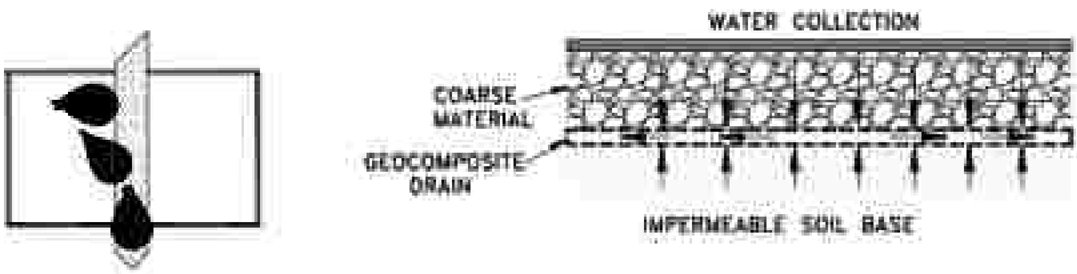


Fig-4.3(a): Drainage in Basal Layer

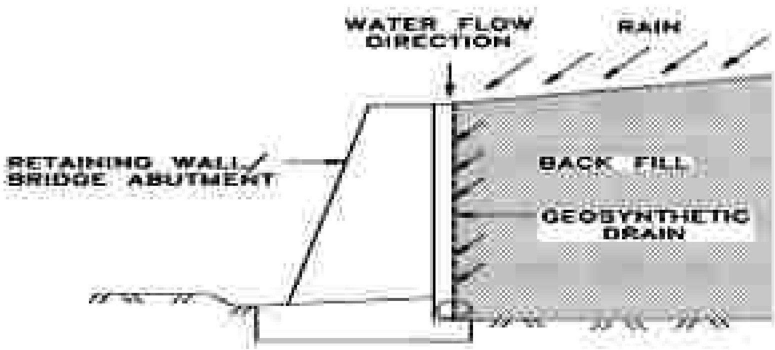


Fig-4.3(b): Drainage behind Bridge Abutment/Retaining Wall

4.2.4 Reinforcement

Geogrid can be used for reinforcement at the bottom of ballast or at the bottom of blanket or within the blanket, which by its reinforcing/interlocking mechanism forms a semi rigid mat that helps in reducing the stresses on the layer below. This can be used to reduce the required blanket thickness.

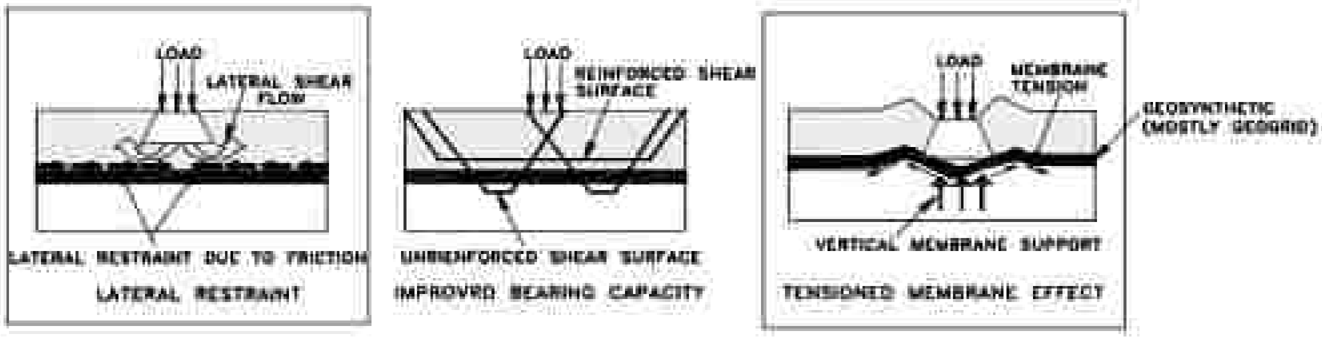


Fig-4.4: Reinforcement of Layers in Embankment

4.3 Types of Geosynthetics

There are various types of Geosynthetics, as under:

i) Geotextiles
ii) Geogrids
iii) Geonets
iv) Geomembranes
v) Geocomposites
vi) Geocell &
vii) Others

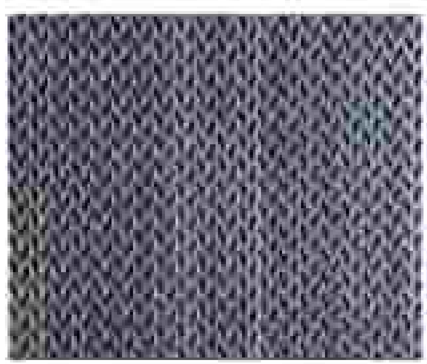
Geosyhnthetics which are/can be used in Railway formations are described in brief, as under:

4.3.1 Geotextile

Geotextiles are planar and permeable members which are manufactured from synthetic fibers, yarns, filaments, tapes etc. The polymers used in manufacturing geotextiles are Polypropylene, Polyester, High Density Polyethylene and Polyamide (nylon) or a combination thereof, but a large majority of geotextiles are made from Polypropylene.

Generally two types of geotextiles are used commonly, as given below:

(i) Woven Type



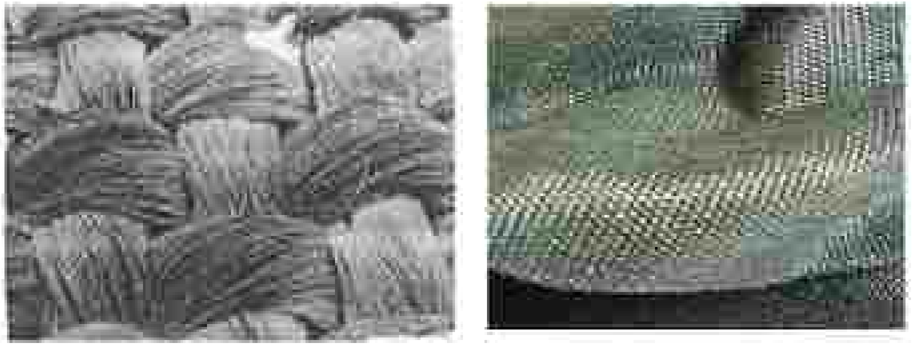


Fig-4.5 : Woven Geotextiles

These geotextiles are woven by interlacing two or more sets of yarns, fibers, filaments, tapes or other elements (Fig-4.5). These threads are generally woven straight and parallel to each other. Woven textiles exhibit high tensile strength, high modulus, high permeability and low elongation.

(ii) Non-woven Type

Non-woven geotextiles are manufactured in the form of sheet or web of directionally or randomly oriented fibres (Fig-4.6), produced by mechanical and/or thermal and/or chemical bonding. Non-woven geotextiles have high permeability and high elongation characteristics. In Railway application it acts as a separator, drainage material, and filter.

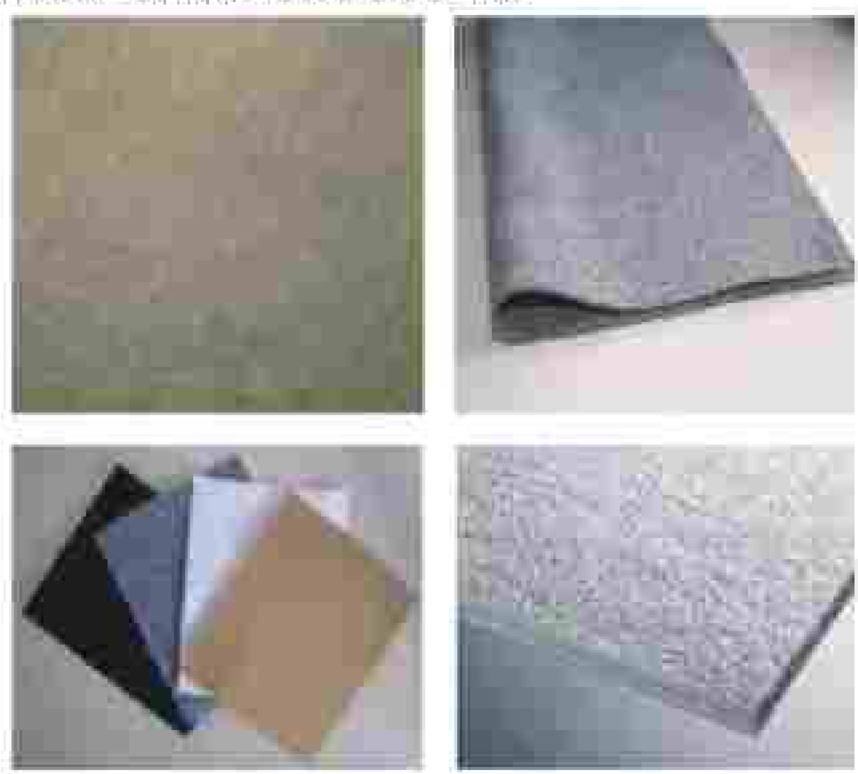


Fig-4.6 : Non-woven Geotextiles

4.3.2 Geogrid

Geogrid is a planar, polymeric structure consisting of a regular open network of integrally connected tensile elements, which may be linked by extrusion, bonding or interlacing. They have an open grid like configuration with large apertures between individual ribs. The key feature of all geogrids is that the apertures are large enough to allow soil communication, or strike through, from one side of the geogrid to the other. Geogrids have relatively high strength, high modulus and low-creep-sensitive polymers.

Geogrids provide uniform distribution of loads over a larger area by increasing stiffness of base, as the same resists flexural deformation.

Woven types of geogrids are manufactured by weaving together polypropylene coated polyester fibers into longitudinal & transverse ribs and joining the crossovers by knitting or intertwining before protecting the entire unit by a subsequent coating (**Fig-4.7**). Extruded types of geogrids are produced by extruding polymers and by stretching uniaxially or biaxially extruded integral structure (**Fig-4.8**). Bonded geogrid is produced by bonding, usually at right angles, two or more sets of strands or other elements (**Fig-4.9**).

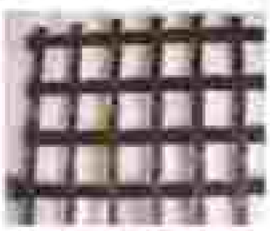


Fig. 4.7 Woven Geogrid

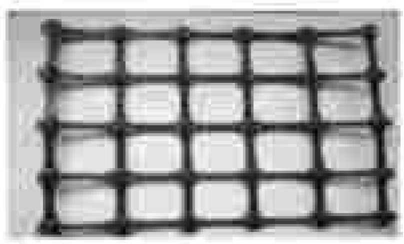


Fig. 4.8 Extruded Geogrid

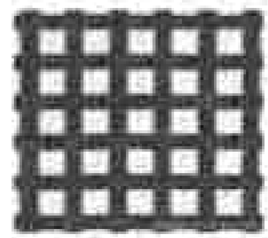


Fig. 4.9 Bonded Geogrid

Following types of geo-grids are generally available in the market:

(i) Geogrid with one axis: Also known as mono-oriented geogrids, it is a planar grid, which possesses a much higher strength in one direction than in the other direction (**Fig-4.10**).

(ii) Geogrid with two axes: Also known as bi-oriented geogrids, it is a planar grid, which possesses similar strength in both ortho direction i.e. longitudinal & transversal (**Fig-4.11**).

Fig-4.10 Geogrid with one axis

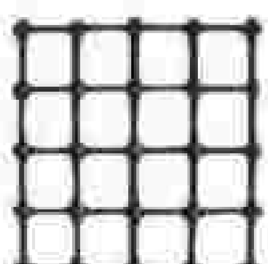


Fig-4.11 Geogrid with two axes

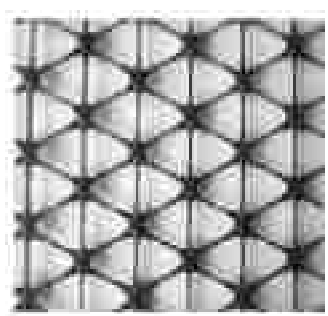


Fig-4.12 Geogrid with three axes

(iii) Geogrid with three axes: A recent addition to the geogrid family, this product is having ribs in triangular pattern or other shapes. These geogrids are manufactured from a punched polypropylene sheet oriented in multiple, equilateral directions to form triangular apertures. (**Fig-4.12**).

4.3.3 Geocomposite

Geocomposite a generic name used to define a geosynthetic product consisting of a combination of two or more geosynthetic materials. The application areas of geocomposites are numerous and growing steadily. The geocomposites used for Raiwlay formations, are as following:

(i) Geocomposite Drain

Geocomposite drains, consisting of a geonet bonded with non-woven geotextile layer(s) on one or both sides are used for drainage from a basal layer in case of embankments and for drainage behind retaining walls and/or bridge abutments.

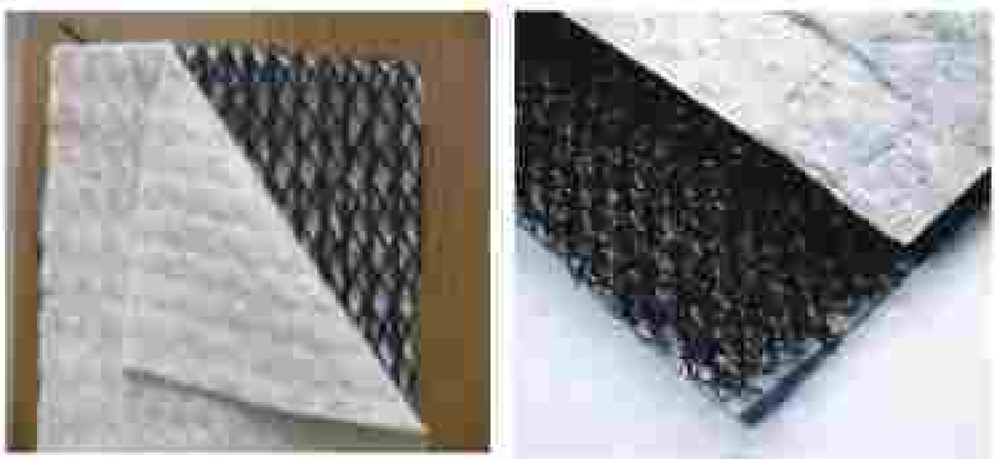


Fig-4.13 Typical Geocomposite Drains

(ii) Prefabricated Vertical Drains (PVD)

Prefabricated Vertical Drains (PVDs) are a geocomposites consisting of a synthetic filter jacket surrounding a plastic core. Normally they are manufactured in rolls of 200-300 m length and are inserted into ground to required depths using special drain stitcher rigs.

4.3.4 Geocell

Geocell is a three dimensional honeycomb like cellular structure, consisting of a regular open network of synthetic strips, linked by extrusion or adhesion or other methods.

4.4 Scope of Use of Geosynthetics In Railway Embankments

The decision on use of geosynthetics shall be taken based on the techno-economic considerations for every site of work, with the approval of PHOD in Open Line and Construction departments of Zonal Railways and equivalent officer in PSUs.

Considering the various functionalities provided by the geosynthetics, they have been used or can be used for following applications related to Railway Embankments:

a) Construction of new Embankment with fine grained soils

b) Ground Improvement in case of soft sub-soils

c) Construction of new Embankment over soft subsoil

d) Reduction in thickness of blanket layer

e) Rehabilitation/Strengthening of weak/unstable formation

f) Drainage behind Bridge Abutment/Retaining Wall.

4.4.1 Construction of new Embankment with fine grained soils

As given in Para 3.10, a non-woven Geo-textile layer is required to be used as "separator layer" in the following cases:

(a) Below blanket layer, if SQ2 soil is used in prepared sub-grade in two layer system.

(b) Below blanket layer, if SQ1 or SQ2 soil is used in sub-grade in single layer system.

RDSO has developed the Specification for Non-woven geotextile to be used as separator/filtration in Railway formation. The specifications have been issued to Zonal Railway/PSU's for trial application initially so as to improve upon the specifications based on its satisfactory performance, before its general adoption.

Specification of Non-woven Geotextile to be used as separator /filtration in Railway formation (Specification No. RDSO/2018/GE: IRS-0004- Part-I, March 2019) is given in **APPENDIX -C.**

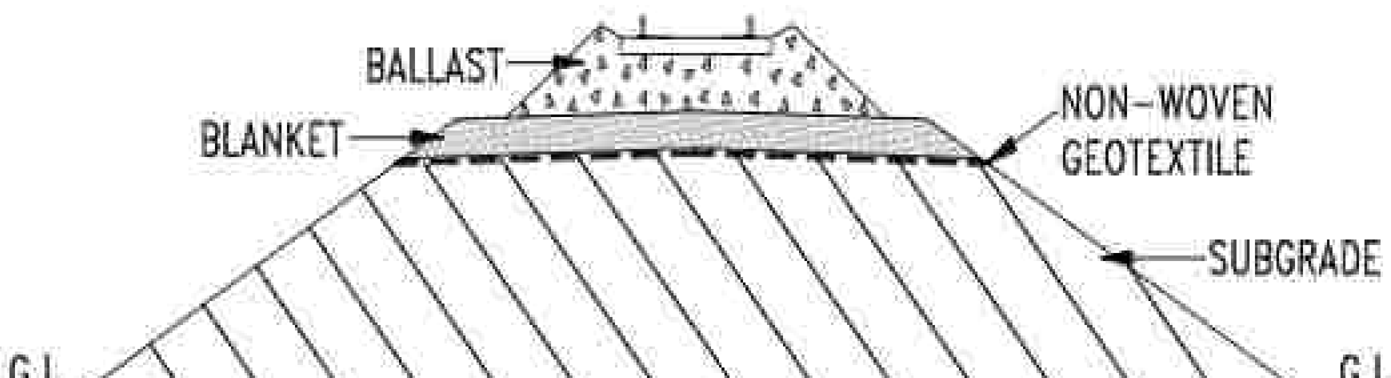


Fig-4.14 (a): Use of non-woven geotextile for fine grained soil

(In Single Layer System)

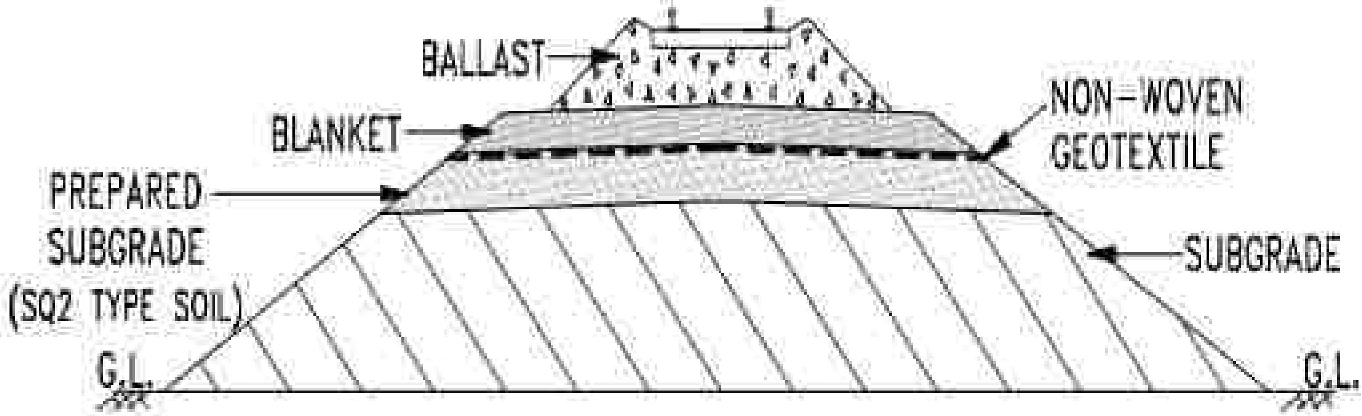


Fig-4.14 (b): Use of non-woven geotextile for fine grained soil

(In Two Layer System)

4.4.2 Ground Improvement in case of soft sub-soils

For construction of embankment over soft sub-soils (which are mostly soft clays), the sub-soil/ground has to be improved for –

a) Reducing the consolidation time (which otherwise can be very long spanning months/year) & associated settlement so that bank can be constructed in faster time; and

b) To increase the bearing capacity/ shear strength of the sub-soil so that the bank constructed over it is stable.

For faster consolidation & associated settlement, Prefabricated Vertical Drain (PVD) can be used. To improve the load support capacity of soft subsoil, Geocell is another form of Geosynthetics which is used as a basal mattress in embankments for ground improvement. For detailed description, **Chapter-2 (Suitability of Subsoil & Ground Improvement Techniques)** can be referred.

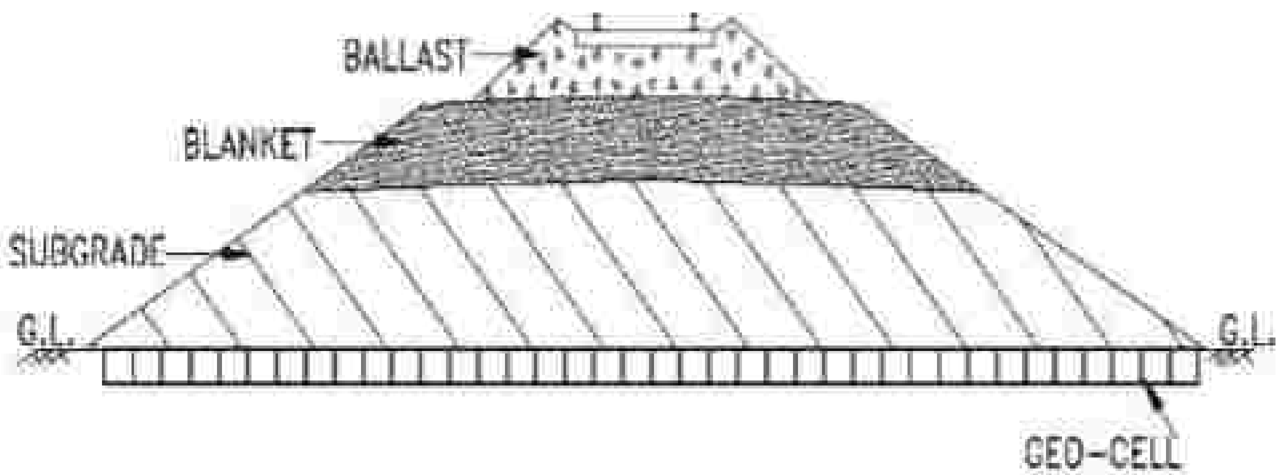


Fig-4.15: Use of Geocell as basal mattress for Ground improvement in soft subsoil

4.4.3 Construction of Embankment over soft subsoil

In case of embankments over weak/fine grained sub-soils (which are mostly soft clays) and having water table at higher level, it is a good practice to provide a "separator-cum-drainage layer" of Geocomposite drain layer, sandwiched between two layers of sand of about 75mm thickness **(Fig-4.16)**, at the ground level to provide adequate drainage path for the water coming from sub-soil (reducing excess pore water pressure in embankment and thereby increasing its' stability) and to prevent fouling of subgrade by the fine grained subsoil. Alternatively, a 1000mm thick sand layer can be provided. Its thickness may be varied depending on the bank height, characteristics of sub-soil and water table. The sand layer to be used in both the cases should be clean medium to coarse sand with minimum permeability of the order of 10^{-5} m/second.

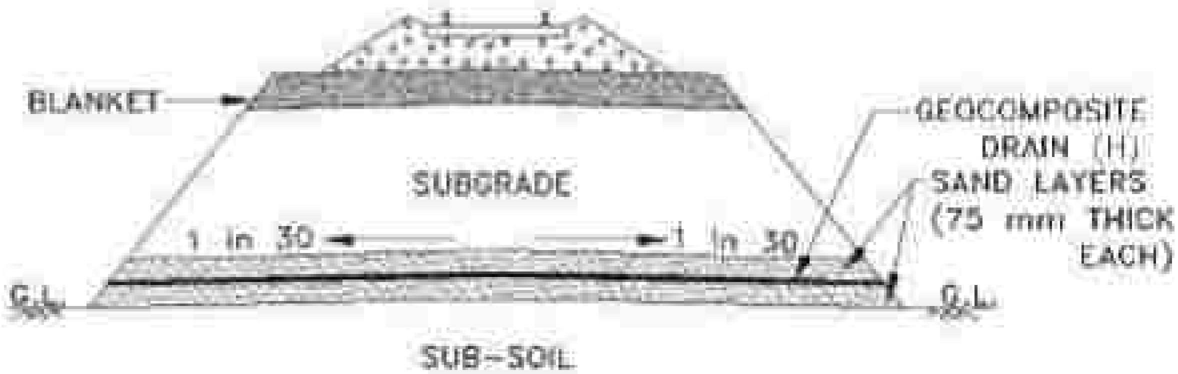


Fig-4.16: Use of Geosynthetic (Geocomposite drain-horizontal) in embankment over soft subsoil

RDSO has already developed the Specification for Geocomposite Drain (Horizontal) at the base of the Embankment (for embankment height upto 8m). The specifications have been issued to Zonal Railway/PSU's for trial application initially so as to improve upon the specifications based on its satisfactory performance, before its general adoption.

Specification of Geocomposite Drain to be used at base of the Embankment (Specification No. RDSO/2018/GE: IRS-0004- Part-II, March 2019) is given in **APPENDIX -C.**

4.4.4 Reduction in thickness of blanket layer

To reduce the thickness of the Blanket Layer (which is costly granular material obtained by quarrying or mining) in case of new constructions or for formation rehabilitation, on techno-economic considerations and/or to reduce the adverse impact on environment due to quarrying/mining, geogrid can be used. (**Fig-4.17**)

RDSO has developed the Specifications for Geogrid to be used as Reinforcement/Stabilisation for Railway Formation. The specifications have been issued to Zonal Railway/PSU's for trial application initially so as to improve upon the specifications based on its satisfactory performance, before its general adoption.

Specifications for Geogrid to be used as reinforcement/stabilisation for Railway Formation (Specification No. RDSO/2018/GE: IRS-0004- Part-III, February 2020) is given in **APPENDIX -C.**

Zonal Railways and Construction units must submit the design of reinforced formation layer to RDSO along with design methodology for use and selection of Geo-grid with minimum specifications as prescribed by RDSO for its approval.

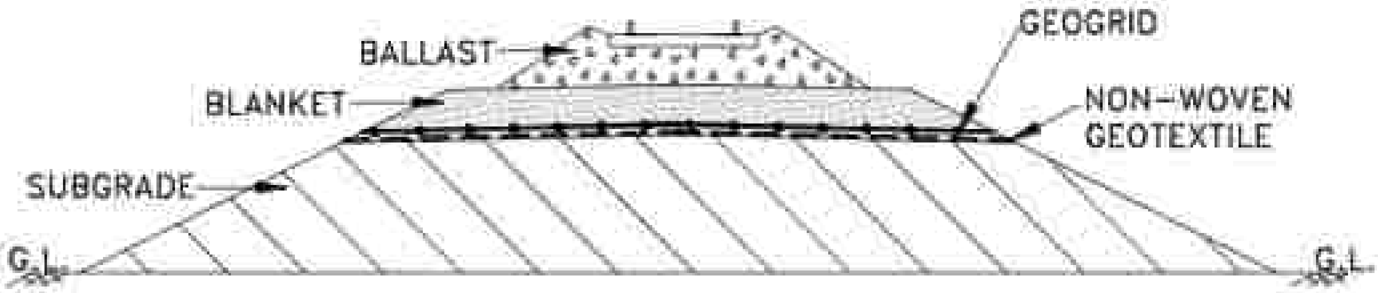


Fig-4.17: Use of geogrid for reduction of blanket layer thicknesses

4.4.5 Rehabilitation/Strengthening of weak/unstable formation

The weak/unstable formations are mostly those formations where subsoil and/or subgrade soil is expansive clay (e.g. Black Cotton Soil). The most significant property of these soils is that when mixed with water they swell considerably, losing their shear strength and on drying they shrink considerably. Because of this swelling and shrinkage, due to ingress of water in rainy season, the track parameters get disturbed and ballast penetrates in the formation. The problems caused by expansive clays can be addressed to a large extent by reducing the ingress of water (during rainy season) by provision of blanket layer of adequate thickness in the top layer of formation. The blanket layer acts as a separator as well as reinforcement layer reducing the pressure on the formation below. In case providing blanket layer of large thickness in running traffic conditions is not possible, its thickness can be reduced with provision of layer(s) of geogrid.

In addition to this by providing a non-woven geotextile, as separator/filtration layer below blanket, will reduce the water from top entering into the sub-grade & also prevents upward migration of fine particles from expansive clays (which are very fine grained) into the top coarse layer.

The preferred method for strengthening/rehabilitation of weak/unstable formations will be provision of a Blanket layer of suitable thickness as detailed above. But in cases where it is not possible to adopt this method, and only shallow depth of formation is considered to be affected/weak, another lesser preferred alternative is laying a separator layer of non-woven geotextile and a reinforcement layer of geogrid over it, just below the ballast along with deep screening work by Ballast Cleaning Machine (BCM), with additional provision in machine for laying of Geogrid/Geotextile. **(Refer Para 10.5, Chapter 10).**

However, before adopting the above method, detailed soil investigation must be done ascertaining the root cause of the formation problem. If the nature of the problems suggests that it cannot be solely rectified by adopting this method, then conventional method of providing blanket layer or other appropriate method as determined from investigation done shall be adopted.

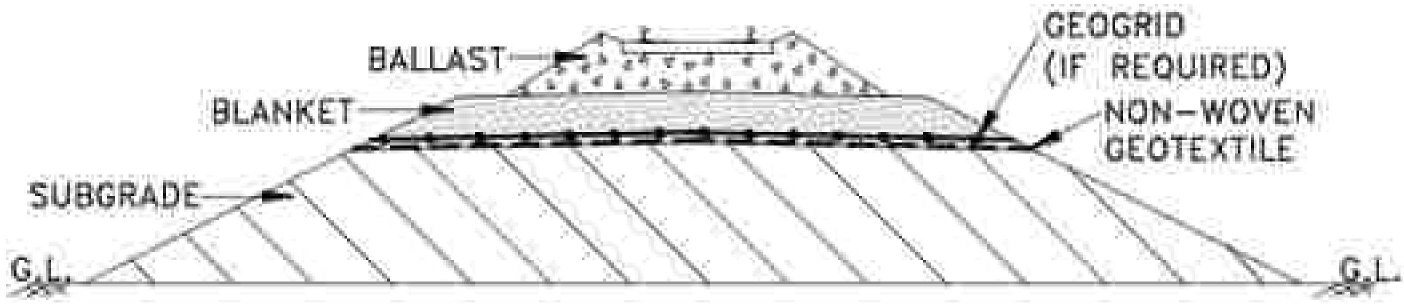


Fig-4.18: Rehabilitation/Strengthening of weak/unstable formation using geogrid & non-woven geotextile

4.4.6 Drainage behind Bridge abutment/Retaining wall

Geocomposite drain (Vertical) can replace the 600 mm thick natural graded filters (consisting of different sizes of boulders and gravels), provided behind bridge abutment and/or retaining walls for drainage, in places where availability of graded filter material is matter of concern. It also eliminates the need for weep holes in bridge abutment and/or retaining walls. The stages in installation of such a synthetic drain are shown in Fig-4.19.

RDSO has developed the Specification for Geocomposite drain (vertical) to be used behind the Bridge Abutment/Retaining wall for drainage purpose. The specifications have been issued to Zonal Railway/PSU's for trial application initially so as to improve upon the specifications based on its satisfactory performance, before its general adoption.

Specification for Geocomposite drains to be used behind Bridge Abutment/Retaining wall (Specification No. RDSO/2018/GE: IRS-0006, March-2019) is given in **APPENDIX-C.**


Fig 4.19: Installation of Geocomposite Drain

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'/γH (where 'H' is height of Embankment and ≥ 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 1.5xH (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. $= m - n \cdot r_u$ ------- (1)

Where: m & n are the stability co-efficient based on $C'/\gamma H$, ϕ', 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, ru **= U/ γ.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.
$r_{ue} = m_{1.25} - m_{1.00} / n_{1.25} - n_{1.00}$ ------------(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
$r_{ue} = m_{1.50} - m_{1.25} / n_{1.50} - n_{1.25}$ ------------(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

Design Register, showing soil parameters & factor of safety as adopted. In case of soft soils, the most critical circle with its center may also be indicated. Computation tables for calculation of 'm' & 'n' factors for different soil parameters are shown from table 5.3 to 5.20.

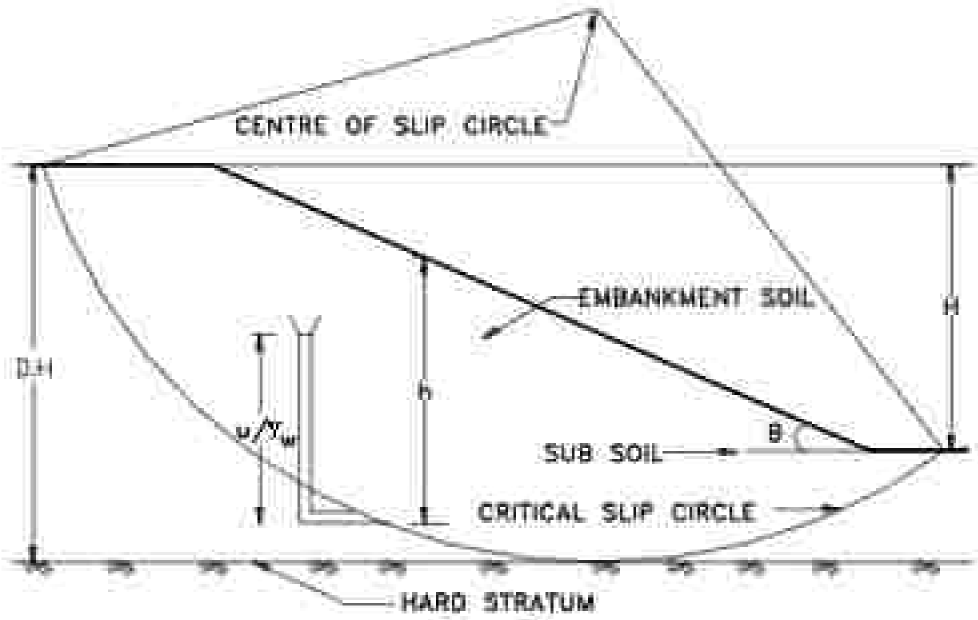


Fig: 5.1

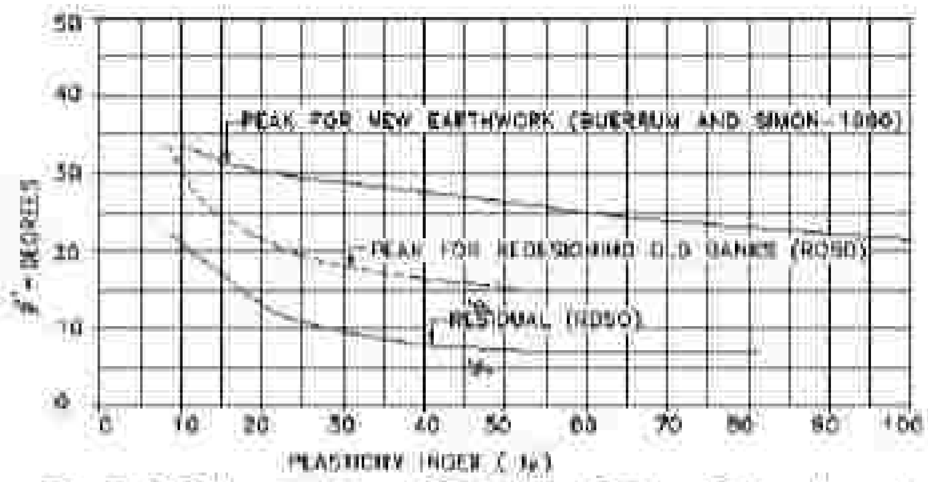


Fig-5.2: Determination of Ip & ϕ for Railway Embankment

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, IS: 2720 (pt. XII)-latest version.	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.

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

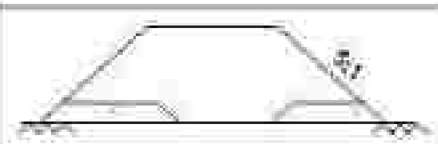
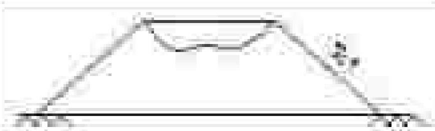
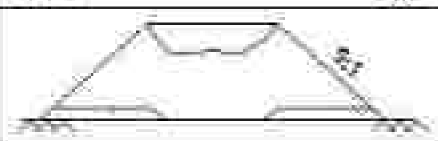
SLOPES → / BANK PROFILES ↓	2:1	2.5:1	2.75:1	3:1	3.5:1	4:1
	0.25	0.23	0.22	0.21	0.19	0.17
	0.13	0.12	0.11	0.10	0.09	0.08
	0.30	0.27	0.26	0.25	0.22	0.20
	0.15	0.14	0.13	0.12	0.11	0.10
	0.00	0.00	0.00	0.00	0.00	0.00

TABLE –5.3

Stability Coefficients m and n for C'/γH = 0

ψ	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'/γH = 0.025 & D=1.00**

ψ	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'/γH = 0.025 & D=1.25**

ψ	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'/γH = 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'/γH = 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'/γH = 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 $C' / \gamma H = 0.15$, $\phi' = 20°$ 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'/γH = 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'/γH = 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'/γH = 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'/γH = 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'/γH = 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'/γH = 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'/γH = 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'/γH = 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	5.697	4.129
40.0	3.728	2.938	4.556	3.509	5.498	4.195	6.490	4.947

TABLE –5.20

Stability Coefficients m and n for **C'/γH = 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 kN/m^2 (Measured in lab.)
c) Effective angle of shear resistance, ϕ'=25° (Measured in lab.)
d) Saturated density of soil, γ_{sat}= 21.53 kN/m3 (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' / γH = 8.2/21.53 x 6 = 0.063
   There is no direct table for this value therefore linear interpolation would be required between values of C' / γH of 0.05 & 0.075.

2. For C' / γH = 0.075 (as 0.063 is more closer to 0.075 than 0.05), ϕ'= 25° 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:
   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)

   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' / γH = 0.063 at D = 1.00 as follows:

   (i) From table 5.6, FOS (for C' / γH = 0.05) = 1.624 – 1.338 x 0.25 = 1.289

   (ii) From table 5.9, FOS (for C' / γH = 0.075) = 1.872 – 1.386 x 0.25 = 1.525

   (iii) Linear interpolation for C' / γ H = 0.063

   FOS = (1.525– 1.289/ 0.075 – 0.05) x (0.063– 0.05) + 1.289
   =1.41 > 1.4
   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 kN/m^2 (Measured in lab.)

c) Effective angle of shear resistance, $\phi'=20°$ (Measured in lab.)
d) Saturated density of soil, $\gamma_{sat} = 22\ kN/m^3$ (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 x 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), ϕ'= 20° and Side Slope = 2H:1V

a) For D = 1.00; from table - 5.6
m = 1.380 & n = 1.071
b) For D = 1.25; from table - 5.7
m = 1.509 & n = 1.226

2. To decide depth factor, r_{ue} will be computed as:
$r_{ue} = m_{1.25} - m_{1.00} / n_{1.25} - n_{1.00}$
= 1.509 - 1.380 / 1.226- 1.071
= 0.66 > 0.25 (r_u)
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 (for $C' / \gamma H$ = 0.025) = 1.124 - 1.022 x 0.25 = 0.868

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

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

FOS = (1.112 - 0.868/ 0.05 - 0.025) x (0.048- 0.025) + 0.868
=1.09 < 1.4

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, ϕ'= 20° remains the same. (Pore pressure ratio will changed to r_u= 0.21 for the Side Slope = 3:1, from table -5.2)

5. For $C' / \gamma H$ = 0.05, ϕ'= 20° and Side Slope = 3:1

a) For D = 1.00; from table - 5.6
m = 1.840 & n = 1.387
b) For D = 1.25; from table - 5.7
m = 1.834 & n = 1.493
c) Calculate r_{ue} to decide depth factor.
$r_{ue} = m_{1.25} - m_{1.00} / n_{1.25} - n_{1.00}$
= 1.834 - 1.840 / 1.493- 1.387
= -0.05 < 0.25 (r_u)

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.
$r_{ue} = m_{1.50} - m_{1.25} / n_{1.50} - n_{1.25}$
= 2.011 - 1.834 / 1.705 - 1.493
= 0.83 > 0.25 (r_u)
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' / γH = 0.048 at D = 1.25 as follows:

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

FOS = (1.521 - 1.308/ 0.050 - 0.025) x (0.048- 0.025) + 1.308
= 1.50 > 1.4
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 disturbed 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 for 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 ±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 ($Cu > 2$) 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.

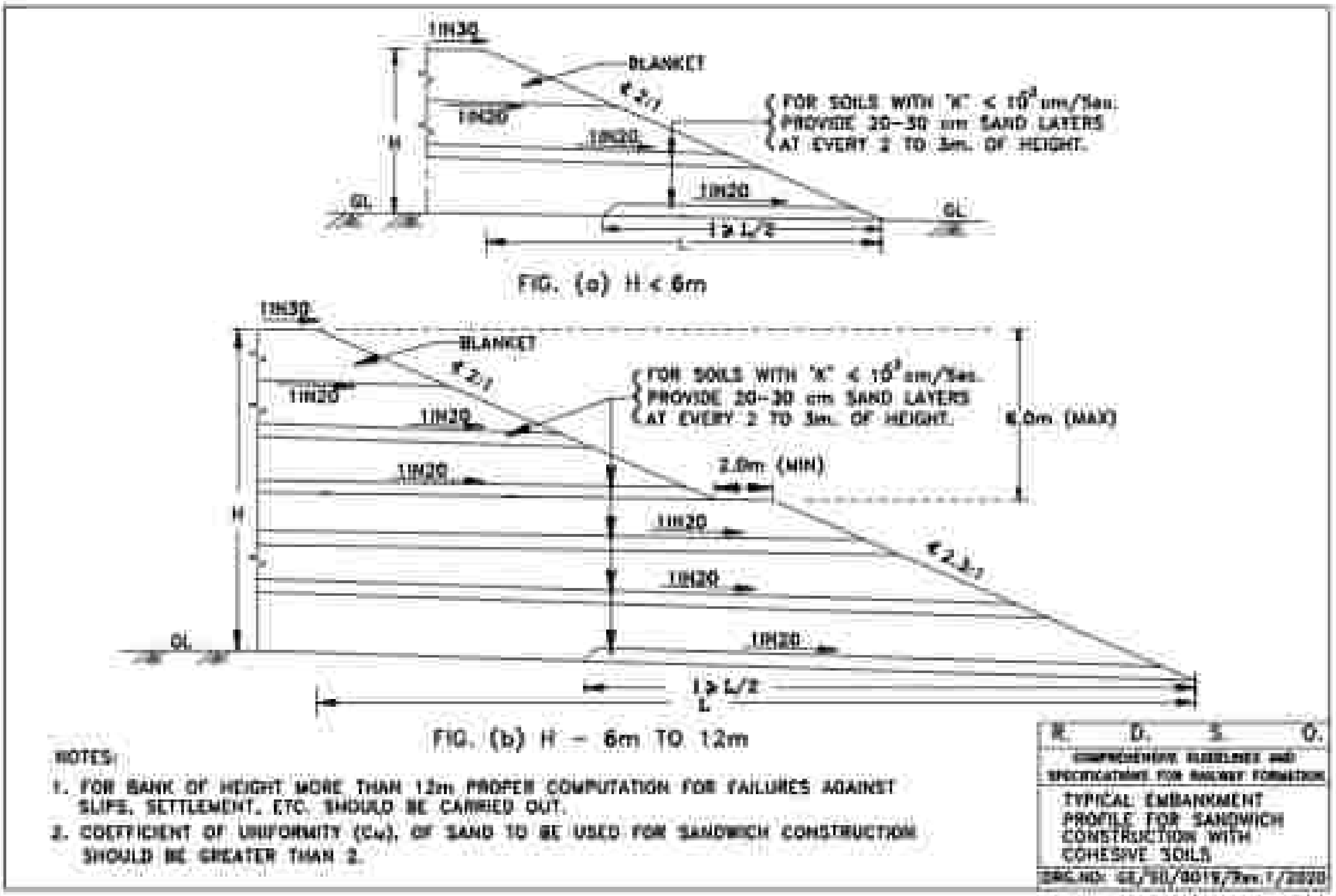
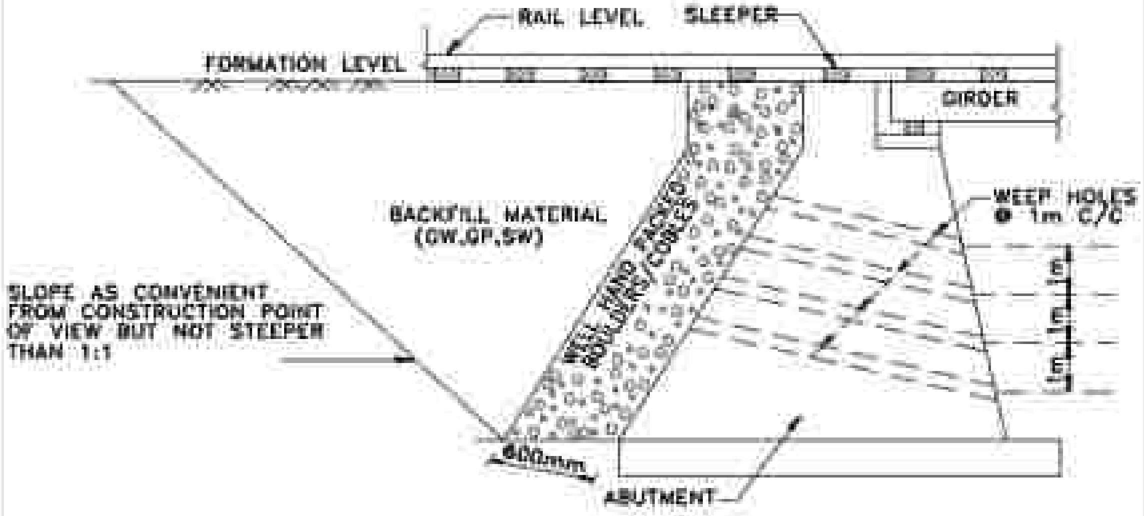


Fig-6.1 Typical embankment profile for sandwich construction with cohesive soil

6.2.5 Placement of Back-Fills on Bridge Approaches and Similar Locations

i) 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.

ii) 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.



NOTE:- 1. BEHIND ABUTMENTS, WING WALLS AND RETURN WALLS, BOULDER FILLING AND BACKFILL MATERIALS SHALL BE PROVIDED UPTO FULL HEIGHT.

2. THE BOULDER FILLING SHALL CONSIST OF WELL HAND PACKED BOULDERS & COBBLES TO THICKNESS NOT LESS THAN 600mm WITH SMALLER SIZE TOWARDS THE BACK. BEHIND THE BOULDER FILLING, BACKFILL MATERIALS, SHALL CONSIST OF GRANULAR MATERIALS OF GW, GP, SW GROUPS AS PER IS: 1498-Latest Edition

	R. D. S. O.
	COMPREHENSIVE GUIDELINES AND SPECIFICATIONS FOR RAILWAY FORMATION
	DETAIL OF BACKFILL BEHIND BRIDGE ABUTMENT
NOT TO SCALE	DRG. NO. GE/SD/0006/Rev.2/2020

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.

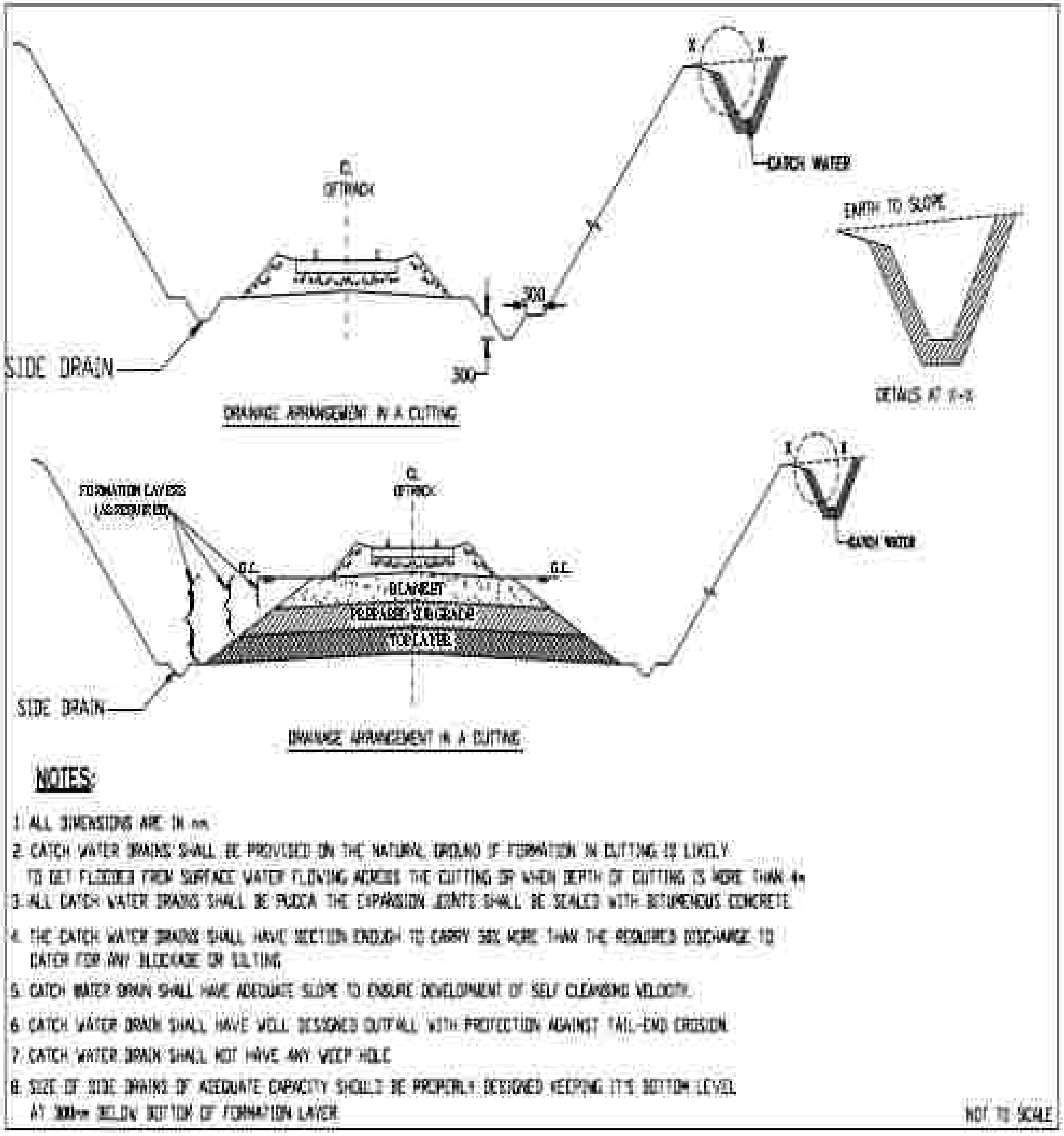


Fig-6.3: Arrangement of drainage in cutting

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.

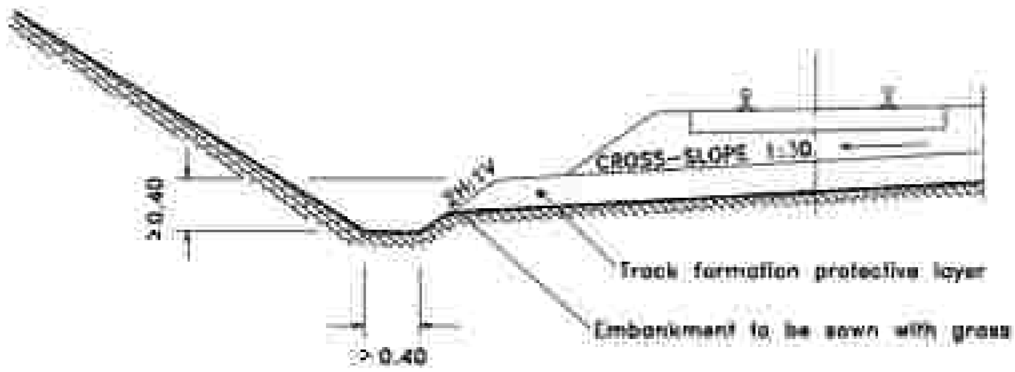
Though capacity and section will depend on terrain characteristics, rainfall etc. but following parameters are important for design of catch water drains:

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.

d) Alignment plan, longitudinal section and soil survey records of catch water drain should be updated from time to time as per development in the area of influence.

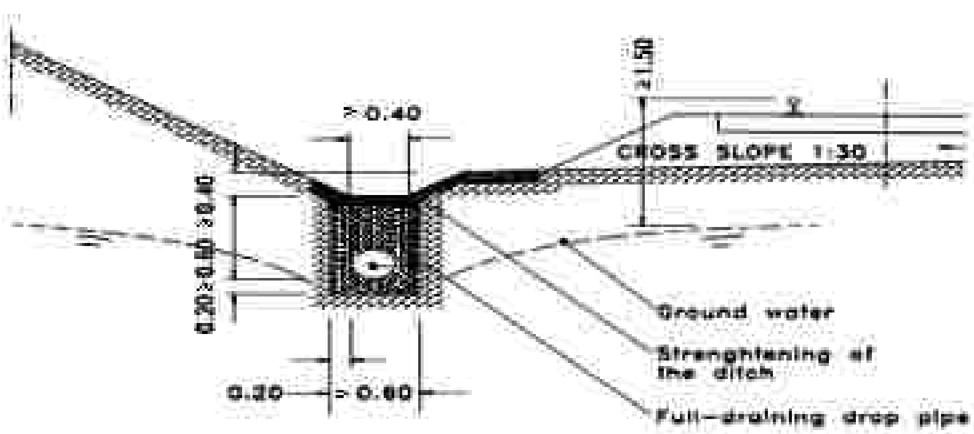
e) Stable slopes and adequate drainage arrangements in cutting areas should be provided as per details given in 'Guidelines for Cuttings in Railway Formations - No. GE: G-2, August 2005'.

iii) **Other Drainage Systems:** Open Drainage system typical as shown in Fig-6.4 below, will facilitate collection of rainwater from embankment, cuttings and side of cuttings and lead it away. Sub-soil Drain System typical as shown in Fig-6.5 below are installed where the groundwater level has to be lowered (from depth < 1.5 m below the rail top), where the soil surrounding the track formation has to be drained or where percolating and layer water has to be drained away.



(All Dimensions of side drain in 'm')

Fig-6.4: Open Longitudinal Drain at Toe of Formation



(Dimensions of side drain in 'm')

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.

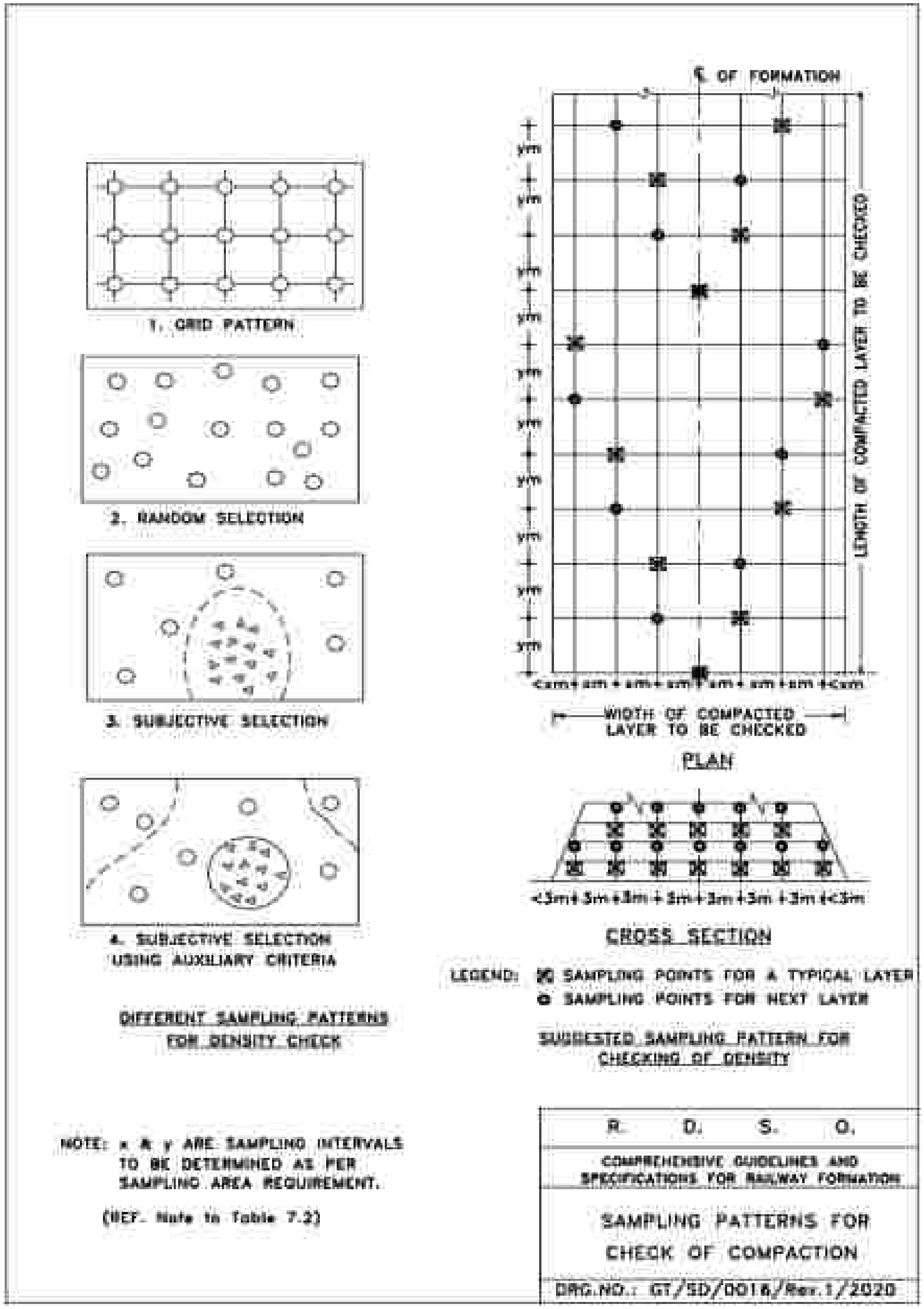


Fig-7.1: Sampling pattern for compaction check

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 (Ev_2) 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)				
	(iv) Abrasion value		IS:2386 – Part-4		
	(v) CBR		IS: 2720-Part-		

			16		
	(vi) Filter criteria		IS 2720 – Part-4		
	(vii) OMC & MDD		IS: 2720 – Part-8		
	(viii) $\geq_{max}$ & $\geq_{min}$ (Determined in Relative Density test If fines are upto 5%)		IS 2720-Part-14		
(ii) Finished earthwork					
(Subgrade /Prepared Subgrade/ Blanket)	(i) Ev_2	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:

i) 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.

ii) At least one density check for layers other than as specified in(i) above, every 500 m^2 or 75 m c/c whichever occurs earlier along the alignment in a staggered pattern of each compacted layer.

iii) 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 shurbs 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 Cynodon dactylon
2.	Cynodon plectostycum
3.	Chloris gayana
4.	Saccharum spontaneum Tall Pernicious Deep rooted Perennial
5.	Sachharum munja (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	Pennisctum 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 flexudosus) for use in elevations around1900 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	Cenchurs ciliaris	Can be used for most type of soil
3	Dichanthium annulatum	For alluvial soil
4	Pennisetum pedicellatum	Sandy loam soil
5	Rochola 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 (a): Slope erosion control using Geo jute

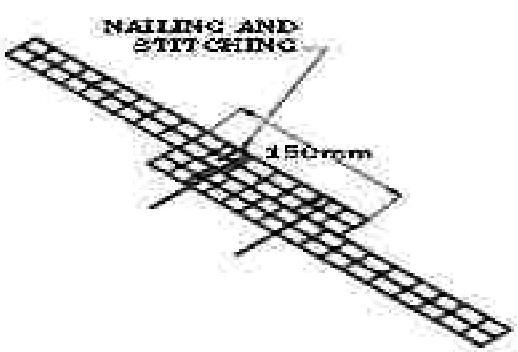


Fig- 8.1: (b) Overlapping Of Jute Netting

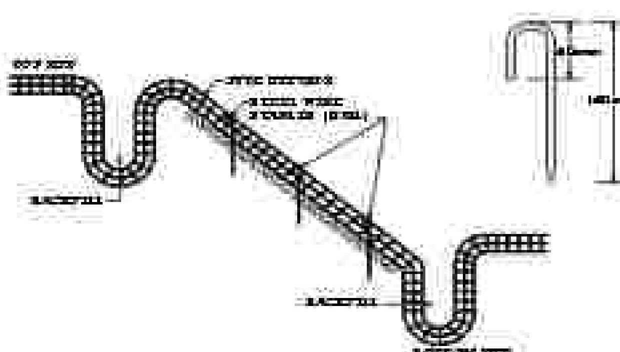


Fig- 8.1(c) Placement of Jute Netting

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.

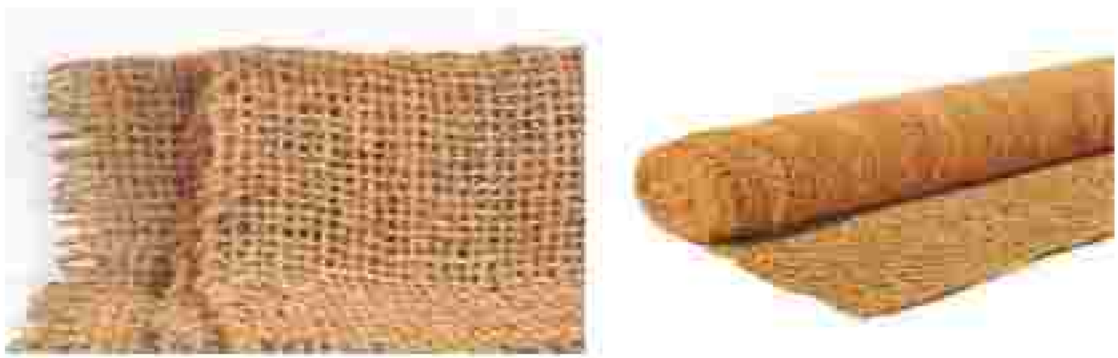


Fig- 8.2 Coir Netting

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.

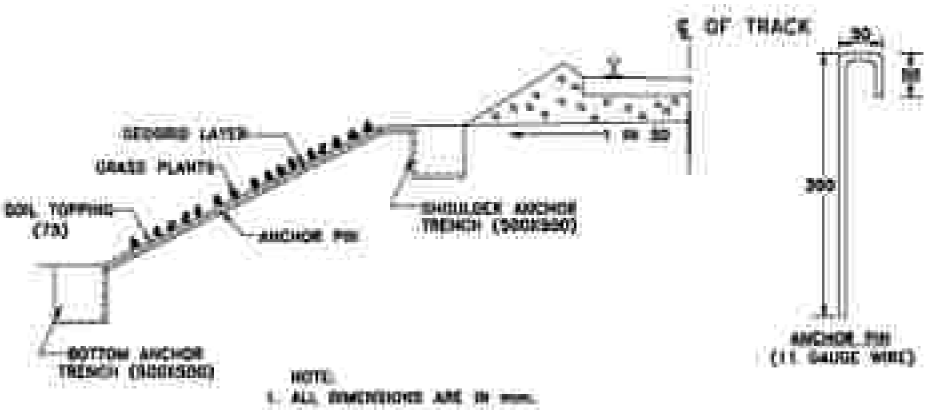


Fig- 5.3 Installation of Geogrid Mesh

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.

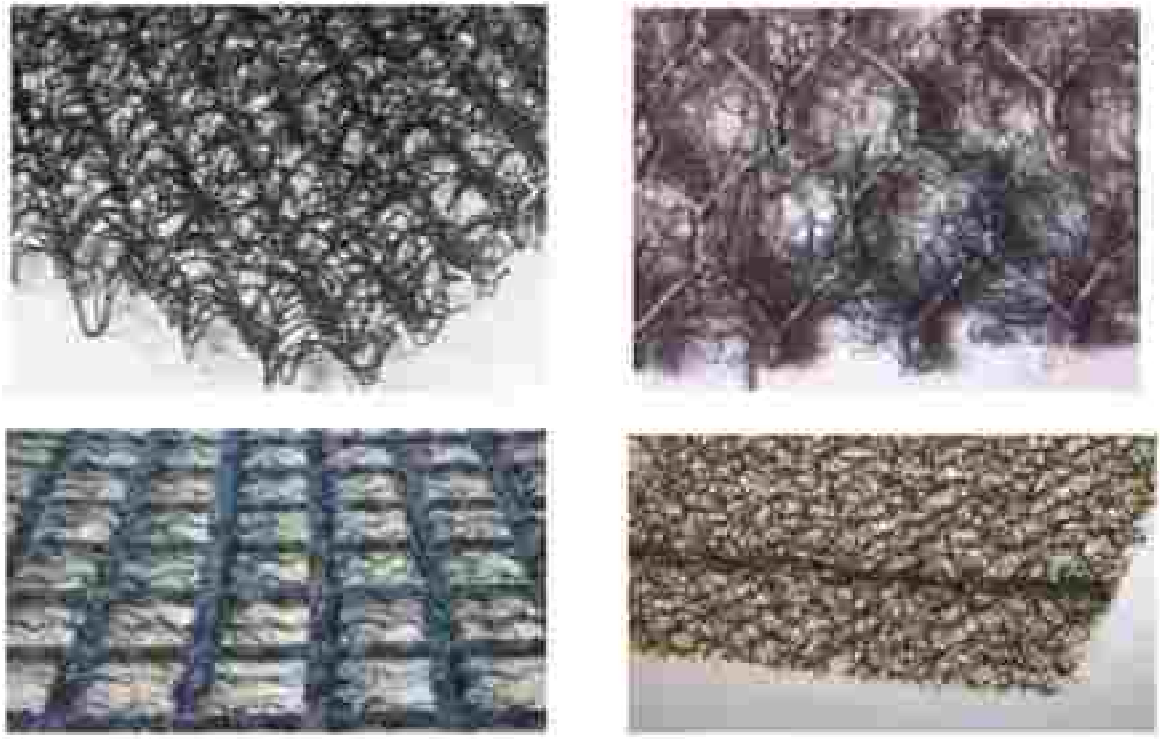


Fig- 8.4 Three Dimensional Erosion Control Mat

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

i) Before taking up widening of Embankment for gauge conversion, it should be ensured that remedial measures for 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 shown in **Fig-9.1** below so as to provide proper amalgamation between the old and new earthwork.

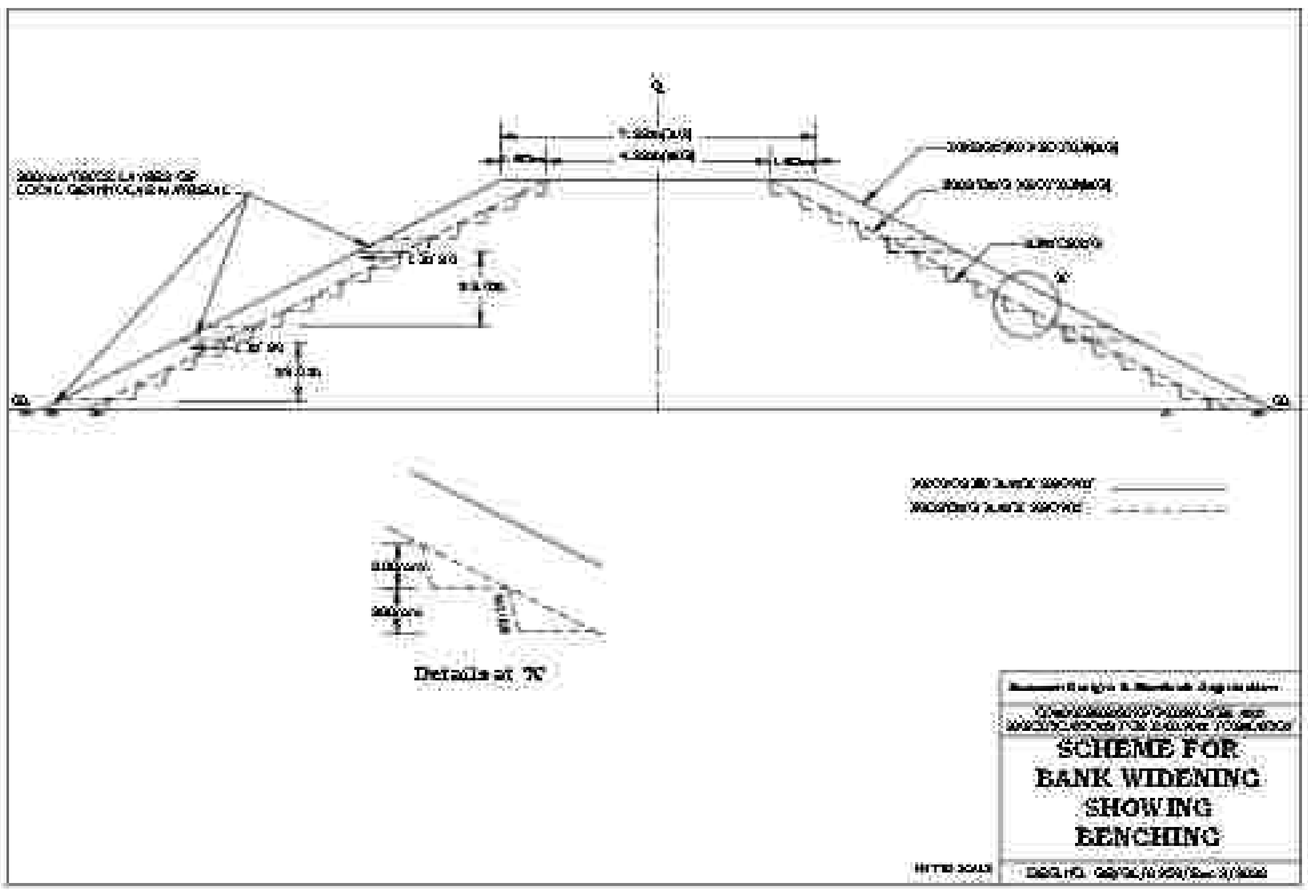


Fig-9.1: Scheme for bank widening showing benching

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.

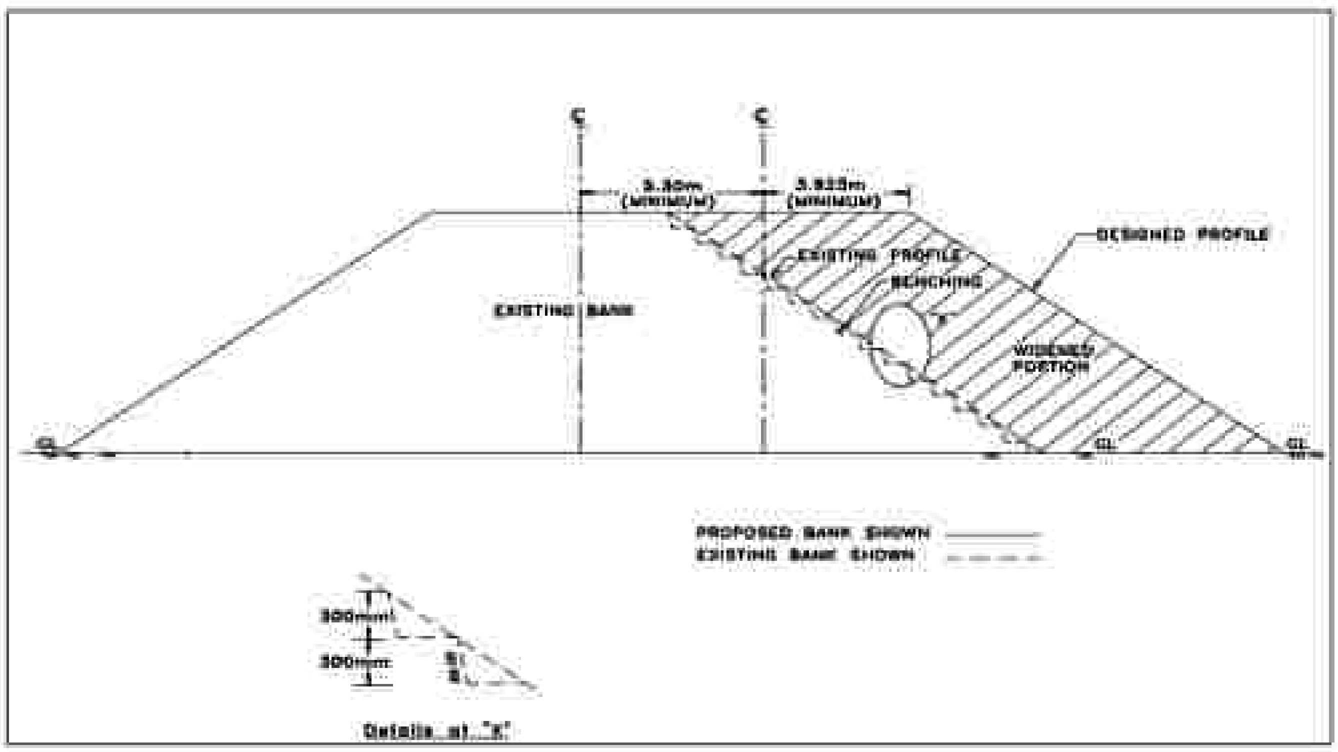


Fig-9.2: Widening of Embankment for doubling

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 fomation 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.

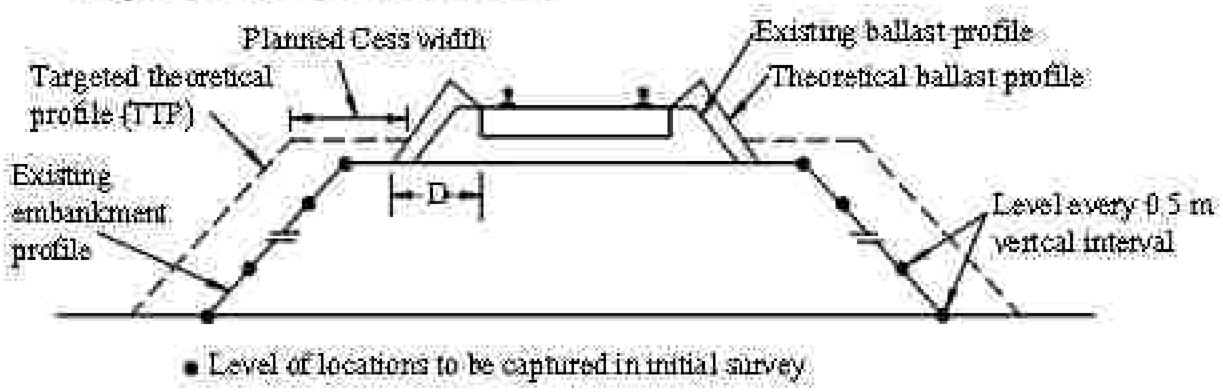


Fig-9.3

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).

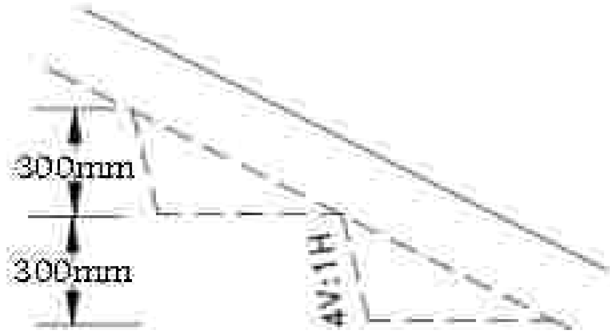


Fig-9.4

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.

CHAPTER-10

FORMATION REHABILITATION

10.1 General

Railway formation may develop instability for reasons of poor bearing capacity of formation, inadequate factor of safety against slope stability, excessive settlement and loss of soil from formation on account of erosion, etc. Existence of one or more of these causative factors may lead to development of others and ultimately leads to instability of formation.

Formation failure due to poor bearing capacity alone or in combination comprises most of the unstable stretches. Increase in axle load & GMT also have a significant effect on adequacy of bearing capacity of formation. Therefore, strengthening of formation against bearing capacity failure is an important rehabilitation work.

10.2 Type of Formation Failure

The railway formation generally fails on account of improper design of embankment profile, lack of compaction of earthwork, poor subgrade material and construction of embankment before consolidation of sub-soil. Once the failure sets in, further deterioration is faster. The main forms of failure are given below:

i) **Failures of the base or sub-soil strata**: Sub-soil strata may fail in shear or settle excessively and cause:
   a) Slips,
   b) Heave beyond toe, or
   c) Excessive deformation.

ii) **Failures of the fill material**: Fill material may fail in shear which may cause:
   a) Slips,
   b) Bulging or creep of slopes, and
   c) Excessive deformation.

iii) **Failure of the formation top**: This is due to poor sub-grade material, which results in ballast penetration, mud pumping and cess heave. This generally occurs during monsoons and the causes of the failures are:

   a) **Due to strength failure**: This occurs due to low shear strength of top soil causing settlement of track with a consequent heave of cess and ballast penetration.

   b) **Pumping failure**: This occurs due to presence of liquid slurry below the bottom of the sleeper. This may be formed with fine particles derived from the attrition of ballast, dust and water. Sometimes the residual negative pore pressure developed in the formation soil after the passage of the trains tends to cause softening of the soil and assists slurry formation. This slurry migrates upwards to the underside of the sleeper due to contraction and dilation of the ballast voids with passage of trains. This causes serious track irregularities

   c) **Due to development of cracks on the formation top during summer months**: Shrinkage cracks form in highly shrinkable soil during summer through which sometimes ballast enters resulting in the settlement of the track. The situation worsens in the rainy season when water enters into the formation through these cracks and causes swelling, resulting in frequent cross level variations.

d) **Due to the formation of gel on the formation top in Thixotropic soils**: Some soils after coming in contact with water assume a gel-like consistency and loose shear strength all together under the load by assuming a liquid like consistency. When the loads are removed, these soils revert back to their original gel-like consistency within a short period of time known as "gelation time". During the period the topsoil is having liquid-like consistency, there is complete loss of shear strength resulting in penetration of ballast and consequent settlement of track.

10.3 Summary of various probable failures and their remedies

Based on the site investigation and soil testing, the relevant remedial measures should be formulated. Some of the remedial measures suggested for the formation troubles generally encountered are listed below for guidance:

Table 10.1

S. No	Type of problem	Remedial Measures (*)
1.	Inadequate drainage due to high cess, fouled ballast	i) Improving side drainage by lowering the cess and screening of ballast
2.	i) Weak soil at formation top in contact with rain water resulting into mud pumping under trains, ii) Fouling of ballast with subgrade fines, iii) Impaired drainage	i) Improve drainage, ii) Provision of blanket of suitable thickness iii) Laying of Non-woven Geotextile below blanket
3.	i) Strength failure below ballast causing heaving up of cess or in between sleepers, ii) Ballast penetration exceeding 30 cm in formation	i) Provision of blanket of suitable thickness, ii) Laying of Non-woven Geotextile below blanket
4.	Seasonal variation in moisture in formation top in expansive soils causing alternate heaving and shrinkage of formation	i) Blanket of suitable thickness, ii) Thickness of blanket may be reduced with provision of Geogrid layer(s). iii) Laying of Non-woven Geotextile below blanket
5.	Gradual consolidation of earth below embankment. (Bank settlement & heaving of soil	i) Sub-bank may be provided or ii) Prefabricated vertical drain along with sand layer at top/ Geocomposite

	beyond toe)	drain (horizontal) or iii) Stone columns in sub soil.
6.	Creep of formation soil.	Flattening of side slopes with sandwiched construction.
7.	i) Inadequate sides slopes, causing embankment slips after prolonged rains, ii) Longitudinal cracks on cess/slopes	Flattening slopes with provision of berms (slopes analysed with slope stability analysis) & proper drainage system.
8.	Hydrostatics pressure built up under live loads in ballast pockets containing water causing embankment slips	Draining out of ballast pockets by sand or boulder drain.
9.	Erosion of slope/cess	i) Repair of slope/cess, ii) Provision of turfing, mats etc.
10.	Cut slope failure	i) Adequacy of slope/slope protection measure as required, ii) Provision of adequate drainage arrangement (Side drain/Pucca catch water drain etc. and ensure their proper functioning).

** The above measures suggested are only indicative in nature and final remedial measures shall be decided based on the site investigation, soil testing, past failure history (if any) etc. RDSO's help wherever necessary, may be taken for formulating the remedial measures.*

10.4 Identification, inspection of weak formation:

As also defined in IRPWM- For classification of formation requiring treatment, following steps shall be adopted:

a) Identification of Weak Formation- Identification of Weak Formation shall include the following-

i) Stretches having speed restrictions due to weak formation.
ii) Stretches where more than normal track attention is required.
iii) Stretches where ballast penetration profile is of 'W' shape and maximum depth of penetration is more than 30 cm.

In case any of the above conditions are met in the field, then the 4 step action plan given below is to be followed-

b) Action to be taken for weak formation- Following 4-step action plan should be adopted for stretches identified as weak formation: -

i) Make the formation width, cess level and side drains strictly in accordance with prescribed profile.
ii) Carry out shallow screening of ballast section (or deep screening where required).
iii) Ensure no loose or missing fitting.
iv) Increase the depth of the ballast section to 30cm or even up to 35cm.

If even after adoption of above measures, track maintenance problem persists, then it is a suspect formation and further detailed Geotechnical investigation is to be done for assessing the problem. Based on investigation results, if the formation is classified as Bad Formation then remedial measures for rehabilitation/Strengthening of bad formation should be taken accordingly.

c) Site inspection:

During site inspection of problematic locations, the Pro-forma for reporting details for unstable formation **(Appendix-J)** should be filled up. This should preferably be done before the soil samples and other site details are collected.
The objective of such inspections and investigation is to know the exact cause of the formation problem.

d) Recommended scheme for soil testing:

The identified and suspected locations shall be subjected to detailed examination as per symptoms of failures. Recommended scheme of soil exploration and testing is given in **Table-1.1 of chapter-1(Soil Exploration and Survey).**

10.5 Methods of Formation Rehabilitation

All formation rehabilitation schemes need to be framed by Railways. Help of an expert may also be taken if required. It is the responsibility of executive authority to ensure that formation rehabilitation work is carried out in accordance with rehabilitation scheme and adequate control is exercised in execution. However, RDSO may also be approached to provide consultancy on weak formation, if required.

In general, following points may be kept in view while planning for rehabilitation:

a) In developing rehabilitation schemes, stretches having similar soil characteristics and Embankment performance should also be included simultaneously.
b) Cause(s) of instability of formation should be analysed and accordingly rehabilitation measures formulated. There may be requirement of re-profiling of slope along with laying of blanket and other measures.
c) Geosynthetics may also be used along with laying of blanket for formation rehabilitation as an alternative, in consultation with RDSO as required.
d) Method of laying of blanket should be appropriate depending upon site conditions/requirements.

Various probable failures and their possible remedies are listed **in Table-10.1** above. Some of the formation rehabilitation measures which can be adopted are as discussed below:-

a) By providing blanket layer
b) By laying Geogrid and Non-woven Geotextile at the bottom of ballast along with deep screening by BCM
c) By cess widening
d) Rehabilitation of Unstable slopes
e) Using Formation Rehabilitation Machines.

10.5.1 By Providing Blanket Layer

The weak/unstable formations are mostly those formations where subgrade soil is expansive clay (e.g. Black Cotton Soil). The most significant property of these soils is that when mixed with water they swell considerably, losing their shear strength and on drying they shrink considerably. Because of this swelling and shrinkage, due to ingress of water in the rainy season, the track parameters get disturbed and ballast penetrates in the formation.

The problems caused by expansive clays can be addressed to a large extent by reducing the ingress of water (during rainy season) by provision of blanket layer of adequate thickness in the top layer of formation. The blanket layer acts as a separator as well as reinforcement layer reducing the pressure on the formation below. In case providing blanket layer of large thickness in running traffic conditions is not possible, its thickness can be reduced with provision of layer(s) of geogrid.

In addition to this by providing a non-woven geotextile as separator/filtration layer below blanket **(Fig-10.1)**, it prevents the water from top entering into the sub-grade & also prevents upward migration of fine particles from expansive clays (which are very fine grained) into the top coarse layer.

Various methods for laying blanket in running traffic conditions are covered in Para 10.6.

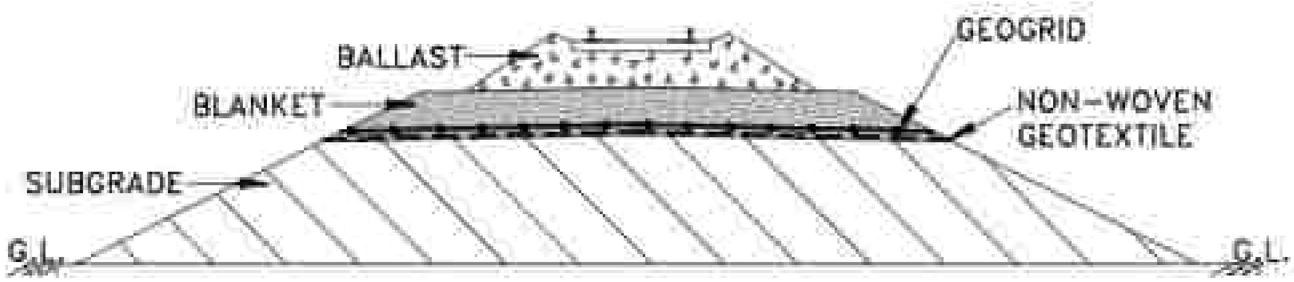


Fig-10.1: Use of Geosynthetic (Geogrid) in formation rehabilitation

10.5.2 By laying Geogrid and Non-woven Geotextile at the bottom of ballast along with deep screening by BCM:

The preferred method for strengthening/rehabilitation of weak/unstable formations will be provision of a Blanket layer of suitable thickness as detailed above. But in cases where it is not possible to adopt this method, and only shallow depth of formation is considered to be affected/weak, another lesser preferred alternative is laying a separator layer of non-woven geotextile and a reinforcement layer of geogrid over it, just below the ballast as shown in Fig-10.2. This type of laying can be done by Ballast Cleaning Machine (BCM) during deep screening of ballast, by adding suitable attachments with BCM for holding and laying non-woven geotextile & geogrid rolls. During the subsequent deep screening cycles, care should be taken not to disturb about 50-100mm thickness of bottom most layer of ballast, which will not only avoid entanglement of geosynthetics (geogrid and non-woven geotextile) with BCM but this layer will act as a confining layer also for Geosynthetics (geogrid and non-woven geotextile) improving their efficiency.

Non-woven Geotextile, will act as a separator layer preventing ballast getting contaminated with fine grained particles below. The non-woven geotextile also acts a drainage layer, thus assisting in reduction of entry of water into the subgrade, thereby preventing alternative swelling and shrinkage of the expansive subgrade soil due to moisture content variation to some extent. The geogrid layer reduces the imposed stress on the subgrade. In addition to this, the cess/side slopes are attended, if needed, to bring them within the standard profile and erosion protection is done, to prevent entry of water into the subgrade. All these measures combined, will help to address the problem.

However, before adopting the above method, detailed soil investigation must be done ascertaining the root cause of the formation problem. If the nature of the problems suggests that it cannot be solely rectified by adopting this method, then conventional method of providing blanket layer or other appropriate method as determined from investigation done shall be adopted.

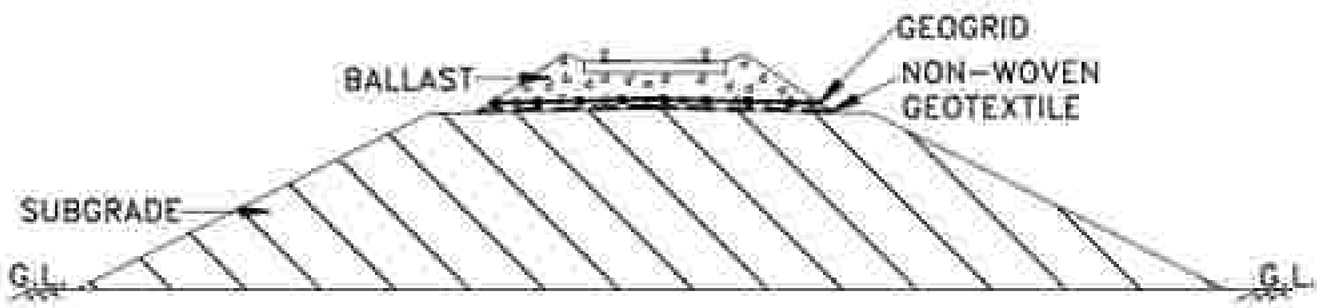


Fig-10.2: Alternative use of Geosynthetic (Geogrid and Non-woven Geotextile) in formation rehabilitation by BCM

Fig-10.3(a): Insertion of Material under BCM

Fig-10.3(b): Linking of Rolls to BCM

10.5.3 By cess widening

Cess widening is one of the methods for improving the strength of Embankment soil by process of confining as the strength of confined material is higher than unconfined material. For detailed procedure, Para 9.2 of Chapter 9 shall be referred to.

This method was used for 9 km length from km 113 to 122 in Vikarabad – Wadi section of South Central Railway, and results were found to be encouraging, as the number of attentions required to maintain track were reduced substantially and TGI values also improved in this stretch.

10.5.4 Rehabilitation of Unstable slopes

i) 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.

ii) Starting from the toe, benching on the slope at every 30cm height shall be provided on the slope surface as shown in Fig-10.4 below so as to provide proper amalgamation between the old and new earthwork.

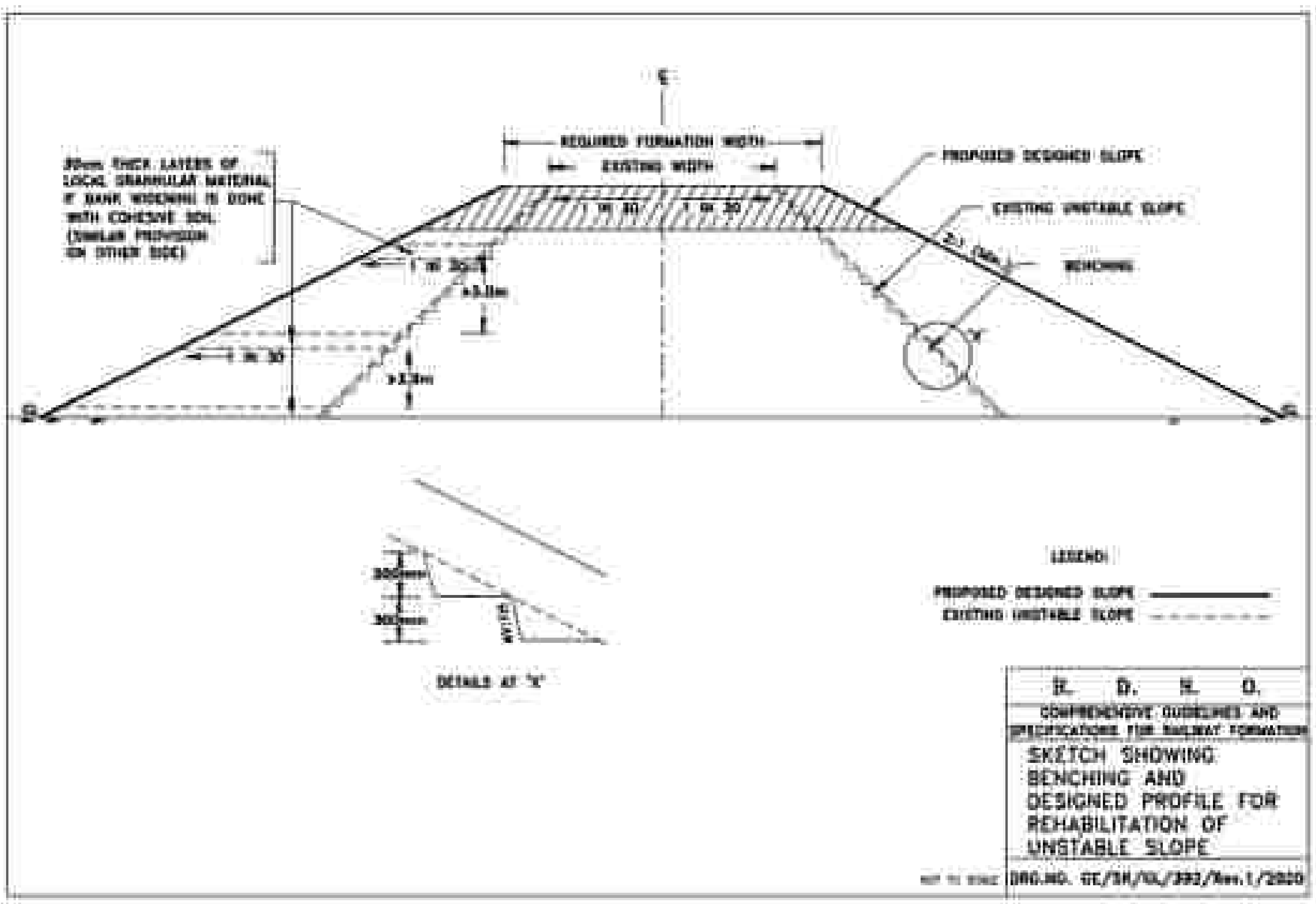


Fig-10.4: Sketch for Rehabilitation of Unstable slopes

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.

iii) 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.

iv) This para covers slope rehabilitation aspects only. Others measures required as per site condition like, drainage arrangement etc. are to be taken as required.

10.5.5 Formation improvement using Formation Rehabilitation Machines

Nowadays Formation Rehabilitation Machines which are fully mechanised are being utilised for rehabilitation of formation in different World Railway systems. Formation Rehabilitation Machines perform all the necessary tasks such as ballast recycling, levelling, lifting, lining and tamping etc.in one operation without disrupting rail traffic on the adjacent track. A formation protective layer (FPL) is installed in order to raise the load-bearing capacity of the subsoil effectively and sustainably.

All these machines are designed for simultaneous introduction of geotextiles and geogrids.

Important features of Formation Rehabilitation Machines are:

i) Total excavation can be achieved in one or two passes
ii) Old ballast is recycled for use as protective layer material
iii) Automatic control and moisture regulation of the new protective layer material.
iv) High uniform consolidation performance thus achieving very good quality of protective layer.
v) Output of the machine ranging from 40 to 80 m/h depending on the thickness of the protective layer.
vi) On a double track line no hindrance to traffic on the adjacent track.
vii) Various thicknesses of protective layers up to 50 cm can be inserted in one pass.

Austrian federal Railways having experience of formation rehabilitation machines known as AHM-800R and RPM 2002.

In addition to the measures detailed in above Paras, proper cross slope should be provided and proper turfing or other erosion control measures shall be undertaken on the side slopes to prevent ingress of moisture in the formation from cess and side slopes.

10.6 Methods of Laying Blanket Layer

(a) Track dismantling method:

The method consists of dismantling a portion of track under traffic block (4hrs duration) and removal of ballast and weak formation layer and replacement with blanket layer and reconnection of track on ballast.

Execution of work:

i) Before traffic block

Decide longitudinal level & select blanketing material (including required moisture content & density), lay single rails if higher length panels exist, provide ramps on to the embankment for movement of tippers to carry blanketing material etc. & remove shoulder ballast.

ii) During traffic block (about 4 hrs. Duration)

a) Lift single rail panels and remove balance ballast with excavators.
b) Excavate formation to required depth with excavator.
c) Roll the formation providing 1 in 30 cross slopes in one direction.
d) Spread blanket material to optimum thickness for full formation width + 50 cm on cess side(s) to facilitate compaction.
e) Compact blanket material (being granular cohesion less & well graded) with vibratory roller to achieve min. 70% relative density (IS code no: 2720 (Pt 14) latest version).
f) Spread ballast & put back track panels (kept on slope of embankment).
g) Attend track and allow traffic.

iii) After traffic block

Dress side slopes with suitable erosion control measures if required.

a) **Progress**
Progress of laying of blanket can be in the range of 100-120m per day. Work can be taken up at more number of sites in shadow block.
b) **Quality:** There is no constraint in achieving good quality of work.
c) **Flexibility in execution**
Depth of excavation of formation & lifting of track both can be carried out to the requirement of site. Similarly, any thickness of blanket also can be laid. It can be adopted in any type of track structure, electrified or non-electrified. Only requirement is that the site should be approachable to bring machineries and space available to keep track panel, blanket material etc. Method has been successfully implemented in some Railways like SC Rly.

(b) Using Formation Rehabilitation Machine: Details discussed in Para 10.5.5.

BIBLIOGRAPHY & REFERENCES:

1. HMSO (1952) – "Soil Mechanics for Road Engineers"
2. Indian Railway Code for the Engineering Department-Revised Edition-1982(Fourth Reprint-2012)
3. RDSO 1972 – Civil Engineering Report no: C – 127 – Report on a study of the Characteristics of compacted and uncompacted Expansive Soils"
4. RDSO (1977) – Civil Engineering Report no: 157 "Compaction Characteristics of Black Cotton Soils.
5. Terzaghi, K and Peck, R.B. (1967) - "Soil Mechanics in Engineering Practice" – John Wiley & Sons.
6. Selig E.T. & John M.Waters - "Track Geo-technology and Substructure Management"
7. Civil Engg. Report no. CE- 267, - 'Role of residual shear strength in railway formation and its determination', Dec., 1991
8. A. Gomes Correia, 'Geotechnics for Roads, Rail Tracks and Earth Strctures, 2001, A. A. Blakema Publishers, Proceedings of European Technical Committee No. 11 of ISSMGE.
9. R. Kerry Rowe – "Geotechnical and Geo-environmental Engg."
10. Hilf J.W., 'A rapid method for construction control for Embankment of cohesive soil, ASTM special publication No. 232, 1957.
11. AREMA Manual, 2019
12. Australian Railway (ARTC) Code RTS 3430
13. Guidelines of Earthwork in Railway Projects, RDSO, No. GE:G-1, July, 2003
14. Guidelines and Specifications for Design of Formation for Heavy Axle Load, Report No. RDSO/2009/GE: G-0014, November'2009.
15. Guidelines for Cuttings in Railway Formations, GE:G-2, Aug' 2005
16. Guidelines on Erosion Control and Drainage of Railway Formation, GE:G-4, Feb 2005
17. Guidelines on Soft Soils- Stage Construction Method, GE:G-5, April 2005
18. Guidelines for Application of Jute Geotextile in Railway Embankments and Hill Slopes RDSO/2007/GE:G-0008
19. Rationalisation of Formation Layer thickness on Indian Railway Track, Spec. No. RDSO/2018/GE: IRS-0004(D) Part-IV.
20. BS EN 13250:2016 Geotextiles and geotextile related products – Characteristics required for use in the construction of Railways.
21. Robert M. Koerner (2016): Designing with Geosynthetics – 6th Edition (Vol. I and II).
22. Sanjay Kumar Shukla and Jian-Hua Yin: Fundamentals of Geosynthetic Engineering, published by Taylor & Francis.
23. Buddhima Indraratna, Wadud Salim and cholachat Rujikiamjorn; Advanced Rail Geotechnology – Ballasted Track, published by CRC press

24. IIT/Kanpur Research report no. 1/93, April-1993.

25. RDSO Report no. CT-23, January 2010.

26. State of the Art Report on sub-grade stress and design of track substructure, Civil Engineering Report No. C – 271.

27. IRC: 37- 'Guidelines & Design of Flexible Pavement', Indian Road Congress.

28. IRC: 56- 'Recommended practices, treatment of Embankment and Roadside slope for Erosion Control', Indian Road Congress.

29. ORE Reports D – 71, RP – 12 & D-117, RP - 28.

30. 'Modern Railway Track', Esveld, Coenard MRT Productions NL, TU Delft, Second Edition 2001.

31. 'Procedure For Railway Track Granular Layer Thickness Determination', Dingqing Li, Theodore R. Sussmann Jr., and Ernest T. Selig, Report no. R-898, October, 1996, Assosiation of American Railroads (AAR), TTC, Pueblo, Colorado, USA.

32. Track Compendium– Formation, Permanent Way, Maintenance, Economics, by Dr. Bernhard Lichtberger, 2005, Eurail Press, Hamburg, Germany.

33. UIC Code 719R: 'Earthworks and Track-bed layers for Railway Line', Third ed., 2008.

34. Paper on behaviour of geosynthetic encapsulated stone column in International society for soil mechanics and Geotechnical Engineering by Professor K. Rajagopal/IIT Madras.

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Mechanical Production of Blanket Material

Normally, the blanket material shall be produced mechanically by crushing the stones and/or by mixing, naturally available materials using suitable equipment/plants like crusher or pug mills. Detail of these two methods is given below:

1.0 Crushing Methodology:

In the event of non-availability of natural source of blanket material, depending on the proximity of project site from the parent rock/boulder sources, it may be decided to crush the rock/boulder in order to produce crushed blanket material. Salient features of this methodology are:

a) Crushed blanket material may be produced as sole product or in conjunction with ballast or any other nominal size.

b) Trials and permutations of feed speed, crushing cycle, and sieve combinations may be required to arrive at the required particle size gradation.

c) It is possible to achieve near total produce of desired gradation through production cycle management. Alternately, it may be possible to get by-products of other sizes in the desired proportion and blanket material as main produce or vice-versa.

d) Optimisation of production rates and costs can be achieved by controlling the output at each sieve stage.

e) It is ideal to mix the required quantity of water for OMC (accounting for loss/gain of moisture due to weather conditions) at the crusher plant and transport the material in wet condition.

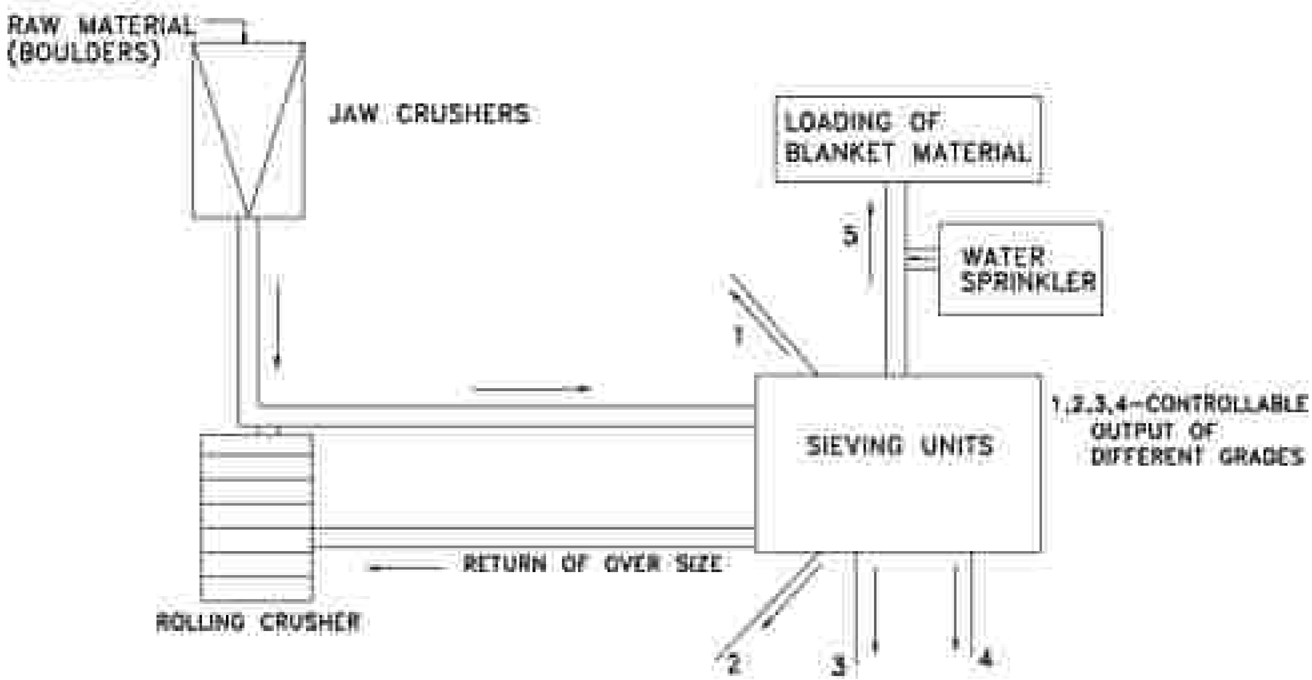


Fig-A1: Schematic Diagram of Manufacture of Blanket Material by Crushers

Fig-A2: General View of Crusher

Fig-A3: View of Storage bin

2.0 Blending Methodology :

a) Blanket material could be obtained by proper blending of two or more soils or in combination with soils and crushed material like stone chips.

b) Before approving such sources, trials for blending to judge the final product, needs to be done. Detail methodology of blending to be adopted to produce large quantity of blanket material with consistent quality, needs also to be laid down in advance.

c) Blending of either natural or crushed materials in a pre-decided ratio could be adopted.

d) Theoretical and laboratory trials are required in order to establish the desirable ratio of the blending materials. This exercise may be done in advance before finalizing the contracts for such a material.

e) The methodology of blending trials is explained below :

i) Identify the usable materials/soils.
ii) Take equal weight of the soils for sieve analysis.
iii) Write down the weight retained at each sieving stage for all the soils.
iv) Apportion a percentage component to each soil and work out a theoretical mix.
v) Draw particle size distribution curve of the mix to find out desirability of gradation.
vi) If not successful, make another trial, and so on.
vii) Trials and plotting work can also be done using simple computer programs.

2.1 Mechanical blenders using simple technology are now available in the market. Two types of mechanical blenders are quite common:

a) **Drum type blenders:** Drum type machines may involve weigh batching or manual feeding of material. They involve more moving parts. Hence, these machines are both manpower and maintenance intensive. They may pose a problem of segregation of material and as such do not afford any cost advantage either in the short or long run. These may be suitable for small quantities and not for large-scale production as required in construction projects.

b) **Pug mill type blenders:** For continuous production of mix in large quantities, the best way is to feed the aggregates/ soils of pre decided gradation by way of 3 or 4 bins with conveyor belt. The required output grading can be achieved by adjustment of gate openings of bins. The use of pug mill type blenders is found very cost effective, as the manpower involvement is very little and only 4-5 people can run a plant of 100 tph. The pug mill blender consists of:

i) Four bin aggregate unit
ii) Pug mill mixer unit
iii) Water tank and metering system
iv) Conveyor belts
v) Storage silos (optional)
vi) Anti-segregation surge hopper
vii) Automation and controls

The other important features of this technology are:

i) Automatic feeding of soils/aggregates under gravity,
ii) Arrangement for precise control of mixing of water,
iii) Either direct loading into trucks, or optional storage at plant,
iv) Availability of domestic manufacturers, and low cost of set up,
v) Advantage of removal and relocation with ease.

A schematic diagram showing the various arrangements is shown below:

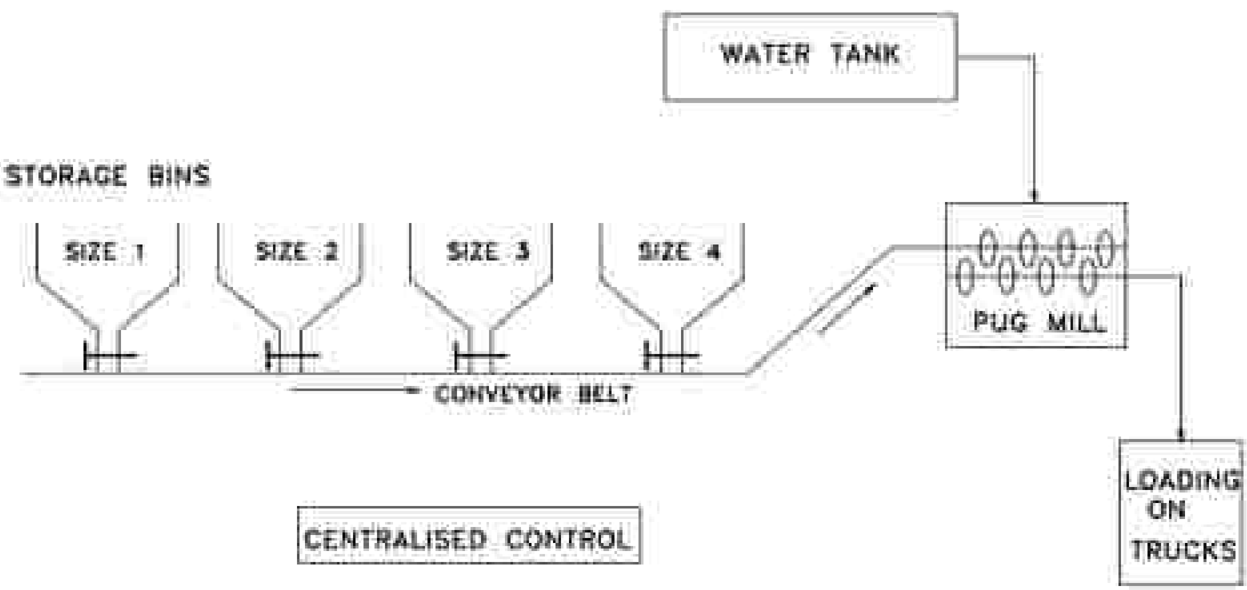


Fig-A4: Schematic Diagram of Manufacture of Blanket Material by Blending

2.2 The equipment for blending should enable blending of two or more materials uniformly so that the blended material satisfies the specification. The equipment chosen should be cost effective and easy to handle with and efficient.

3.0 Specifications of Mechanically Produced Blanket Material: Blanket material produced in a plant should generally conform to specifications as mentioned in Table 3.3 to table 3.6, Chapter 3 of this Comprehensive Guideline and specification.

4.0 Quality Control on Blanket Material at production site:

It is desirable to have a check on quality of material at source/manufacturing point so that major deviation in quality of the material being sent to site does not exist. It would be in the interest of the supplier to have such tests conducted on his own to avoid any complication at a later stage.

4.1 Method of Test: Blanket material should be tested in pursuance to specifications for blanket material as laid down in Table 3.3 to 3.6 of this Comprehensive Guideline and specification.

4.2 Frequency of Tests at Site: As per Table 7.2 of this Comprehensive Guideline and specification.

Fig-A5: Computer Controlled Bins for Mixing

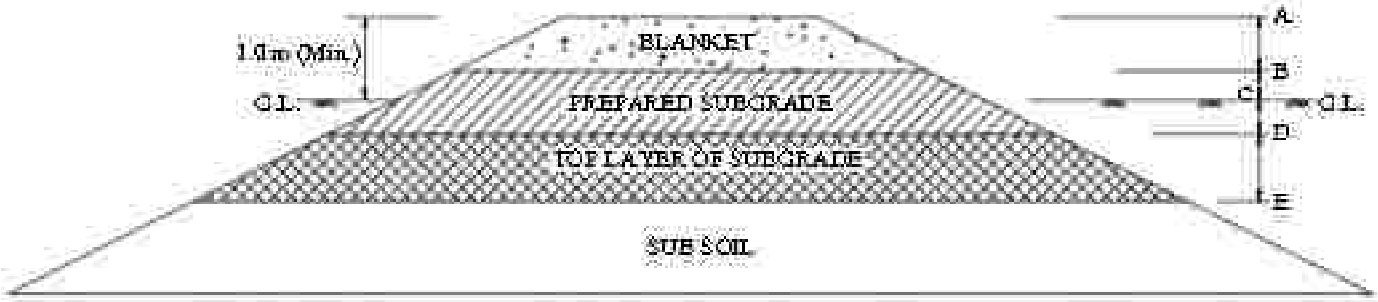
Fig-A6: Blanket Material Being Loaded into Truck

APPENDIX-B

Illustrative Examples for providing minimum thickness of Formation Layers

1.0 Construction of Formation in Embankment & Cutting:

1.1 For Embankment (where height is less than required total uniform thickness)



Fig–B 1: Formation Layers in Embankment

a) If sub-soil material CD is of better quality than the specifications of prepared subgrade and DE part is of better quality than the specifications of top layer of subgrade, then remaining part of prepared subgrade (BC) and blanket layer (AB) of specified thickness only is required to be provided above ground level for embankment construction. No excavation below ground level is required.

b) If minimum required depth of sub-soil CE is of better quality than the specifications of top layer of subgrade and inferior to that of prepared subgrade, then upper layer upto CD will be required to be replaced with specified quality of soil equivalent to prepared subgrade. Above ground level remaining part of prepared subgrade (BC) and blanket layer (AB) of specified thickness are required to be provided.

c) If layer CE upto minimum required depth do not meet the specifications of top layer of subgrade, then upper layers of sub-soil upto "E" level should be removed and compacted with specified quality of soil i.e. in CD, soil with specified quality for prepared subgrade and in DE, soil with specified quality better than that for subgrade/top layer. Above ground level, remaining part of prepared subgrade (BC) and blanket layer (AB) of specified thickness are required to be provided.

Few representative sketches showing thickness of formation layers in embankment depending on site conditions:

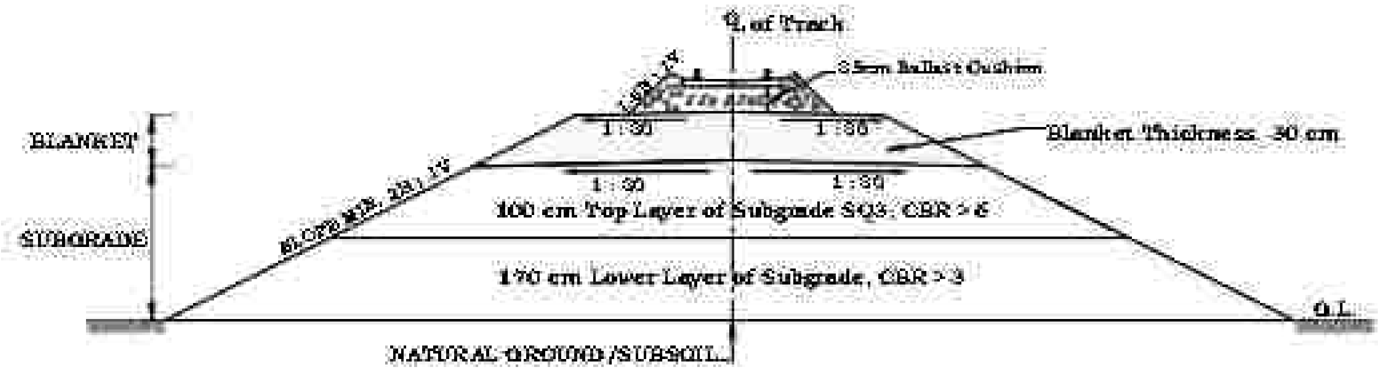


Fig-B2: Height of Bank=3.0m, **Single layer system** (25T Axle load), with SQ3 subgrade (CBR≥6)

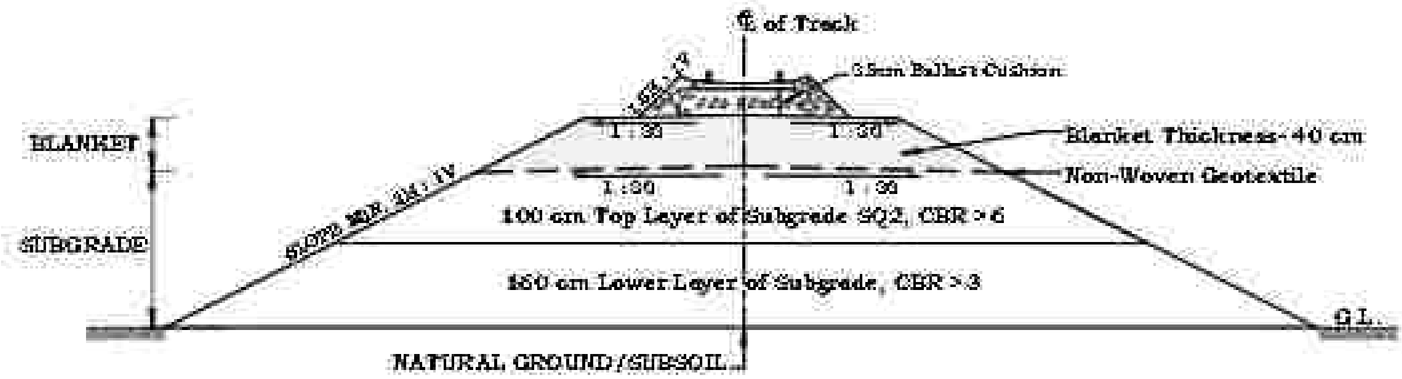


Fig-B3: Height of Bank=3.0m, **Single layer system** (25T Axle load), with SQ2 subgrade (CBR≥6)

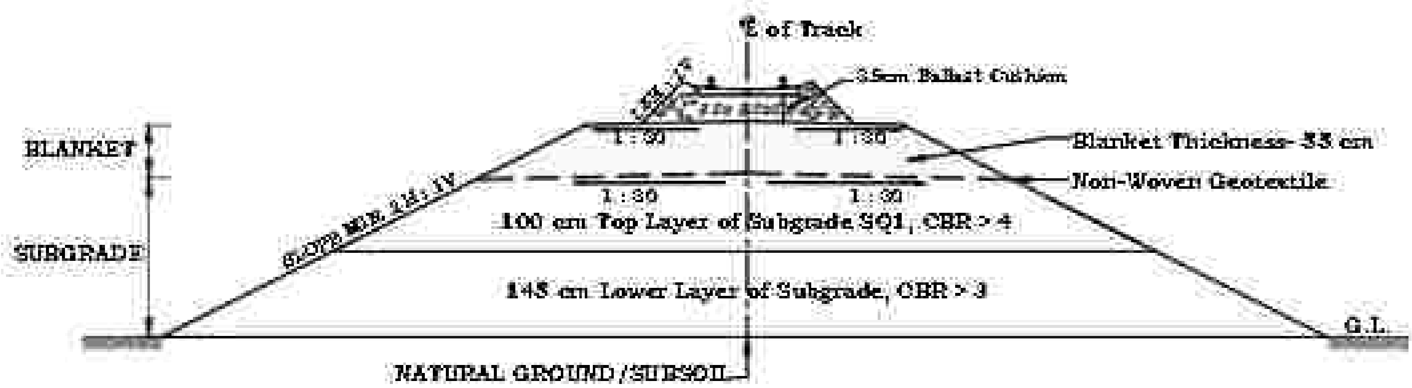


Fig-B4: Height of Bank= 3.0m, **Single layer system** (25t Axle load), with SQ1 Subgrade (CBR≥4)

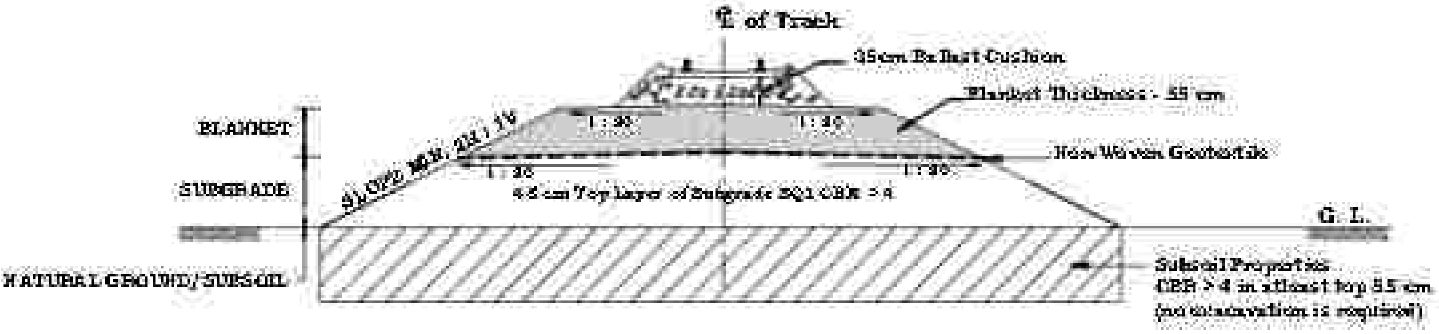


Fig-85: Height of Bank 1.0m, **Single layer system** (25T Axle load), with SQ1 subgrade & Subsoil with CBR≥4 (No excavation below GL)

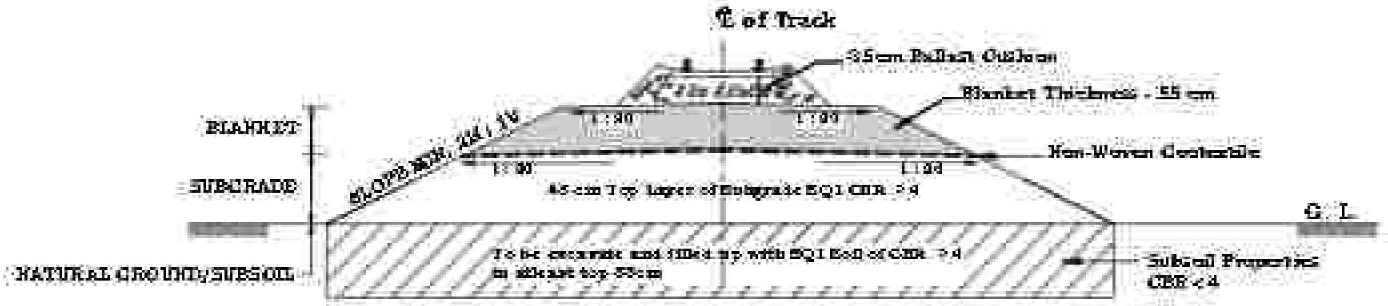


Fig-86: Height of Bank 1.0m, **Single layer system** (25T Axle load), with SQ1 subgrade & Subsoil with CBR<4 (Excavation & replacement of min 55cm with CBR≥4 soil below GL)

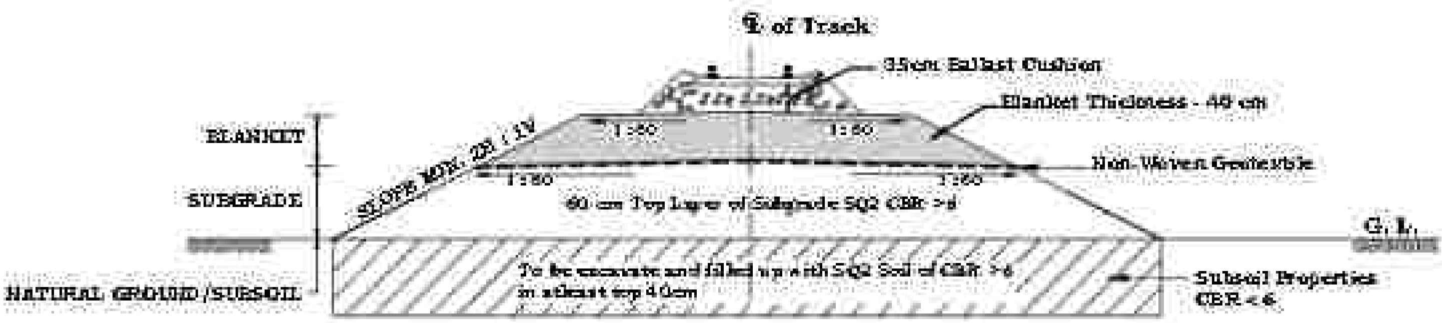


Fig-87: Height of Bank 1.0m, **Single layer system** (25T Axle load), with SQ2 subgrade & Subsoil with CBR<6 (Excavation & replacement of min 40cm with CBR≥6 soil below GL)

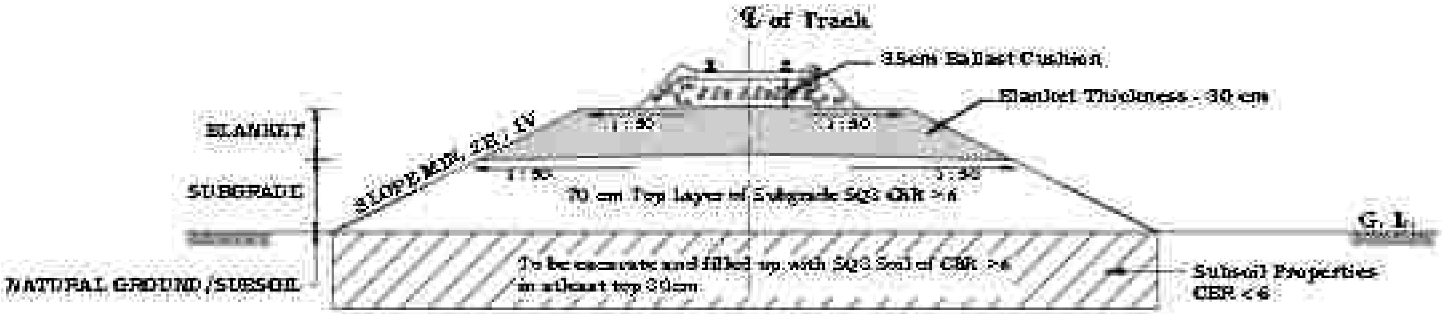


Fig-B8: Height of Bank 1.0m, **Single layer system** (25T Axle load), with SQ3 subgrade & Subsoil with CBR<6 (Excavation & replacement of min 30cm with CBR≥6 soil below GL)

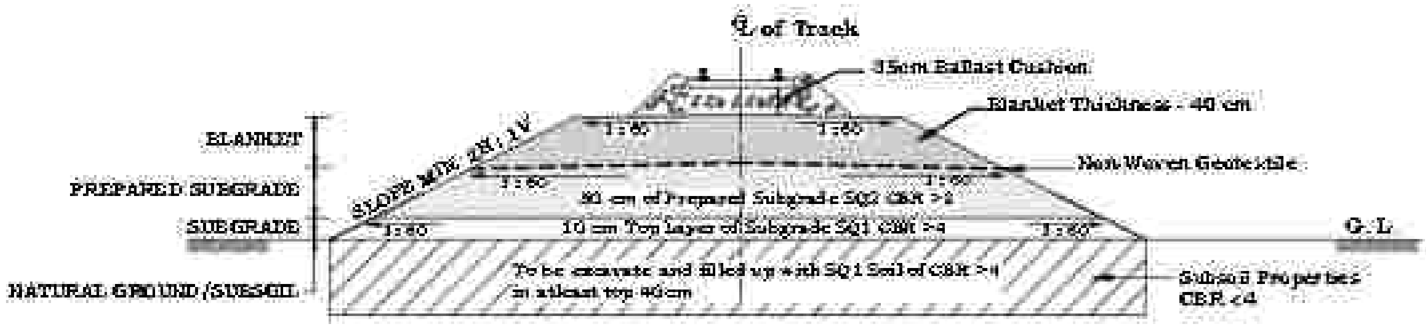


Fig-B9: Height of Bank 1.0m, **Two layer system** (25T Axle load), with SQ2 Prepared Subgrade, SQ1 Subgrade & Subsoil with CBR<4 (Excavation & replacement of min 40cm with CBR≥4 soil below GL)

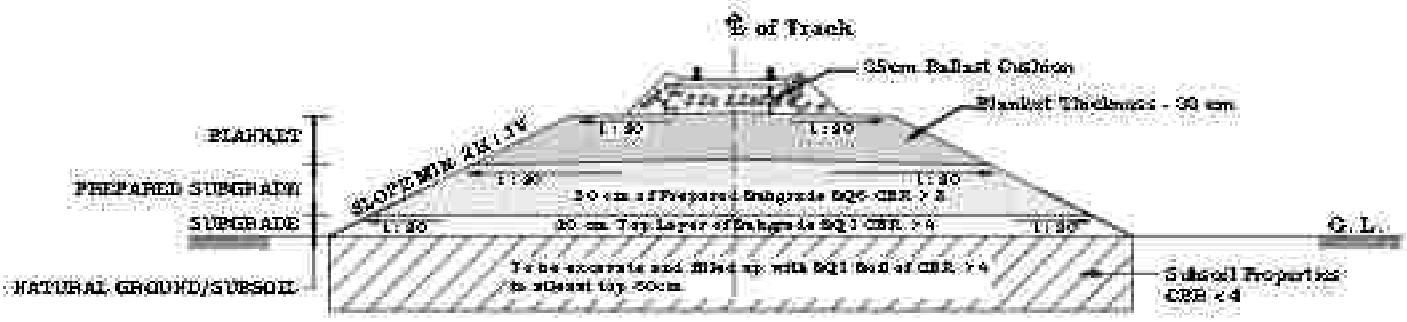


Fig-B10: Height of Bank 1.0m, **Two layer system** (25T Axle load), with SQ3 Prepared Subgrade, SQ1 Subgrade & Subsoil with CBR<4 (Excavation & replacement of min 30cm with CBR≥4 soil below GL)

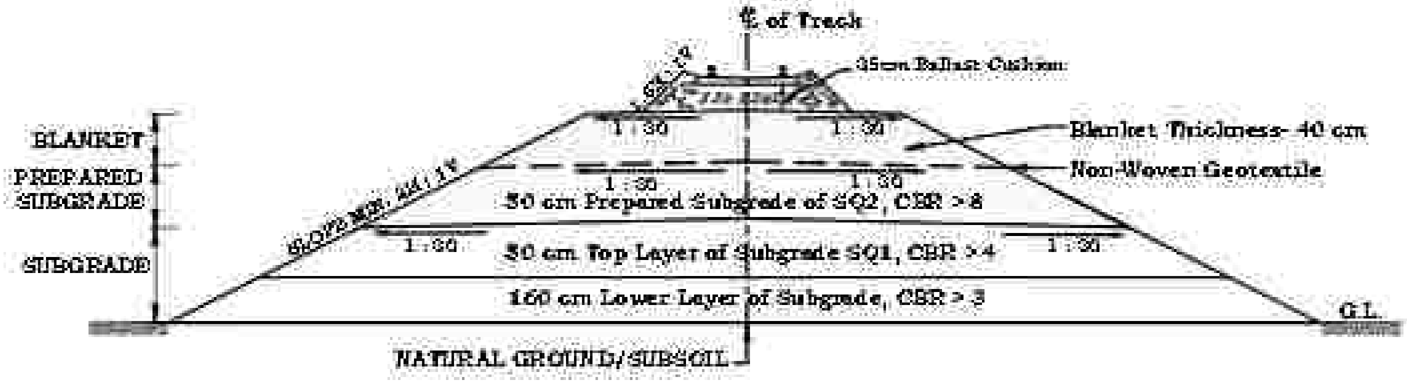


Fig-B11: Height of Bank 3.0m (**Two layer system**), 25T axle load, with SQ2 Prepared subgrade and SQ1 Subgrade

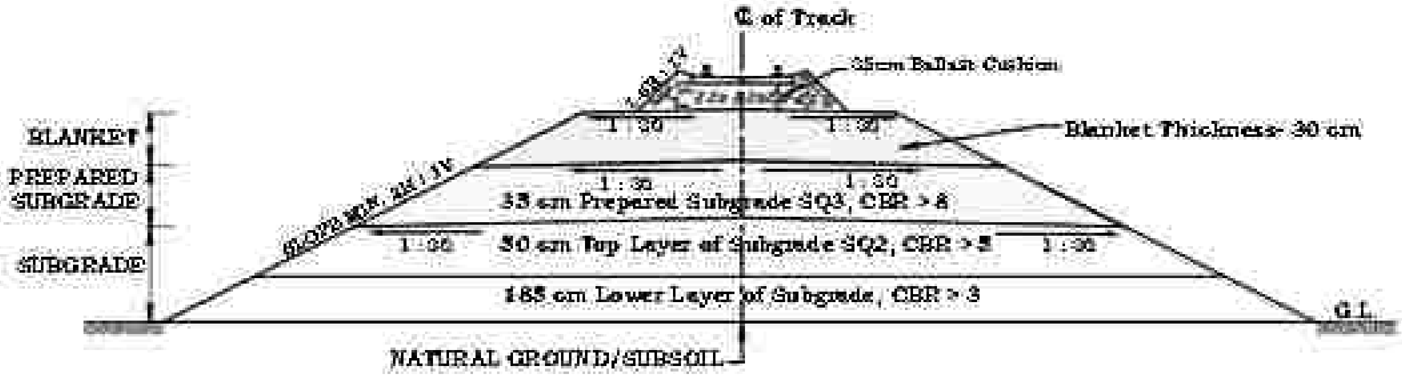


Fig-B12: Height of Bank 3.0m (Two layer system), 25T axle load, with SQ3 Prepared Subgrade & SQ2 Subgrade

1.2 For Cutting

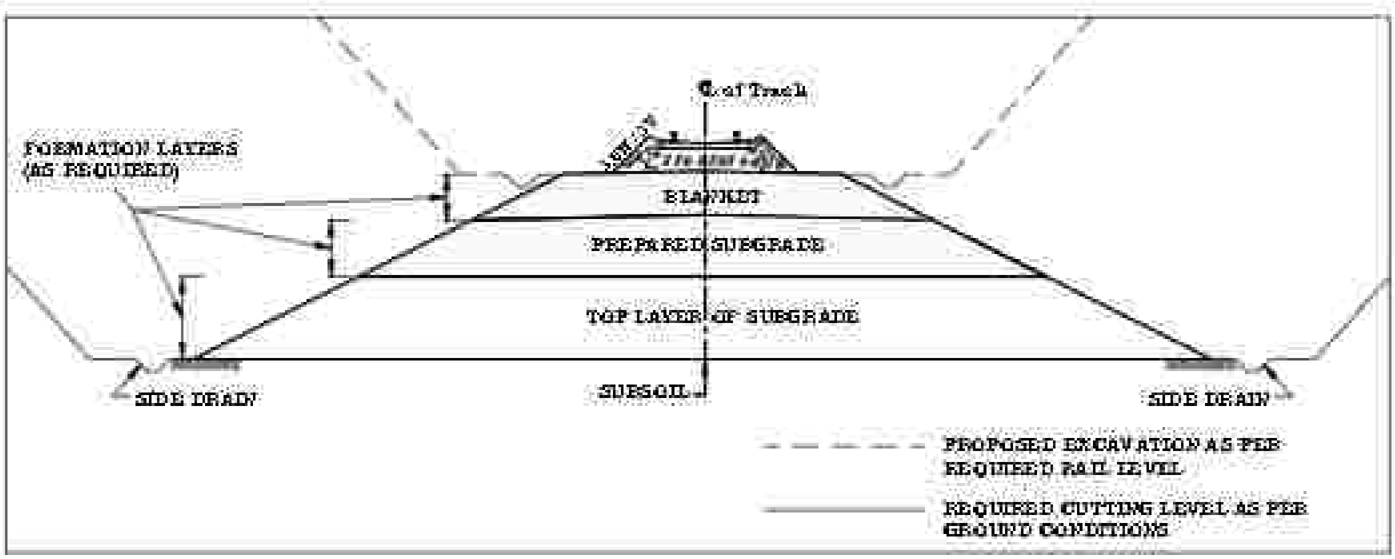


Fig-B13: Formation Layers in Cutting

a) As per bore log details from soil exploration & survey, at least 1.5m depth below the required cutting level, should be checked for conformity with specifications of construction material (quality of formation layers-blanket/prepared sub-grade/sub-grade top layer) as mentioned in **Para 3.10.**

If soil encountered in this depth is of poorer quality than as specified in **Para 3.10** then the excavation for cutting will have to be planned accordingly taking into consideration the additional provisions for conformity with quality of soil as specified for formation layers (blanket/prepared sub-grade/sub-grade top layer) in the required depth, which will then cater to the requirement of heavy axle load. Same has been illustrated in **Fig-B 2** given above.

b) For example, if in the depth of 1.5m below the proposed cutting level (as per required grade/level), soil encountered meets the specification of subgrade-top layer, then additional depth of excavation for cutting should take into account the depth of prepared subgrade & blanket only.

c) Suitable drainage system shall be ensured in cuttings as described in Chapter 6 for Execution of Earthwork.

Representative sketches showing thickness of formation layers in Cutting depending on site conditions is given below:

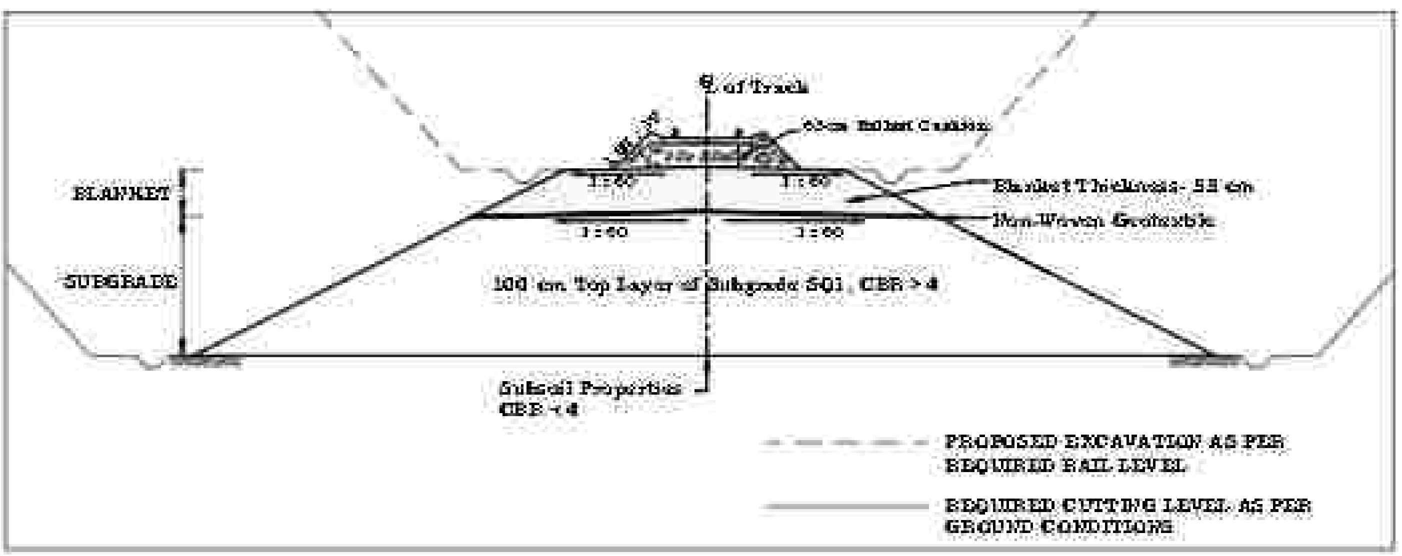


Fig-B14: Cuttings, 25T Axle Load **(Single Layer System)**

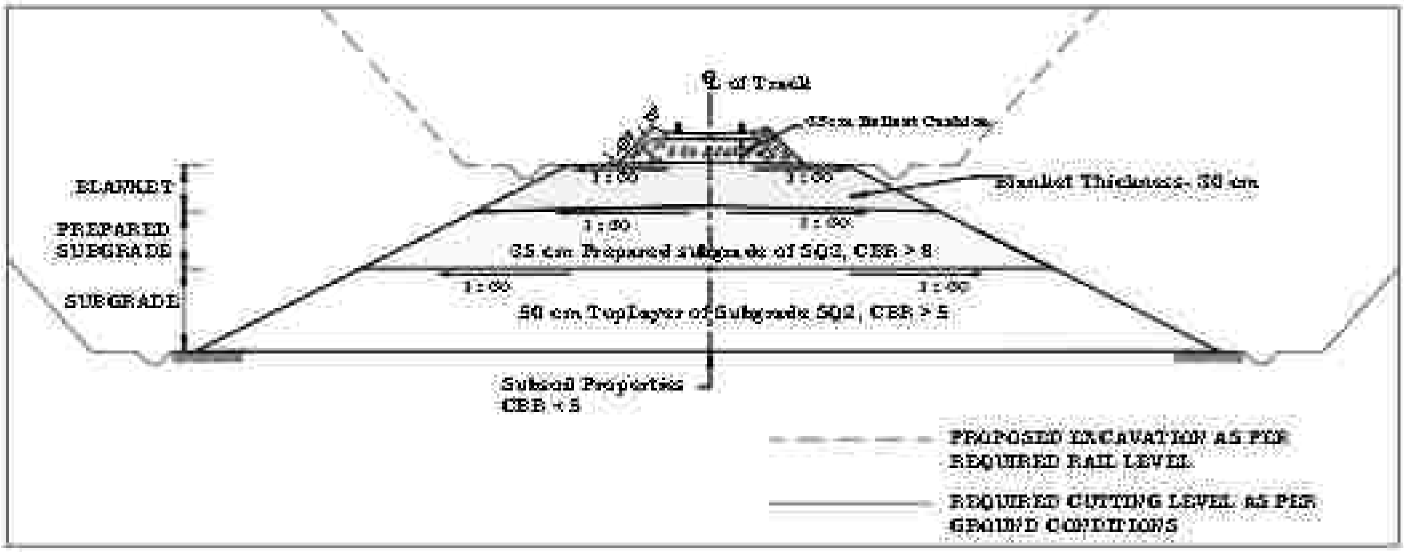


Fig-B15: Cuttings, 25T Axle Load **(Two Layer System)**

Note:* 1. *Any Ground improvement measures (if required) shall be taken prior to the construction of embankment/cuttings (for details Refer Chapter 2).

2. All the above figures are just for guidance purpose. All the construction work shall conform to various relevant provisions described in this Guideline.

Specifications of Geosynthetic Products

1.0 Specification of Non-woven Geotextile to be used as separator/filtration in Railway Formation Specification No. RDSO/2018/GE: IRS-0004-Part-I (March 2019)

A) Properties of Nonwoven Geotextile :

The Non-woven geotextile to be used as separator/filtration layer (Primary role as separator and secondary role as filtration), shall have following properties, when tested as per the latest edition of the test method indicated therein, for Railway application:

Sl. No.	Property	Test Method	Value
I	**Polymer and Type**		
1	**Material/Polymer**	-	Polypropylene/ Polyethylene/ Polyamide, Polyester or any combination thereof
2	**Type/Structure**	-	Non-woven Needle Punched and Mechanically or Thermally bonded type or equivalent
II	**Mechanical Properties**		
1	**Elongation at Failure** (*)	ASTM D4632 - 2015	>50% in both direction
2	**Grab Strength** (*): On top of subgrade or prepared subgrade before laying blanket or anywhere within the embankment Below the ballast and above the Blanket Layer		700 N 1750 N
III	**Hydraulic Properties**		
1	**Apparent Opening size**	ASTM D4751-2016	≤ 85 micron
2	**Water Flow Rate normal to the Plane**	ASTM D4491-2017	20 lit/m^2/Sec
IV	**Survivability Properties**		

1	**Trapezoidal Tear Strength** (*): On top of subgrade or prepared subgrade before laying blanket or anywhere within the embankment Below the ballast and above the Blanket Layer	ASTM D4533-2018	250 N 800 N
2	**Puncture Strength-CBR** (*): On top of subgrade or prepared subgrade before laying blanket or anywhere within the embankment. Below the ballast and above the Blanket Layer	ASTM D6241-2014	1800 N 5800 N
V	**Durability Properties**		
1	**Abrasion Strength** (% strength retained in breaking load) (*)	ASTM D4886 - 2018	80%
2	**Resistance to U.V. Light Weathering** (% strength retained in breaking strength) after 500 hrs. of exposure	ASTM D4355-2018	Not less than 70% (After unwrapping, the geotextile should be installed and covered within a maximum of 14 days)
3	**Minimum retained Ultimate Tensile Strength(*)**	EN:12447-2001 and EN ISO: 13438-2004	50% (tested as per Clause B.4 of EN: 13250-2016, for 100 year service life)

* is Minimum Average Roll Value (MARV), which is derived statistically as average value minus two standard deviations.

Note:

1. The adherence to above listed specification should be checked by testing the samples at IIT, NIT, Government labs or any other NABL accredited lab.
2. Manufacturing of non-woven geotextile shall be in accordance with the manufacturer's QAP for quality control.
3. The product being supplied by the manufacturer should have been successfully used for similar application (separator /filtration-Primary role as separator and secondary role as filtration) at minimum 3 locations, with minimum 3 years' experience at one of the locations, with supporting documents as an evidence for satisfactory performance.
4. To ensure proper quality assurance and reproducibility of the product, following stipulations are as under:
   i) The manufacturer of non-woven geotextile should have ISO: 9001/CE Certification for the product being supplied. The manufacturer of Geo-synthetics should have a well-

documented Quality Assurance Procedure (QAP)/Factory Production Control (FPC) Manual, covering every specific product produced on specific production site, which shall be referred/stipulated in the ISO: 9001/CE Certification. The QAP/FPC Manual shall consist of a permanent internal production control system to ensure that product being manufactured conforms to the requisite properties and it addresses following items:

a) Produce design requirement and criteria.
b) Acceptance criteria of raw/incoming material and procedures to ensure that these are met.
c) Relevant features of the plant and production process; giving frequency of Inspections, checks & tests, together with values/criteria required on equipment and action(s) to be taken when control values or criteria are not obtained.
d) Tests on finished products – Size of the samples and frequency of sampling with results obtained.
e) Details of alternative tests and procedures, if any, and their correlation with reference tests.
f) Calibration of equipment having influence on test results.
g) Records to be maintained for various inspections, checks and tests carried out during factory production.
h) Assessment of results of various inspections, checks and tests carried out during factory production; where possible and applicable.
i) System of traceability and control of designs, incoming materials and use of materials.
j) Corrective action for non-conforming materials and finished products.
k) Training, job description and responsibility of the personnel involved in the manufacturing process.

ii) Any subsequent changes in raw materials, manufacturing procedures or the control scheme that affects the properties of a product shall be recorded/revised in the QAP/FPC Manual and certified by the ISO: 9001/CE Certification.

iii) Surveillance of QAP/FPC Manual shall be undertaken at least once per year. The surveillance shall include a review of the test plan(s) and production processes for each product to determine if any changes have been made since the last assessment or surveillance. The significance of changes shall be assessed.

iv) Records of all in-house test results, as per QAP/FPC Manual, shall be shown to the purchaser; whenever requested by the purchaser

(B) Packing, Handling, Storage and Laying of Geotextiles

i) A t¯g or other method of identific¯tion sh¯ll be ¯tt¯ched to e¯ch roll of non –woven geotextile indic¯ting following:

¯) M¯nuf¯cturer or Supplier N¯me
b) Product or Style N¯me
c) Roll Number
d) Lot or B¯tch Number

ii) Rolls of non -woven geotextiles should not be dragged on the ground and they must be lifted off the ground before moving them.

iii) Non -woven Geotextiles slowly degrade in the presence of Ultra Violet (UV) rays which are present in sunlight. Hence, they should be wrapped with a material that will protect them from damage due to shipment, sunlight (UV exposure) and contaminates. The protective wrapping, in which the non -woven geotextiles come wrapped from factory, should be kept on till their storage and installation. After unwrapping, the geotextile should be installed and covered within a maximum of 14 days.

iv) If stored outside, they should be elevated from the ground surface and adequately covered to protect them from site construction damage, precipitation, UV radiation including sun light, chemicals that are strong acids/bases, flames including welding sparks, temperatures in excess of 710C etc.

v) If the protective wrapping of the non -woven geotextile roll is damaged, the rolls must be elevated off the ground surface and covered with a tarpaulin or opaque plastic sheet. If the outer layer of the geotextile itself is damaged, the outermost wraps of the geotextile must be removed and discarded. This is also required when the roll is exposed to sunlight for a period beyond that permitted by the project specifications.

vi) If the non -woven geotextiles is exposed to moisture or water, prior to installation, it absorbs water up to three times their weight. This can lead to serious handling problems due to extra weight and installation problem because it is nearly impossible to unroll wet rolls. In addition, the strength of wet non -woven geotextile may also diminish to the point that it may not support the required load during installation/construction.

vii) If the non -woven geotextile becomes wet, it is permissible to remove the waterproof cover to allow for a few days of exposure to wind in order to dry the fabric.

viii) In trenches, after placing the backfill material, the non -woven geotextile shall be folded over the top of the filter material to produce a minimum overlap of 300mm for trenches greater than 300mm wide. In trenches, less than 300mm wide, the overlap shall be equal to the width of the trench. The non -woven geotextile shall then be covered with the subsequent course.

ix) Damages to non -woven geotextile, if any during installation, shall be repaired by placing a non -woven geotextile patch over the damaged area and extending it 1m beyond the perimeter of the tear or damage.

x) For laying of Non-woven geotextile:

a) Major protrusions on the surface on which non -woven geotextile is to be laid, such as rocks & bush stamps, shall be removed and local depressions etc. shall be filled with approved soil before laying the geotextile. The geotextile shall be rolled out smoothly. The non -woven geotextile should not be dragged across the subgrade. The entire roll should be placed and rolled out as smoothly as possible. Wrinkles and folds in the fabric shall be removed by stretching as required.

b) Adjacent rolls of non -woven geotextiles shall be overlapped, sewn or joined as required. Overlaps can be used to provide continuity between adjacent non -woven geotextile rolls through frictional resistance between the overlaps. The amount of overlap depends primarily on the soil conditions as given in the Table below:

Soil CBR	Minimum Overlap
Greater than 3	300- 450 mm
1 – 3	600 – 1000 mm
Less than 1	Sewn

c) For curves, the non -woven geotextile shall be folded or cut and overlapped in the direction of construction. Folds in the non -woven geotextile shall be stapled or pinned approximately 0.6m centre-to-centre. Before covering, the condition of the non -woven geotextile shall be checked for damage (i.e. holes, nips, tears etc.).

xi) Before laying the first lift of granular subgrade on the non -woven geotextile, a trial stretch of 100m shall be laid to establish a proper construction methodology of placing and compacting the sub-grade in a manner that no damages are caused to the separation layer of non-woven geotextile.

(C) Measurement for Payment of Geotextiles

The geotextiles for separation / filter layer shall be measured in square metres, with no allowance for overlapping at transverse & longitudinal joints. The contract unit rate for the accepted quantities of geotextile shall be in full compensation for furnishing, preparing, hauling and placing geotextiles including all labour, freight, tools, equipment and incidentals to complete the work as per specifications.

2.0 Specifications for Geogrid to be used as reinforcement/stabilisation for Railway Formation (Specification No. RDSO/2018/GE: IRS-0004- Part-III) February 2020.

A) Properties of Geogrid

The geogrid used as reinforcement/stabilisation layer shall have following properties, when tested as per the latest edition of the test method indicated therein, for Railway application:

Sl. No.	Property	Test Method	Value
I	**Material/Polymer**		
1	**Material/Polymer**	-	Polypropylene
II	**Mechanical Properties**		

1.	**Tensile Strength at 2% Strain (**)** **(i)** For use below ballast in existing line **(ii)** For use below blanket in new line	ISO 10319-2015	10 KN/m x 10 KN/m* 9 KN/m x 9 KN/m*
2.	**Strain at Ultimate Tensile Strength (**)**	ISO 10319-2015	6-15 %
3.	**Aperture Stability/Torsional Rigidity Modulus (**)** (i) For use below ballast in existing line (ii) For use below blanket in new line	ASTM-D7864 -2015	Average Torsional Stiffness ≥0.33 N-m/deg ≥0.40 N-m/deg
4.	**Junction Efficiency (**)**	ASTM-D7737 -2015	90%
III	**Durability Characteristics**		
1.	**Resistance to Installation damage**(% tensile strength at 2% strain) (**)	ASTM-D5818 -2018	90%
2.	**Resistance to Chemical Degradation** (% Average Ultimate rib Tensile Strength) (**)	ASTM D6213 -2017	100%
3.	**Resistance to U.V. Light Weathering** (% strength retained in breaking strength) after 500 hrs of exposure (**)	ASTM-D4355 -2018	95%
4.	**Minimum retained Ultimate Tensile Strength (**)**	EN ISO-13438 -2004	50% (tested as per Clause B.4.2 of EN:13250-2016, for 100 Year Service Life)

* MD: Machine Direction (Longitudinal to the roll) X CD (90° of Machine Direction): Transverse Direction (Across the roll width)

** Values marked are Minimum Average Roll Value (MARV), which is derived statistically as average value minus two standard deviations.

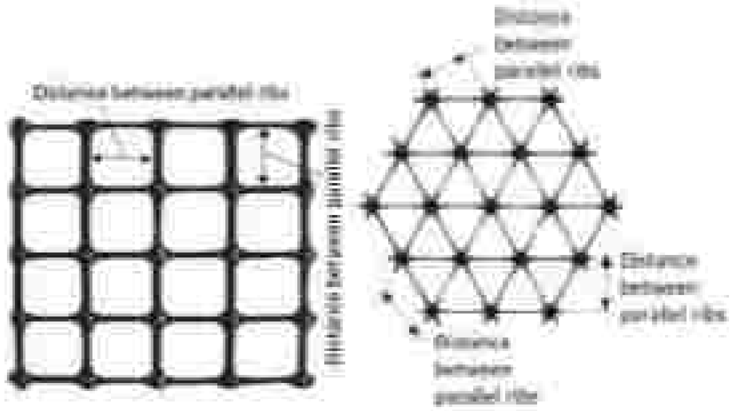
Note:

1. The adherence to above listed specification should be checked by testing the samples at IIT, NIT, Government labs or any other NABL accredited lab.

2. Aperture Opening of Geogrid:
   a) For use below ballast in existing line, the distance between parallel ribs of the geogrid should be 60mm ± 5mm.

b) For use below blanket in new line, the distance between parallel ribs of the geogrid should be 30mm ± 5mm.

Aperture size/opening specified above is the clear distance between inner faces of ribs. Reference diagrams are as given below for illustrations.



(Ref. ISO 10319-2015)

3. The particle grading for the installation damage test result determined in accordance with ASTM D5818 shall use Ballast grading as defined in IRS-GE-1 June 2016, for use below bottom of ballast in existing line and Blanket grading as defined in table 3.7 of chapter 3, for use below in blanket layer in new line.

4. The product being supplied by the manufacturer should have been successfully used as per functional requirement for similar Railway application (reinforcement / stabilization) at minimum 3 locations, with minimum 3 years India/International experience at one of the locations, and certificate duly certified by client/executive which is a government agency/PSU, should be submitted as an evidence for satisfactory performance.

5. Manufacturing of geogrid shall be performed in accordance with the manufacturer's QAP for quality control.

6. To ensure proper quality assurance and reproducibility of the product, following stipulations are as under:

   a) The manufacturer of the Geogrid should have ISO: 9001 and CE Certification of the product being supplied. The manufacturer of Geo-synthetics should have a well-documented Quality Assurance Procedure (QAP)/Factory Production Control (FPC) Manual, covering every specific product produced on specific production site, which shall be referred/stipulated in the ISO: 9001 and CE Certification. The QAP/FPC Manual shall consist of a permanent internal production control system to ensure that product being manufactured conforms to the requisite properties and it addresses following items:

      i) Produce design requirement and criteria.
      ii) Acceptance criteria of raw/incoming material and procedures to ensure that these are met.

iii) Relevant features of the plant and production process; giving frequency of inspections, checks & tests, together with values/criteria required on equipment and action(s) to be taken when control values or criteria are not obtained.
iv) Tests on finished products – Size of the samples and frequency of sampling with results obtained.
v) Details of alternative tests and procedures, if any, and their correlation with reference tests.
vi) Calibration of equipment having influence on test results.
vii) Records to be maintained for various inspections, checks and tests carried out during factory production.
viii) Assessment of results of various inspections, checks and tests carried out during factory production; where possible and applicable.
ix) System of traceability and control of designs, incoming materials and use of materials.
x) Corrective action for non-conforming materials and finished products.
xi) Training, job description and responsibility of the personnel involved in the manufacturing process.

b) Any subsequent changes in raw materials, manufacturing procedures or the control scheme that effects the properties of a product shall be recorded/revised in the QAP/FPC Manual and certified by the ISO: 9001 and CE Certification.

c) Surveillance of QAP/FPC Manual shall be undertaken at least once per year. The surveillance shall include a review of the test plan(s) and production processes for each product to determine if any changes have been made since the last assessment or surveillance. The significance of changes shall be assessed.

d) Records of all in-house test results, as per QAP/FPC Manual, shall be shown to the purchaser; whenever requested by the purchaser.

B) Packing, Handling, Storage and Laying of Geogrid

i) A tag or other method of identification shall be attached to each roll indicating the following:
   a) Manufacturer or Supplier Name
   b) Product name and Style
   c) Roll Number
   d) Lot or Batch Number

ii) Geogrids shall be stored in a manner that prevents excessive mud, wet concrete, epoxy or other deleterious materials from coming in contact with and affixing to the geogrid.
iii) If the geogrid comes in the protective wrapping, it should be kept in wrapped condition till their storage and installation. After unwrapping, the geogrid should be installed and covered within a maximum period of 1 month.

If the Geogrid is supplied in unwrapped condition, it should be installed and covered within a maximum period of 1 month from the date of manufacturing. In case Geogrid is supplied after more than a month's period to the site it should be ensured that it conforms to Resistance to UV light weathering criteria before laying.

iv) Prior to laying of geogrid as reinforcement layer, the surface shall be properly prepared, ruts should be made good and dressed to the specified lines and levels.

v) Geogrid reinforcement shall be placed flat, pulled tight and held in position by pins or suitable means until the subsequent layer is placed. Geogrid should be rolled out on the compacted surface parallel to the centre line of track.

vi) The minimum overlap shall be of

CBR (%)	Overlap
Greater than 3	300 mm
1-3	600 mm

Overlaps must be maintained during the filling operation. This is generally achieved by placing small heaps of fill locally over the overlaps ahead of main filling operation.

vii) No vehicle shall be allowed on geogrid unless it is covered by at least 150mm thick overlying material.

C) Measurement for Payment of Geogrid

The geogrid shall be measured in square metres, with no allowance for overlapping at transverse & longitudinal joints. The contract unit rate for the accepted quantities of geogrid shall be in full compensation for furnishing, preparing, hauling and placing geogrid including all labour, freight, tools, equipment and incidentals to complete the work as per specifications.

D) Acceptance Criteria

Conformance testing on the geogrid delivered to the site shall be undertaken by the Contractor in accordance with the requirements of Clause.

i) General

The Chief Engineer (open line/Construction) or equivalent in PSU's shall be the accepting authority and shall accept test certificates, verifying compliance with Clause (A'), for tests carried out, in accordance with this Technical Specification, on the materials to be used for the specific project. In addition, Contractor's quality system shall demonstrate that the specified minimum frequency of testing has been maintained and ensuring traceability of the material.

Presently Tests Aperture Stability/Torsional Rigidity Modulus are not carried out in India, therefore upto one year, Manufacturer certificate is required for the procurement of Geogrid. All manufacturers should develop Testing facilities in one year time and this should be carried out as routine testing of Geogrid. The test certificates shall not be older than 12 months on the date of the supply to the site.

ii) Site sampling

a) Frequency for test other than durability tests

Where the total required batch size for the Contract is less than 5000 m^2, sampling and testing need not be undertaken. If the material supplied is higher than 5000 m^2 on-site sampling shall be carried out in accordance with ASTM D4354 at the frequency stated in Table D.2.

Table D.2 – On Site sampling frequency

Batch or order size defined as the lot size	Number of rolls to be sampled representing the lot
The initial 10,000 m² or part thereof	1
Each subsequent 20,000 m² or part thereof	1

The representative sample shall be no less than four linear metres along the roll for the full production width but not within two metres of the start or end of the roll.

Identification information including the geogrid supplier, type, batch identification, and details of the order represented by sample, sample date and roll directional markings shall be shown on or attached to the test reports.

b) Frequency for Durability Tests

Random checks on material supplied to project sites once every 5,00,000 sqm. or once in a 3 year whichever is earlier for each manufacturer.

iii) Acceptance

A lot shall be deemed to achieve conformance, if all samples tested comply with the Technical Specification. If a lot fails to achieve conformance, the lot may be re-sampled in accordance with Clause D.2 to verify whether the lot conforms or not. If it still does not conform to the technical specifications, the lot should be rejected.

The geogrid shall not be placed prior to the acceptance as per para D (i) above.

iv) Audit testing During audit testing, samples may be selected from the site and accordingly arrangement for audit testing has to be done, regardless of the quantity of geogrid supplied.

3.0 Specification of Geocomposite Drain to be used behind Bridge Abutment/ Retaining Wall for Railway Bridge- For height up to 10 m. (Specification No. RDSO/2018/GE: IRS-0006 -March 2019)

A) Properties of Geocomposite Drain (Vertical)

The Geocomposite Drain (or Drainage Composite) consisting of a geonet core sandwiched between non-woven geotextile filters on both sides, to be used behind Bridge Abutment/Retaining Wall of Height up to 10m, shall have following properties, when tested as per the latest edition of the test method indicated therein:

Sl. No.	Property	Test Method	Proposed value
I	**Composite Drain (Non-woven geotextile on both sides)**		
1	**Tensile Strength**	ASTM D4595-2017	20 KN/m in both MD & CD (± 10%)

2	**In-plane Water Flow** (For I=1, Rigid/Soft Contacts) At 100 kPa (To be tested in lab)	ASTM D4716-2014	1.5 lit/m.sec.
3	**Static Puncture Resistance CBR**(*)	ASTM D 6241-2014	3000 N
4	**Resistance to U.V. Light Weathering** (% strength retained in breaking strength) after 500 hrs of exposure	ASTM D4355-2018	Not less than 70% (After unwrapping, the Geocomposite should be installed and covered within a maximum of 14 days)
5	Minimum retained Ultimate Tensile Strength(*)	EN:12447-2001 and EN ISO: 13438-2004	50% (tested as per Clause B.4 of EN: 13250-2016, for 100 year service life)
II	**Core**		
1	**Material**	-	HDPE/Polypropylene/ Polyethylene or combination thereof
III	**Filter (Non-woven Geotextile)**		
1	**Material**	-	Polypropylene/Polyamide/Polyethylene, Polyester or combination thereof
2	**Type/Structure**	-	Non-woven Needle Punched & Mechanically or Thermally bonded type or equivalent
3	**Permeability (Perpendicular to Plane)**	ASTM D4491-2016	70 lit./m^2.s (Min.)
4	**Apparent Opening Size**	ASTM D4751-2016	150 Micron (Max.)
5	**Puncture Strength – CBR** (*)	ASTM D6241-2014	1400 N
6	**Resistance to U.V. Light Weathering** (% strength retained in breaking strength) after 500 hrs of exposure	ASTM D4355-2018	Not less than 70% (After unwrapping, the Geocomposite should be installed and covered within a maximum of 14 days)

- MD: Machine Direction (Longitudinal to the roll)

- CD: Transverse Direction i.e., 90^{0} to MD, (Across the roll width)

* Is Minimum Average Roll Value (MARV), which is derived statistically as average value minus two standard deviations.

Note:

1. The adherence to above listed specification should be checked by testing the samples at IIT, NIT, Government labs or any other NABL accredited lab.

2. Manufacturing of Geosynthetics shall be in accordance with the manufacturer's QAP for quality control.

3. The product being supplied by the manufacturer should have been successfully used for similar application (i.e. for drainage behind bridge abutment/retaining wall) at minimum 3 locations, with minimum 3 years' experience at one of the locations, with supporting documents as an evidence for satisfactory performance.

4. To ensure proper quality assurance and reproducibility of the product, following stipulations are as under:
   a) The manufacturer of Geocomposite drain should have ISO: 9001/CE Certification for the product being supplied. The manufacturer of Geo-synthetics should have a well-documented Quality Assurance Procedure (QAP)/Factory Production Control (FPC) Manual, covering every specific product produced on specific production site, which shall be referred/stipulated in the ISO: 9001/CE Certification. The QAP/FPC Manual shall consist of a permanent internal production control system to ensure that product being manufactured conforms to the requisite properties and it addresses following items:
      i) Produce design requirement and criteria.
      ii) Acceptance criteria of raw/incoming material and procedures to ensure that these are met.
      iii) Relevant features of the plant and production process; giving frequency of inspections, checks & tests, together with values/criteria required on equipment and action(s) to be taken when control values or criteria are not obtained.
      iv) Tests on finished products – Size of the samples and frequency of sampling with results obtained.
      v) Details of alternative tests and procedures, if any, and their correlation with reference tests.
      vi) Calibration of equipment having influence on test results.
      vii) Records to be maintained for various inspections, checks and tests carried out during factory production.
      viii) Assessment of results of various inspections, checks and tests carried out during factory production; where possible and applicable.
      ix) System of traceability and control of designs, incoming materials and use of materials.
      x) Corrective action for non-conforming materials and finished products.
      xi) Training, job description and responsibility of the personnel involved in the manufacturing process.

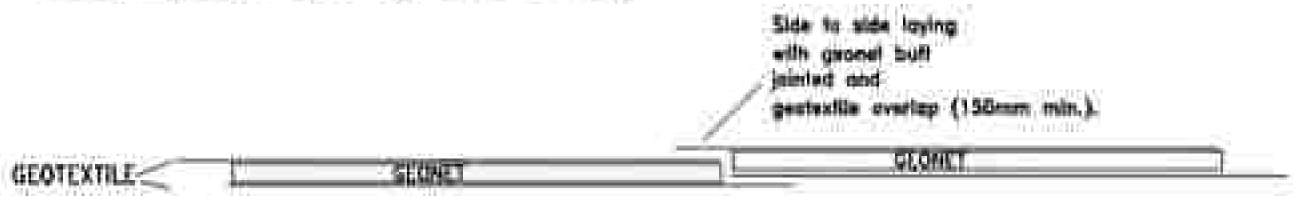
   b) Any subsequent changes in raw materials, manufacturing procedures or the control scheme that affects the properties of a product shall be recorded/revised in the QAP/FPC Manual and certified by the ISO: 9001/CE Certification.

c) Surveillance of QAP/FPC Manual shall be undertaken at least once per year. The surveillance shall include a review of the test plan(s) and production processes for each product to determine if any changes have been made since the last assessment or surveillance. The significance of changes shall be assessed.
d) Records of all in-house test results, as per QAP/FPC Manual, shall be shown to the purchaser; whenever requested by the purchaser.
e) Geo-composite Drain shall be manufactured by thermal bonding of filter and core. Melt temperature of the bonding materials must be compatible so that the properties of each material are retained. Adhesion of filter & core using glue/adhesive tape shall not be permitted particularly for this application.
f) In-plane water flow as per item I (2) of Specification is 1.5 lit/m.sec which is to be tested in lab. For calculating the value of short term flow creep factor is taken as 1.3. Manufactures have to give the test certificate indicating the value of creep factor for their product tested accordingly to ASTM D7931-2018. The value of creep factor of the product should be less than or equal to 1.3 for 100 years design life under 100 kPa pressure. In case the creep factor of a product is greater than 1.3 then in-plane water flow to be tested in lab i.e., 1.5 lit/m.sec as mentioned in specification at I(2) should be increased proportionally.
g) Geocomposite drain consisting of cuspated core shall not be used.

B) Packing, Handling and Installation of Geo-composite Drains (Vertical)

i) The Geocomposite drain shall be provided in wraps with a protective covering. A tag or other method of identification shall be attached to each wrapped package indicating the following:
   a) Manufacturer or Supplier Name
   b) Product Name and Style
   c) Roll Identification Number
   d) Lot or Batch Number
ii) Rolls of Geocomposite drain should not be dragged on the ground and they must be lifted off the ground before moving them.
iii) Geocomposite drain should be adequately protected from Ultraviolet (UV) exposure during storage at site. The protective wrapping, in which the Geo-composite drain come wrapped from factory, should be kept on till their installation. After unwrapping, the Geo-composite drain should be installed and covered within a maximum of 14 days.
iv) If stored outside, they should be elevated from the ground surface and adequately covered to protect them from site construction damage, precipitation, UV radiation, chemicals that are strong acids/bases, flames including welding sparks, temperatures in excess of 710C etc.
v) When Geo-composite drains are assembled on site, the assembly area shall be clean and dry.
vi) Geocomposite drains shall be capable of being connected longitudinally or laterally into pipe systems or chambers for outflow purpose. Joint parallel to the direction of flow and any exposed edge shall be protected from the ingress of soil by wrapping with a minimum overlap of 150mm or other measures.

Geocomposite jointing and overlap



Overlap of Geocomposite drains

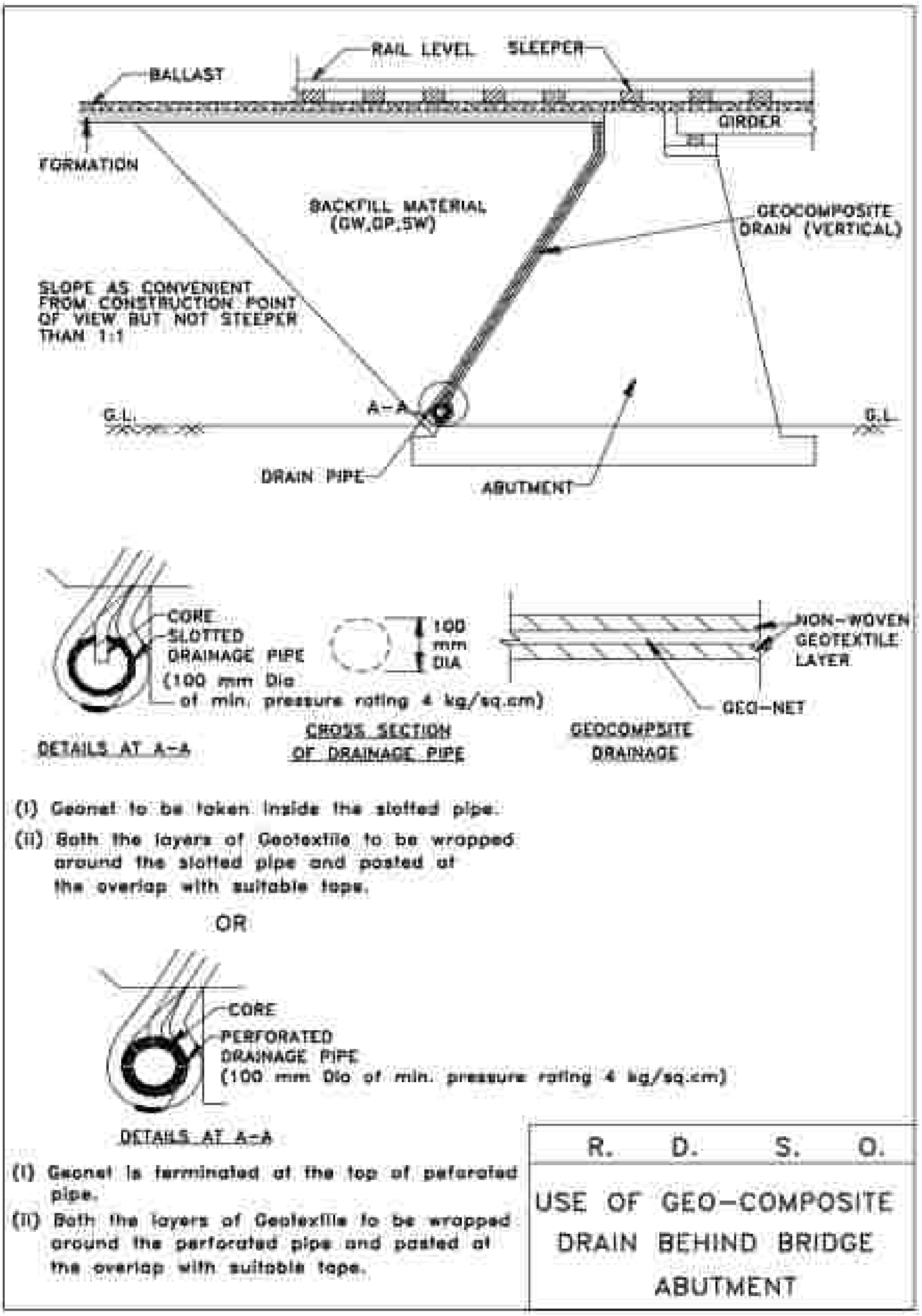
(vii) Care must be taken to ensure that large stones are not allowed in the soil & large projections abutment surface to damage the surface of the geotextile filter.

(viii) In case of use behind Bridge Abutment or Retaining Wall, slotted pipe can be provided for horizontal drainage at bottom, by placing Geonet inside slot and both layers of geotextile to be wrapped around the slotted pipe & pasted at the overlap with suitable tape. Or perforated pipe can be provided for horizontal drainage at bottom, by placing Geonet is terminated at the top of perforated pipe and both layers of geotextile to be wrapped around the perforated pipe & pasted at the overlap with suitable tape.

(ix) A diagram showing GeoComposite Drain behind bridge abutment is shown below.

C) Measurement for Payment of Geo-composite Drain (Vertical)

The Geocomposite drain shall be measured in square metres, with no allowance for overlapping at transverse & longitudinal joints. The contract unit rate for the accepted quantities of Geo-composite drain shall be in full compensation for furnishing, preparing, hauling and placing Geo-composite drain including all labour, freight, tools, equipment and incidentals to complete the work as per specifications.



Use of Geocomposite drains behind bridge abutment

4.0 Specification for Geo-composite drain to be used at the base of the Embankment"- for height of embankment upto 8m, for Railway Formation (Specification No. RDSO/2018/GE: IRS-0004 Part-II)

A) Properties of Geocomposite Drain (Horizontal)

In case of embankments over weak/fine grained sub-soils (which are mostly soft clays) and having water table at higher level, it is a good practice to provide a "separator-cum-drainage layer" of sand at the ground level to provide adequate drainage path for the water coming from sub-soil (reducing excess pore water pressure in embankment and thereby increasing its' stability) and to prevent fouling of subgrade by the fine grained subsoil.

For reducing the thickness of "drainage-cum-separator layer of sand" at the base of embankment, Geo-composite Drain (or Drainage Composite) consisting of a geonet core sandwiched between non-woven geotextile filters on both sides can be laid with cross slope of 1 in 30. Such geo-composite drain is sandwiched between two sand layers of thickness 75mm each.

The specification of geo-composite Drain shall be as listed below when tested as per the latest edition of the test method indicated therein. These specifications are for embankments of height up to 8m when laid over weak/fine grained sub-soils.

S. No	Property	Test Method	Value
I	**Composite Drain (Non-woven geotextile on both sides)**		
1	**Tensile Strength**	ASTM D4595-2017	20 KN/m in both MD & CD (± 10%)
2	**In-plane Water Flow** (Min.) (For i=1.0, Soft/Soft Contacts) At 200 kPa (To be tested in lab)	ASTM D4716 -2014	0.45 lit/m.sec.
3	**Static Puncture Resistance CBR**(*)	ASTM D6241-2014	3000 N
4	**Resistance to U.V. Light Weathering** (% strength retained in breaking strength) after 500 hrs of exposure	ASTM D4355-2018	Not less than 70% (After unwrapping, the Geocomposite should be installed and covered within a maximum of 14 days)
5	**Minimum retained Ultimate Tensile Strength**(*)	EN:12447-2001 and EN ISO: 13438-2004	50% (tested as per Clause B.4 of EN: 13250-2016, for 100 year service life)
6	**Resistance to Installation damage** (% retained of In-plane Water Flow (Min.) (For	ASTM- D5818-2018	90%

	i=1.0, Soft/Soft Contacts) At 200 kPa (To be tested in lab))		
II	**Core**		
1	**Material**	-	HDPE/Polypropylene/ Polyethylene or combination thereof
III	**Filter (Non-woven Geotextile)**		
1	**Material**	-	Polypropylene/Polyamide/ Polyethylene, Polyester or combination thereof
2	**Type/Structure**	-	Non-woven Needle Punched & Mechanically or Thermally bonded type or equivalent
3	**Permeability** (Perpendicular to Plane)	ASTM D4491-2016	70 lit./m^2.s (Min.)
4	**Apparent Opening Size**	ASTM D4751-2016	150 Micron (Max.)
5	**Puncture Strength – CBR** (*)	ASTM D6241 – 2014	1400 N
6	**Resistance to U.V. Light Weathering** (% strength retained in breaking strength) after 500 hrs of exposure	ASTM D4355-2018	Not less than 70% (After unwrapping, the Geocomposite should be installed and covered within a maximum of 14 days)

- MD: Machine Direction (Longitudinal to the roll)
- CD: Transverse Direction i.e., 90^0 to MD, (Across the roll width)

* Is Minimum Average Roll Value (MARV), which is derived statistically as average value minus two standard deviations.

Note:

1. The adherence to above listed specification should be checked by testing the samples at IIT, NIT, Government labs or any other NABL accredited lab.

2. Manufacturing of Geosynthetics shall be in accordance with the manufacturer's QAP for quality control.

3. The product being supplied by the manufacturer should have been successfully used for similar application (i.e., Geo-composite Drain at base of the Embankment) at minimum 3 locations, with minimum 3 years' experience at one of the locations, with supporting documents as an evidence for satisfactory performance.

4. To ensure proper quality assurance and reproducibility of the product, following stipulations are as under:
   i) The manufacturer of the Geo-composite Drain should have ISO: 9001/CE Certification for the product being supplied. The manufacturer of Geo-synthetics should have a well-documented Quality Assurance Procedure (QAP)/Factory Production Control (FPC) Manual, covering every specific product produced on

specific production site, which shall be referred/ stipulated in the ISO: 9001/CE Certification. The QAP/FPC Manual shall consist of a permanent internal production control system to ensure that product being manufactured conforms to the requisite properties and it addresses following items:

i) Produce design requirement and criteria.
ii) Acceptance criteria of raw/incoming material and procedures to ensure that these are met.
iii) Relevant features of the plant and production process; giving frequency of inspections, checks & tests, together with values/criteria required on equipment and action(s) to be taken when control values or criteria are not obtained.
iv) Tests on finished products – Size of the samples and frequency of sampling with results obtained.
v) Details of alternative tests and procedures, if any, and their correlation with reference tests.
vi) Calibration of equipment having influence on test results.
vii) Records to be maintained for various inspections, checks and tests carried out during factory production.
viii) Assessment of results of various inspections, checks and tests carried out during factory production; where possible and applicable.
ix) System of traceability and control of designs, incoming materials and use of materials.
x) Corrective action for non-conforming materials and finished products.
xi) Training, job description and responsibility of the personnel involved in the manufacturing process.

ii) Any subsequent changes in raw materials, manufacturing procedures or the control scheme that affects the properties of a product shall be recorded/revised in the QAP/FPC Manual and certified by the ISO: 9001/CE Certification.

iii) Surveillance of QAP/FPC Manual shall be undertaken at least once per year. The surveillance shall include a review of the test plan(s) and production processes for each product to determine if any changes have been made since the last assessment or surveillance. The significance of changes shall be assessed.

iv) Records of all in-house test results, as per QAP/FPC Manual, shall be shown to the purchaser; whenever requested by the purchaser.

v) Geo-composite Drain shall be manufactured by thermal bonding of filter and core. Melt temperature of the bonding materials must be compatible so that the properties of each material are retained. Adhesion of filter & core using glue/adhesive tape shall not be permitted particularly for this application.

vi) In-plane water flow as per **item I (2)** of Specification is 0.45 lit/m.sec which is to be tested in lab. For calculating the value of short term flow creep factor is taken as 1.3. Manufactures have to give the test certificate indicating the value of creep factor for their product tested accordingly to ASTM D7931-2018. The value of creep factor of the product should be less than or equal to 1.3 for 100 years design life under 200 kPa pressure. In case the creep factor of a product is greater than 1.3 then in-plane water flow to be tested in lab i.e., 0.45 lit/m.sec as mentioned in specification at I(2) should be increased proportionally.

vii) Geocomposite drain consisting of cuspated core shall not be used.

B) Packing, Handling and Installation of Geo-composite Drains (Horizontal)

i) The Geo-composite drain shall be provided in wraps with a protective covering. A tag or other method of identification shall be attached to each wrapped package indicating the following:
   a) Manufacturer or Supplier Name
   b) Product Name and Style
   c) Roll Identification Number
   d) Lot or Batch Number

ii) Rolls of Geo-composite drain should not be dragged on the ground and they must be lifted off the ground before moving them.

iii) Geo-composite drain should be adequately protected from Ultraviolet (UV) exposure during storage at site. The protective wrapping, in which the Geo-composite drain come wrapped from factory, should be kept on till their installation. After unwrapping, the Geo-composite drain should be installed and covered within a maximum of 14 days.

iv) If stored outside, they should be elevated from the ground surface and adequately covered to protect them from site construction damage, precipitation, UV radiation, chemicals that are strong acids/bases, flames including welding sparks, temperatures in excess of 710C etc.

v) When Geo-composite drains are assembled on site, the assembly area shall be clean and dry.

vi) Geo-composite drains shall be capable of being connected longitudinally or laterally into pipe systems or chambers for outflow purpose. Joint parallel to the direction of flow and any exposed edge shall be protected from the ingress of soil by wrapping with a minimum overlap of 150mm or other measures.

Showing overlap of Geo-Composite Drain

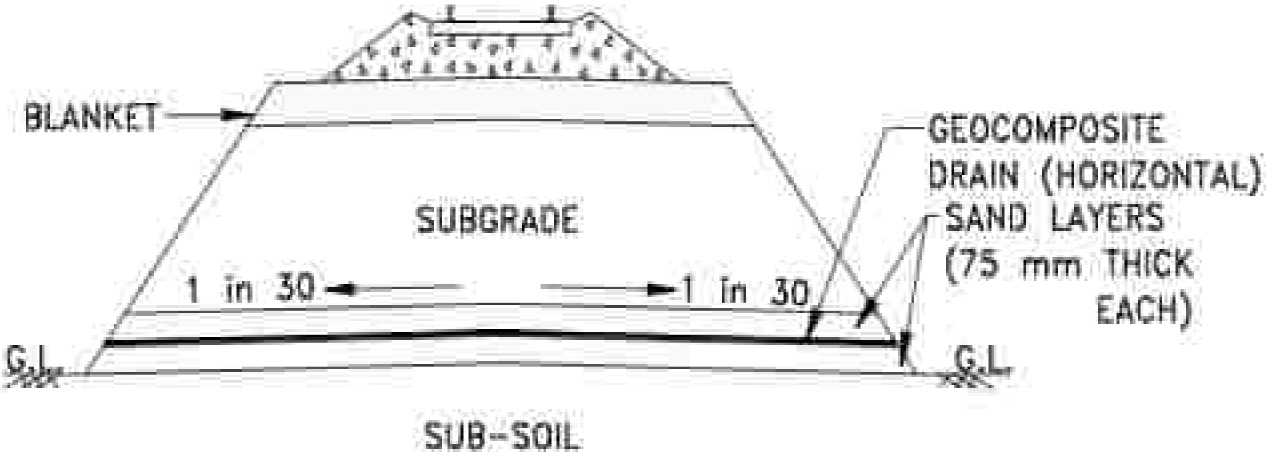
vii) Care must be taken to ensure that large stones are not allowed in sub soil & subgrade soil to damage the surface of the geotextile filter.

viii) The water coming from the Geo-Composite Drain can be disposed off by providing side drain along the embankment.

ix) A diagram showing Use of Geo-Composite Drain in bank over soft subsoil is shown below.

C) Measurement for Payment of Geo-composite Drain (Horizontal)

The Geo-composite drain shall be measured in square metres, with no allowance for overlapping at transverse & longitudinal joints. The contract unit rate for the accepted quantities of Geo-composite drain shall be in full compensation for furnishing, preparing, hauling and placing Geo-composite drain including all labour, freight, tools, equipment and incidentals to complete the work as per specifications.



Use of Geo-Composite Drain in bank over soft subsoil

APPENDIX-D

FIELD COMPACTION TRIAL OBSERVATIONS & COMPUTATION SHEETS
COMPACTION EQUIPMENT DATA
TABLE - D-1

Project...................... Location .... Date......................

Item		Roller - 1	Roller -2	Roller -3
Type of Roller				
Gross weight (tonnes)				
Drum Dimension (Roller Type)	Width (mm)			
	Diameter (mm)			
Foot (Sheep foot Type)	Type			
	Number			
	Length (mm)			
	Area (mm^2)			
Contact Area (cm^2) (Sheep foot/Pneumatic Tyred/Vibratory Plate Type)				
Tyre Inflation Pressure(Kg/cm^2)				
Nominal Amplitude(mm)				
Frequency(Hz)				
Dynamic Force(Kg)				
Operational Speed(Kmph)				
Static Linear Loads(Kg/cm)				
Contact Pressure(Kg/cm^2)				

LIST OF EQUIPMENT FOR FIELD TRIALS/MONITORING

S.No	Equipment	No. Reqd.	No. available
1.	Field density apparatus complete: a) Sand replacement b) Core cutter with dolly and hammer	 4 Sets 4 Sets	
2.	Balance: a) Electronic balance 20 kg capacity (with 2.0 gm Least Count) b) Electronic balance 500 gm capacity (with 0.1 gm Least Count)	 1 Set 1 Set	
3.	Straight edge 300mm long	4 Nos.	
4.	Frying Pan	1 No.	
5.	Containers plastic (about 500g capacity)	8 Nos.	
6.	Enamel plates: 6 inch dia. 8 inch dia. 10 inch dia.	10 Nos. 3 Nos. 3 Nos.	
7.	Uniform clean sand (Ottawa Sand) (bags of 50 Kg)	10 Bags	
8.	Measuring tape (3M/5M)	1 No.	
9.	Measuring tape (15 M/30M)	1 No.	
10.	Kerosene oil stove	1 No.	

Signature of Monitoring Official Name Designation Date	Signature of Project Official Name Designation Date

FIELD COMPACTION TRIAL OBSERVATION
TABLE- D-2

Project ______________________ Date ______________________

Location ______________________

Strip No.	Location on the ramp	Moisture content before watering				Moisture content after adding the water			
		Container No.	Weight of wet soil.(gms)	Weight of dry soil.(gms)	Moisture content (%)	Containe r No.	Weight of wet soil.(gms)	Weight of dry soil.(gms)	Moisture content (%)
1	2	3	4	5	6	7	8	9	10
J	1								
	2								
	3								
	4								
K	1								
	2								
	3								
	4								
L	1								
	2								
	3								
	4								
M	1								
	2								
	3								
	4								

Signature of Monitoring official______________________
Name______________________
Designation______________________
Date ______________________

Signature of Project Official______________________
Name______________________
Designation______________________
Date ______________________

FIELD COMPACTION TRIAL OBSERVATION
TABLE- D-3

Project ______________________________ Location: ______________________________ Date______________

STRIP No. _______________OMC____________________% MDD__________________gms/cc Volume of core cutters:___________C.C.

No. of roller passes	Location of the Ramp	In-situ bulk density					Moisture content				Dry density of soil	Percent of MDD	Remark
		Core cutter No.	Wt. Of empty core cutter (gm)	Wt. of wet soil with core cutter (gm)	Wt. of wet soil (gm)	Bulk density of soil (gm/cc)	Contain er No.	Wt. of wet soil (gms)	Wt. of dry soil (gms)	Moisture content (%)			
1	2	3	4	5	6	7	8	9	10	11	12	13	14
4	1												
	2												
	3												
	4												
6	1												
	2												
	3												
	4												
8	1												
	2												
	3												
	4												
10	1												
	2												
	3												
	4												
12	1												
	2												
	3												
	4												
14	1												
	2												
	3												
	4												

Signature of monitoring official_________________

Name ___________________________

Designation ____________

Date __________________________

Signature of project official ____________________

Name ______________________________________

Designation _________________________________

Date ____

FIELD COMPACTION TRIAL-COMPUTATION SHEET
TABLE- D-4

Project______________ Location__________________________

S. No	Lift thickness (mm)	Moisture content %	Dry density of soil(gm/cc) Nos. of the roller passes						Remarks
			4	6	8	10	12	14	
1.	225								
2.	300								
3.	375								
4.	450								

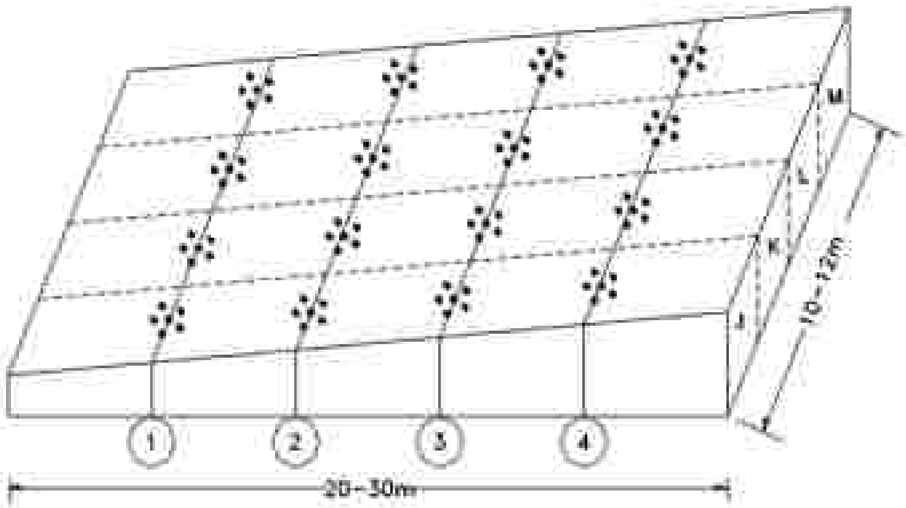
Computed by______________________ Checked by ________________

Name ___________________________ Name______________________

Designation_______________________ Designation_________________

Date _____________________ Date______________________

Fig -D-1

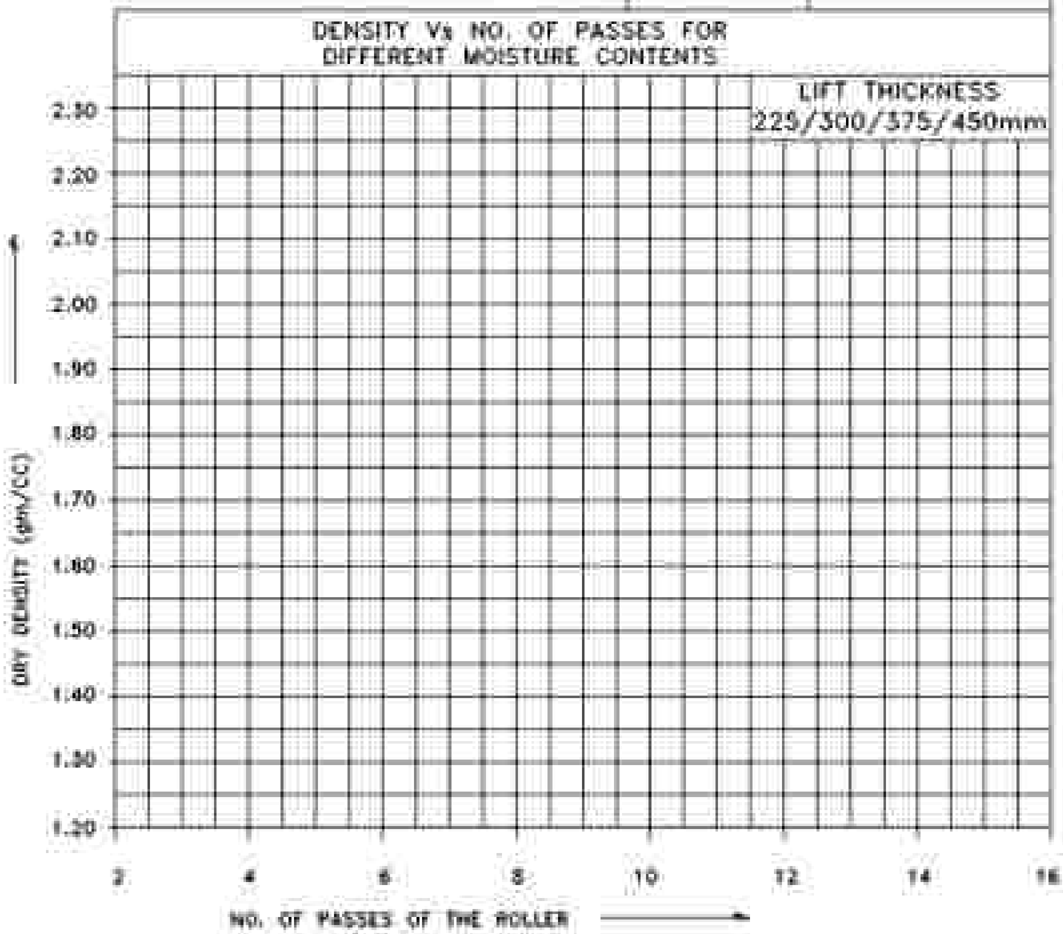


RAMP OF EARTH FOR COMPACTION TRIALS IN THE FIELD

• SAMPLING	–	J K L M
• MOISTURE CONTENT (%) (WITH VARIATIONS OF ±2%)	–	OMC–4 OMC OMC+4 PL–2
• SAMPLING POINTS	–	J_1, J_2, J_3, J_4 ; K_1, K_2, K_3, K_4 ; L_1, L_2, L_3, L_4 ; M_1, M_2, M_3, M_4
• THICKNESS IN MM.	–	225, 300, 375 & 450
• NO. OF TIMES FOR OBSERVATIONS	–	6(SIX), (AFTER INTERVAL OF 4,6,8,10,12 & 14 PASSES OF ROLLER)
• TOTAL NO. OF OBSERVATIONS	–	4x4x6 = 96

Fig – D-2

NAME OF PROJECT	OMC–4	○—○
LOCATION	OMC	●—●
	OMC+4	△—△
	PL–2	▲—▲

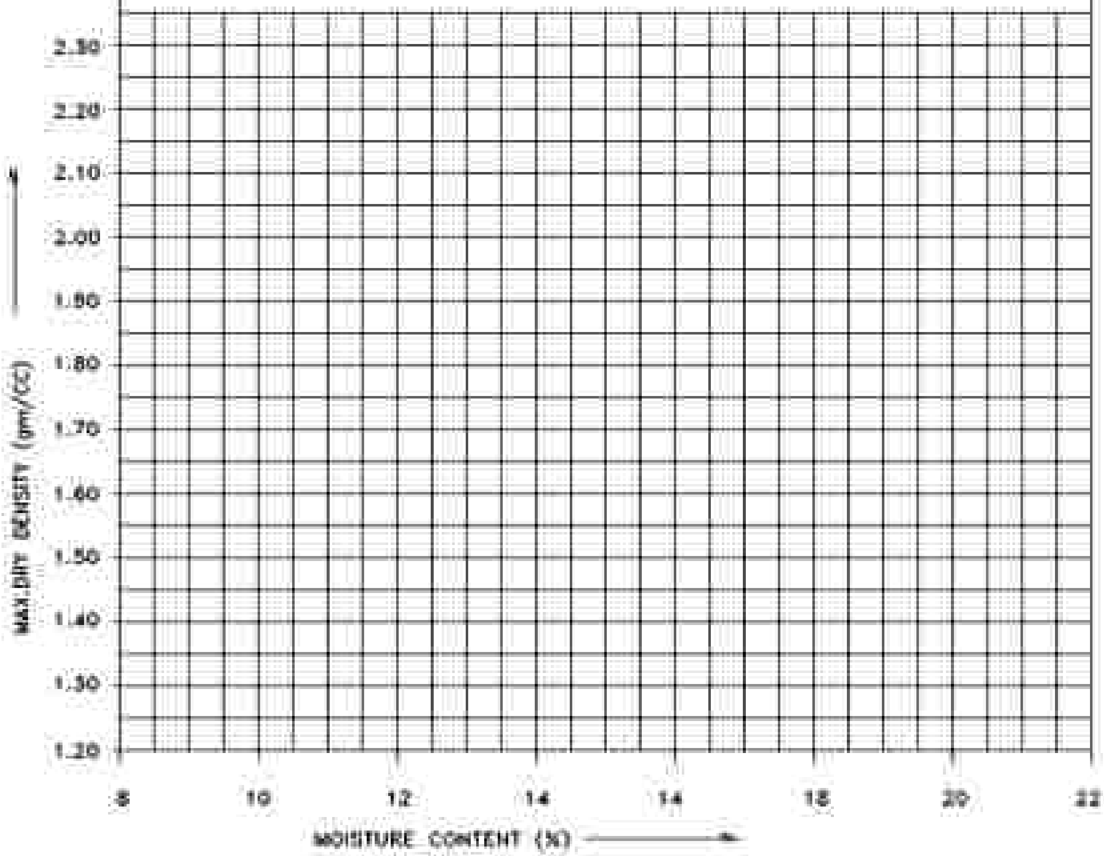


OFFICIALS – IN – CHARGE	QUALITY CONTROL OFFICIALS
SIGNATURE ____________	SIGNATURE ____________
NAME OF OFFICER ____________	NAME OF OFFICER ____________
DESIGNATION ____________	DESIGNATION ____________
DATE ____________	DATE ____________

Fig– D-3

NAME OF PROJECT	LIFT	NOTATION
LOCATION	225mm	○———○
	300mm	●———●
	375mm	△———△
	450mm	▲———▲

MOISTURE CONTENT Vs MAX.DRY DENSITY FOR VARIOUS LIFT THICKNESS



OFFICIALS – IN – CHARGE	QUALITY CONTROL OFFICIALS
SIGNATURE ____________	SIGNATURE ____________
NAME OF OFFICER ____________	NAME OF OFFICER ____________
DESIGNATION ____________	DESIGNATION ____________
DATE ____________	DATE ____________
SIGNATURE ____________	SIGNATURE ____________
NAME OF OFFICER ____________	NAME OF OFFICER ____________
DESIGNATION ____________	DESIGNATION ____________
DATE ____________	DATE ____________

Modern Equipment's for Earth Work

The details given below are based on the information available in the public domain and the list is not exhaustive. There may be many manufactures / suppliers of these equipment's and many such similar equipment's.

1.0 Compactors/Rollers

1.1 Slope Compactors

(a) Slope Compactor Vibratory Roller (Double Drum) Rope Start

Slope compactor vibratory roller (Double drum) with Hydraulic drive can work on slope of 1:2 to 1:1.5, a pair of compactors works on Counter Balance Principle have to be linked via wire rope pulley (i.e. two compactors (One at the top and other at bottom of the slope), supported on loaded truck at the top. The two compactors with individual operator have to operate Single lever simultaneously in downward and upward direction from two ends of slope. One of the Slope Compactor Vibratory Roller (Double Drum) Rope Start in operation is given below for illustration.

Fig-E1: Slope Compactor Working with counter balance Method

(b) Slope Vibratory Roller

Slope Vibratory Compactor is a unique attachment which can be attached to any Excavators/Backhoes/Long Reach. This attachment is specially designed for various applications like Railway track extension /Canal / Dam Slope Compaction and sloping surface where compaction is required. This attachment is capable of reaching surfaces where normal compactors cannot reach and can-do deep compaction than an ordinary compactor.

On Steep Slopes, slushy and most difficult terrains, where the normal Roller would easily swamp down, Slope Vibratory Compactors can easily work. These rollers work on the double vibratory principle that provides superior compaction.

Fig-E2: Slope Vibratory Roller

Fig-E3: Working of Slope Vibratory Roller

(c) Slope Vibratory Compactor

Slope Vibratory Compactor is an attachment to normal excavators. The major advantage of this compactor is that it can compact 360 degrees for a height of 2m to 17m depending on size of excavator and attachment length.

Fig-E4: Slope Vibratory Compactor

1.2 Vibrating Plate Compactors:

The vibratory plate compactor is power-engines, walk-behind equipment that imparts powerful vibratory compaction effort to loose materials, by transmitting vibration through the vibrating plate which generates power from the single rotor in vibration case. A plate compactor works by vibrating or driving a flat metal plate against the ground over and over. This flat plate helps to compress and smoothen out the rough and uneven dirt. Plate compactors work best on granular soil, such as sand and gravel. These vary in weight from 100 kg to 2 tonne with plate areas between 0.16 sqm and 1.6 sq cm. Smaller versions are manually guided and therefore suitable for compacting small or awkwardly shaped areas. They usually travel at about 0.7 km/h. They are classified in terms of mass divided by the area of the base in contact with the ground.

Fig-E5: Vibrating Plate Compactor

1.3 Small Width Vibratory Roller for Compaction of Earthwork in Gauge Conversion Work and Narrow Width Portion

Proper compaction in the widened portion of embankment is difficult to achieve with conventional means of compaction like ramming & hand rollers. The small width vibratory roller is to achieve the desired compaction in widening of embankment in narrow width portion, from MG to BG in Gauge Conversion Works.

Fig-E6: Small Width Vibratory Roller (Drum width 90 cm)

1.4 Walk behind Vibratory Roller

Walk behind Double Drum Vibratory Roller is modern compact design for use in a wide range of compaction application. Hydraulic with integrated travel control eases the operating effort required for movement. Walk behind Roller has the vibratory source located in the drum which provides maximum compaction and traction performance.

Fig-E7: Walk behind Roller

1.5 Vibratory Rollers with Latest Techniques:

Even some latest techniques have been developed in World Railways, where vibratory roller includes the machine to directly determine the vibration modulus as parameter for the dynamic stiffness of the soil. There is continuous optimization of amplitude and compaction energy which reduces loosening in upper layers on uniform and granular material types.

1.6 Double Drum Vibratory Roller:

Double Drum Vibratory rollers are used primarily to compact paving materials & their surface layer. It can also be used for the compaction of small and medium-sized foundations, sub-foundations and filling materials. These machines have two steel drums that vibrate via an internal, eccentric mechanism, which often can be adjusted to vary the frequency and amplitude of the vibratory action.

Fig-E8. Double Drum Vibratory Roller

Few Models Of The Double Drum Vibratory Rollers Manufactured In India	
	
Fig-E4.1 Delivers excellent mat density, good visibility and comfort, fuel efficiency with Eco-mode & good water spray system	**Fig-E4.2** (Solid drum type & excels on a variety of asphalt mix designs as well as other granular materials)

1.7 Single Drum Vibratory Roller:

Single Drum Vibratory Roller which is widely used in the construction to compact the granular layer. It ensure smooth surface after the application and therefore, used for the bridges, patching, footpath and landscaping applications. These machines have one steel drum that vibrates via an internal, eccentric mechanism, which often can be adjusted to vary the frequency and amplitude of the vibratory action.

Fig-E5: Single Drum Vibratory Roller

Few Models Of The Single Drum Vibratory Rollers Manufactured In India

Fig-E9.1: (Drum Type & used for better gradeability)

Fig-E9.2: (Available in Standard, Drum & Pads + Drum type & used for better gradeability & breaking clods)

Fig-E9.3: Vibratory Rollers(Drum Type & used for better gradeability)

2.0 Heavy Machinery for Railway Embankment Construction: Rail Road construction equipment's are found in a wide variety ranging from the very heavy equipment to portable and lighter equipment. This modern and heavy construction equipment makes the construction job easier and quicker. Also the work done by heavy machinery is of good quality. The heavy machines make possible a lot of tasks to be completed safely reliably and time saving that cannot be carried out manually properly.

2.1 Backhoe:

Backhoe comprises a bucket on the end of an articulated boom, set on a pneumatic tyred or crawler tractor unit. The boom, bucket arm and bucket are usually controlled by hydraulic rams. Back-acters operate by digging towards the machine in an arc from a small distance above the surface on which the machine stands to a position vertically below the outer edge of the machine. The maximum depth of excavation is related to the length of the boom and machines with depth capacities between 2.6 and 6 m are in common use. Long reach machines with nominal reach and depth capacities up to 18 to 14m respectively are also available. Buckets are available for back-acters in different sizes up to 3cum, depending on the power of the machine and the use. Loading is generally carried out by lifting the bucket and swinging the boom away from the working face to the awaiting haulage vehicle. Alternatively, material can be dumped adjacent to the machine.

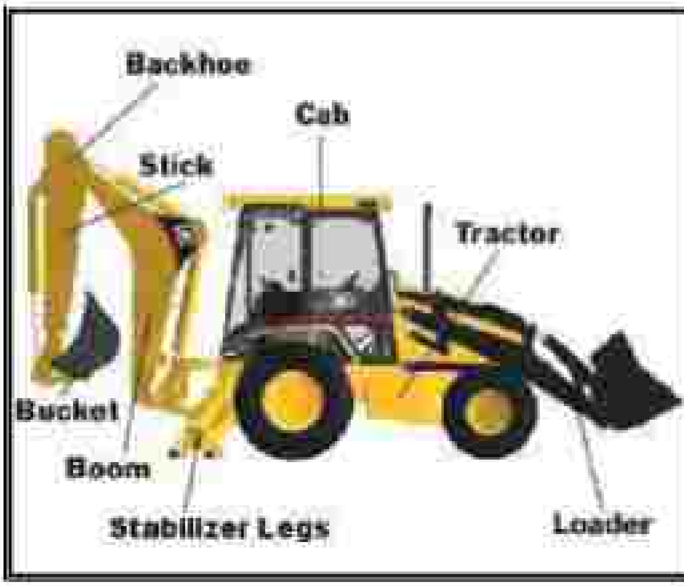


Fig-E 10: Backhoe

2.2 Face, Front or Loading Shovel:

Face, front or loading shovel is constructed in a similar manner to a back-acter except the boom, bucket arm and bucket operate in the opposite direction, i.e. up and away from the machine. Generally used for excavating faces upto about 8m high and stockpiles. Buckets are available in different sizes upto 4cum (heaped) depending on the power of the machine. Loading is carried out in a similar manner to the back-acter, although some machines have bottom dump buckets to increase the speed of loading. It is useful in excavating soils, weak rocks and blasted rocks from faces in cutting etc. some larger excavators can be converted from back-acters to face shovels.

	
Fig-E 11: Shovel	**Fig-E 12: Crawler Hydraulic Excavator with Face Shovel**

2.3 Forward Loader:

Forward loader consists of a pneumatic tyred or crawler tractor at the front of which is mounted a wide bucket that can be moved in a vertical plane. Excavation is carried out by driving the machine towards and the bucket into the material; the bucket is then turned and lifted upwards, thus catching and excavating the material. The hauling vehicle is loaded by driving the loader to and emptying the bucket into the body of a vehicle. Loaders are generally used to excavate the materials at and for a distance above ground level and can be used to push or haul material in the bucket over a short distance. Modern loaders have hydrostatically powered buckets and the smaller units may be equipped with back-acters (i.e. backhoe loader).

Fig-E 13: Forward Loader

2.4 Excavator:

Excavators are heavy construction equipment consisting of a boom, dipper, bucket and cab on a rotating platform known as the "house". The house sits atop an undercarriage with tracks or wheels. They are a natural progression from the steam shovels and often mistakenly called power shovels. These machineries are used for various earthwork purposes such as excavation of earth and loading etc.

Fig-E14: Excavator

2.5 Graders:

Graders are used for levelling the surface during earthwork in embankments and providing blanket surface before spreading ballast and laying track. Graders are used to spread fill and finely trim the subgrade. They consists of a blade which can rotate in a circular arc about a sub horizontal axis and which is supported beneath a longitudinal frame joining the front steering wheels and the rear drive wheels. The front wheels are generally articulated whilst the rear wheels are set in tandem beneath the motor and control units. The blade is used to trim and redistribute soil and therefore graders usually operate in the forward direction.

Fig-E15: Grader

2.6 Dumpers:

Dump trucks or dumpers generally vary in size from 1 to about 80 tonne capacity. Large capacity machines are also available but are generally used in mines, quaries or open cast sites. In recent years articulated dump trucks with capacities upto 35 tonne have become popular as they are versatile and are especially suitable for hauling on softer sub grades. The speed of tipping in increased over a road lorry by the absence of a tailgate. Small dumper units are available for work on small sites and mounted dump trucks are also available with load capacities upto about 20 tonne.

Fig-E 16: Dumper

2.7 Dozers:

Bulldozer also called Dozer, powerful machine for pushing earth or rocks, used in road building, farming, construction, and wrecking, is a tractor equipped with affront pusher blade, which can be raised and lowered by hydraulic rams. An angle dozer has a blade that is capable of being set an angle to push material sideways whilst the tractor moves forward. The tractor unit is usually mounted on crawler tracks thus allowing it to travel over and push off a wide variety of ground conditions although wheel mounted units is available. Blades are manufactured in a variety of styles but are all of heavy duty construction with a hardened steel basal leading edge driven into the ground to cut and push the material to be excavated. Dozers have a wide variety of roles including excavating soils and weak rocks, ripping moving excavated material over short distances spreading materials, trimming earthworks and acting as a pusher to boost the effective power of scrapers and other plants. Wide ranges of crawler units are available ranging from 45 to 575 kW.

Fig-E 17: Dozer

2.8 Scraper:

A scraper is a machine used for moving or removing dirt, gravel and any other unnecessary material from the surface. Scraper can excavate load and deposit material in one cycle and may be towed or self-propelled. It consists of a centrally mounted bowl, the bottom, leading edge of which can be controlled. Both towed and self-propelled scrapers are effectively articulated between the front motorized or towing unit and the bowl and larger self-propelled scraper may second engine mounted on the rear.

Fig-E 18: Scraper

APPENDIX – F

Typical Compaction Characteristics for natural soils & rocks (Ref: BS: 6031 (latest version)

Material (1)	Major divisions (2)	Sub groups (3)	Suitable type of compaction plant (4)	Maximum number of passes for satisfactory compaction (5)	Maximum thickness of compacted layer (mm) (6)	Remarks (7)
Rock-like materials	Natural rocks	All rock fill (except chalk)	Heavy vibratory roller not less than 180 kg per 100 mm of roll Grid roller not less 180 kg per 100 mm of roll Self- propelled tamping rollers	4 to 12	500 to 1500 depending on plant used	If well graded or easily broken down then this can be classified as a coarse-grained soil for the purpose of compaction. The maximum diameter of the rock fragment should not exceed two third of the layer thickness.
Coarse-grained soils	Gravel sand, gravelly soils	Well graded gravel and gravel/sand mixture: little or no fines Well graded gravel/ sand mixtures with excellent clay binder Uniform gravel: little or no fines Poorly graded gravel and gravel/sand mixtures: little or no fines Gravel with excess fines, silty gravel, clayey gravel,poorly graded gravel/ sand/clay mixtures	Grid roller over 540 kg per 100mm of roll Pneumatic tired over 2000 kg per wheel Vibratory plate compactor over 1100 kg/sq.m. of base plate Smooth wheel roller Vibratory roller Vibro-rammer Self-propelled temping roller	3 to 12 depending on type of plant	75 to 275 depending on type of plant	

	Sand and sandy soils	Well graded sands and gravelly sands, little or no fines Well graded sands it e ellent lay inder				
1	2	3	4	5	6	7
	Uniform sands and gravels	Uniform gravels; little or no fines Uniform sands; little or no fines poorly graded sands; little or no fines Sands it fines silty sands layey sands poorly graded sand, lay mi tures	Smoot eeled roller belo 500kg per 100mm of roll Grid roller belo 540kg per 100mm of rolling Pneumati tired roller belo 1500kg per eel vibratory roller vibrating plate compa tor vibro tamper	to 16 depending on type of plant	75 to 100 depending on type of plant	
Fines soils	Soils aving lo plasti ity	Silts (inorgani) and very fine sands ro k flour silty or layey fine sands it slig t plasti ity Clayey silts (inorgani) Organi silts of lo plasti ity	Sheep foot roller Smoot eeled roller Pneumati tired roller vibratory roller over 70 kg per 100 mm of roll vibratory plate compa tor over 1400 kg/sq.m of base plate vibro tamper Po er rammer	4 to 8 depending on type of plant	100 to 450 depending on type of plant	If ater ontent is lo it may be preferable to use vibratory roller. S eep foot rollers are best suited to soils at ater ontents belo t eir plasti limit.
	Soils aving medium plasti ity	Silty and sandy lays (inorgani) of medium plasti ity Clays (inorgani) of medium plasti ity				

Note: *The information in this table should be taken only as a general guide. Field trials for compaction should be conducted for working out optimum layer thickness and number of roller passes for the type of compaction equipment being used. Compaction of mixed soils should be based on that subgrade requiring most compactive effort.*

APPENDIX- G

QUALITY CHECKS PROFORMA

Proforma No. G-1

Details of Borrow soil/ Formation subgrade/Prepared Subgrade

S no	Date of taking sample	Location layer Ch./Km	Soil type				Soil classification	LL	PL	PI
			Gravel %	Sand %	Silt %	Clay %				
1	2	3	4	5	6		7	8	9	10

CBR value	Whether of dispersive nature	Suitable/ Non suitable	Signature and name of Engineer's representative	Signature and name of contractor representative	Remarks
11	12	13	14	15	16

Proforma No. G-2

QUALITY OF BLANKET MATERIAL

1. Type of material: Manufactured/Naturally available
2. Source location:

S.no	Date of taking sample	Location of laying	Soil type			C_U	C_C	Abrasion Value
			Gravel %	Sand %	Fines passing 75 micron sieve %			
1	2	3	4	5	6	8	9	10

CBR value	Signature and name of Rly official	Signature and name of contractor	Remarks
11	12	13	14

Proforma No. G-3

PROFORMA FOR FIELD COMPACTION RECORD

Chainage / km from........ to.........

Soil Classification: Height of embankment:

OMC:

Type of roller being used: Lab MDD/ Field Trial MDD:

CORE CUTTER METHOD

Date of Laying	Layer no.	location coordinate for check	Placement moisture content (%)	No. of passes	Wt. of core cutter+ wet soil (W_s) (g)	Wt. of core cutter (Wc) (g)	Wt of wet soil ($W_s - W_c$) (g)	Vol. of core cutter (V_c) (cc)	Bulk density, $\gamma_b = \frac{(W_s - W_c)}{V_c}$ (g/cc)
1	2	3	4	5	6	7	8	9	10

Moisture content of compacted layer (w) (%)	Dry Density(γ_d) = γ_b / 1+w *100 (g/cc)	Degree of compaction (%)	Sig and name of Rly officer	Sig. and name of contractor	Remarks
11	12	13	14	15	16

Note: 1. In case of compaction of blanket material, percentage of fines should also be mentioned in a column.

2. Determination of Dry Density, (γd) of soil in above table is done as per IS: 2720 Pt 29 – 1975 (latest version) titled as Determination of Dry Density of Soils In-Place By The Core-Cutter Method

Proforma No. G-4

PROFORMA FOR FIELD COMPACTION RECORD

Chainage /km from ...... to.........

Soil Classification:

Height of embankment:

SAND REPLACEMENT METHOD

Location	Bulk density of sand, (γ_s) g/cum	Wt. of wet soil from hole, W_w (g)	Wt of Cylinder + Sand, before pouring W_1 (g)	Wt of sand + Cylinder after pouring W_2 (g)	Mean weight of sand in cone W_3 (g)	Wt of sand in hole W_b = W1 - W2-W3	Bulk Density of soil γ_b= (W_w /Wb) * γ_s
1	2	3	4	5	6	7	8

Moisture content of soil (w), %	Dry Density of soil γ_d = γb/1+w	Relative Density I_D	Sign. and name of Rly Official	Sign and name of contractor	Remarks
9	10	11	12	13	14

Ref: IS: 2720 (Pt 28)1974 (latest version)

(Determination of dry density (γ_d) of soils in-place, by the sand Replacement method)

Note: 1. Density Index (Relative Density) shall be find out as per IS 2720 (Part 14) – 1963 – (latest version).

2. The density index, Id (relative density) expressed as a percentage should be calculated as follows:

Relative density (ID) = $\gamma_{max} (\gamma_d - \gamma_{min}) / \gamma_d (\gamma_{max} - \gamma_{min}) \times 100$

γ_{max} **(from lab as per IS 2720 (Part 14) ....**

γ_{min} **(from lab as per IS 2720 (Part 14) ....**

γ_d determined in field as shown in above table by the sand Replacement method.

APPENDIX-H

QUALITY ASSURANCE TESTS (STANDARD TEST PROCEDURES)

1.0 California Bearing Ratio (Laboratory Method)

(Ref: IS: 2720 (part 16)–Laboratory Determination of CBR (latest version)

1.1 California Bearing Ratio

California Bearing Ratio (CBR) test is a penetration test developed by the California State Highway Department of USA for the evaluation of subgrade strengths for roads and pavements.

California Bearing Ratio (CBR) is defined as the Ratio of Force per unit Area required to penetrate a soil mass with a circular plunger of 50 mm diameter at the rate of 1.25 mm/minute to that required for corresponding penetration of a standard material. The test results may not be directly related to fundamental properties governing the strength of soils such as cohesion, angle of internal friction etc. Schematic of CBR Test shown below:

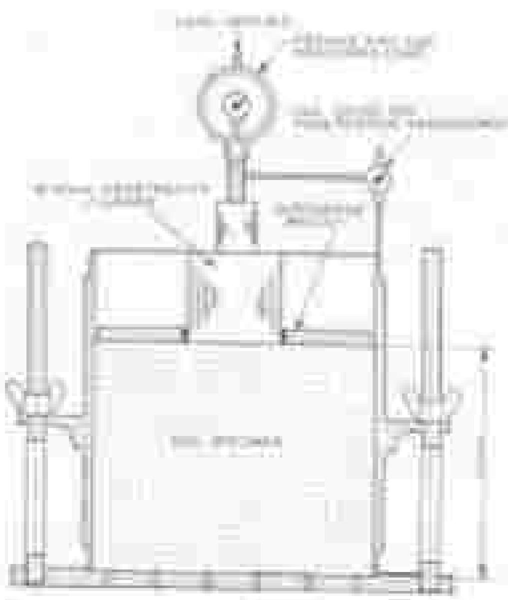


Fig-H 1

1.2 Apparatus:

i) CBR mould 150 mm diameter and 175 mm high with detachable perforated base plate. (Net capacity is 2250 ml).
ii) Collar 50 mm high.
iii) Penetration plunger - 50 mm diameter.
iv) One annular and a few slotted surcharge masses 2.5 kg each.
v) Rammer 2.6 kg with 310 mm drop and 4.89 kg with 450 mm drop.
vi) Steel rod 15-20 mm in dia and 400 mm long.
vii) Cutting edge.

viii) Loading machine of approximately 5000 kg capacity, fitted with a calibrated proving ring giving a constant rate of penetration of about 1.25 mm/minute.
ix) Penetration measuring 2 dial gauges accurate to 0.01 mm.
x) Soaking tank of pan, drying oven, dishes and calibrated measuring jar.
xi) Swelling gauge consisting of a perforated plate with an adjustable extension stem.
xii) I.S. Sieves 4.75 mm and 19 mm.
xiii) Straight edge, mixing basin.
xiv) Filter paper
xv) Weights

1.3 Preparation of test specimen:

The test may be conducted on undisturbed as well as disturbed (remoulded) soil specimen which may be compacted statically or dynamically.

i) Undisturbed soil specimen

Undisturbed soil specimen shall be obtained from the field in natural condition. For this, use 127.3 mm high mould and attach the steel cutting edge to its one end. Push the mould gently into the ground. When the mould is full of soil, it shall be taken out carefully. The top and bottom surfaces are then trimmed flat so as to achieve the correct length of specimen for testing. The specimen is then sealed with paraffin wax on both sides of the mould so as to preserve it with the natural moisture content.

ii) Remoulded specimen (From disturbed sample) :(As per para 4.3 of IS 2720- Part-16)

The dry density for a remoulding shall be either the field density or the value of the maximum dry density estimated by the compaction test (IS: 2720 part.7 & part.8) or any other density at which bearing ratio is desired. The water content used for compaction should be at optimum moisture content or the field moisture as the case may be.

Remoulded specimens are prepared in the laboratory by compaction. The material used in the remoulded specimen shall pass 19 mm I.S. sieve. Allowance for large material shall be made by replacing it by an equal amount of material which passes a 19mm I.S.Sieve but is retained on 4.75 mm sieve.

1.4 Test Procedure:

i) Soaking of remoulded specimen:

Weight the mould with base plate and the specimen. Keep the filter paper on the specimen and place the perforated top plate with adjustable stem over the specimen. Keep the mould in a tank in which water is filled for soaking. Apply weights to produce a surcharge equal to the weight of base material and pavement to the nearest 2.5 kg on the compacted soil specimen. The whole mould and weights shall be immersed in a tank of water allowing free access of water to top and bottom of the specimen. The tripod for the expansion measuring device shall be mounted on the edge of the mould and the initial dial gauge reading recorded. This set up shall be kept as such undisturbed for 96 hours and noting down the readings every day against the time of reading. A constant water level shall be maintained in the tank throughout the period.

At the end of the soaking period, the final reading of the dial gauge shall be noted, the tripod removed and the mould is taken out of the water tank.

The free water collected in the mould shall be removed and the specimen allowed to draining downward for 15 minutes. After draining out water, the weights, the perforated plate and the top filter paper shall be removed and the mould with the soaked soil sample shall be weighed and the mass recorded.

ii) Penetration Test:

The mould containing the test specimen is placed on the lower plate of the testing machine with the base plate in position and the top surface exposed. Surcharge mass is placed on the specimen. If the specimen has been soaked previously, the surcharge shall be equal to that use during the soaking period. To prevent upheaval of soil into the hole of the surcharge weights, 2.5 kg annular weight shall be placed on the soil surface. The plunger shall be seated under a load of 4 kg so that full contact is established between the surface of the specimen and the plunger. Load shall be applied to the penetration plunger so that the penetration is approximately 1.25 mm per minute. Reading of the load shall be taken at penetrations of 0.0, 0.5, 1.0, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0 and 12.5 mm.

After the completion of the test, the plunger is raised and the mould is detached from the loading equipment. About 20 to 50 g of soil shall be collected from the top 30 mm layer of specimen for water content determination.

iii) Load Penetration Curve

The load penetration curve is drawn as shown in Fig-H 2. The curve is generally convex upwards, although the initial portion of the curve may be concave upwards due to surface irregularities. A correction shall then be applied by drawing a tangent to the upper curve at the point of contra flexure. The corrected curve shall then be taken to be this tangent plus the convex portion of the original curve with the origin of strains shifted to the point where the tangent cuts the horizontal strain axis as illustrated in Fig-H 2 below:

Fig-H 2: Load Penetration Curve for a CBR Test

iv) Determination of CBR

Corrected load value shall then be taken from the load penetration curve corresponding to the penetration value at which CBR is desired. The CBR is then determined as follows:-

$$CBR = P_T/P_S x100$$

Where, P_T= Corrected load corresponding to the chosen penetration from the load penetration curve,

P_S =Standard load for the same depth of penetration as for P_s

The CBR values are usually calculated for penetration of 2.5mm and 5mm. Generally, the CBR value at 2.5 mm penetration will be greater than that at 5mm penetration and in such a case; the former shall be taken as the CBR value for design purpose. If the CBR value corresponding to a penetration of 5mm exceeds that for 2.5mm, the test shall be repeated. If identical results follow, the bearing ratio corresponding to 5mm penetration shall be taken for design.

Table-H-1 Standard Loads for CBR test

Penetration Depth (mm)	Unit Standard Load (kg/cm^2)	Total Standard Load (kg)
2.5	70	1370
5.0	105	2055
7.5	134	2630
10.0	162	3180
12.5	183	3600

Test Observations are recorded in the table as given in the code.

5.0 Report:

The CBR value shall then be reported correct to the first decimal place. The details shall be reported in prescribed proforma:-

CBR of specimen at 2.5 mm penetration -

CBR of specimen at 5 mm penetration -

CBR of specimen at ......Penetration -

Results of repeat test, if conducted

2.0 Field determination of Ev_2

(Ref.: DIN 18134 – April 2012)

2.1 Introduction:

Deformation Modulus (Ev_2) is a parameter which gives the deformation characteristics of a finished layer of soil and it is determined from the second cycle of loading in the Plate Load Test. It is to be determined on top of compacted Blanket layer, prepared sub-grade layer and Subgrade layer.

2.2 Test Procedure

a) Apparatus

i) Reaction Loading System

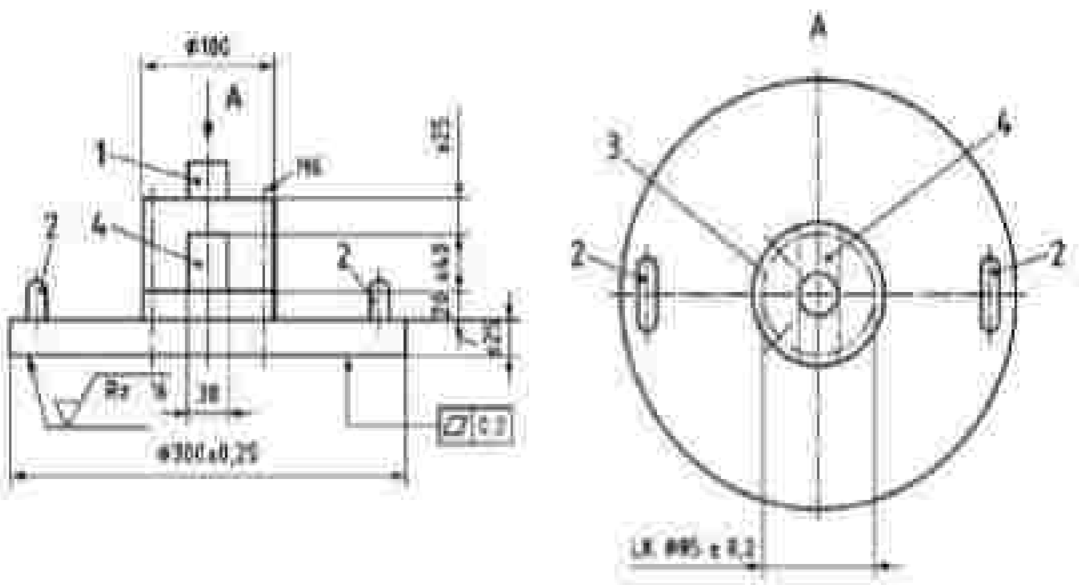
The reaction loading system shall produce a reaction load which is at least 10 kN greater than the maximum test load required. It may be a loaded truck or roller or any other object of sufficient mass.

Loading plate

The 300mm dia loading plate shall have two handles (Fig-H 3) and minimum thickness of 25 mm.

Dimensions in millimetres

General tolerances: ISO 2768 – mL



Key

1 Centring pin to hold the force transducer with articulated top
2 Handle
3 Hole circle (e.g. 85 mm with three M8 bolts (distributed equally on hole circle))
4 Measuring tunnel

Fig-H 3: 300mm Dia Loading Plate

ii) Loading system

The loading system consists of a hydraulic jack, capable of applying and releasing the load in stages. The hydraulic jack shall be hinged on both sides and secured against tilting. The pressure piston shall act through at least 150mm.

The height of the plate loading apparatus during operation should not exceed 600 mm. In order to compensate for differences in the heights of the vehicles used as reaction loads, elements shall be provided that allow the initial length of the hydraulic jack to be increased to at least 1000 mm. Suitable means shall be provided to prevent buckling of these elements.

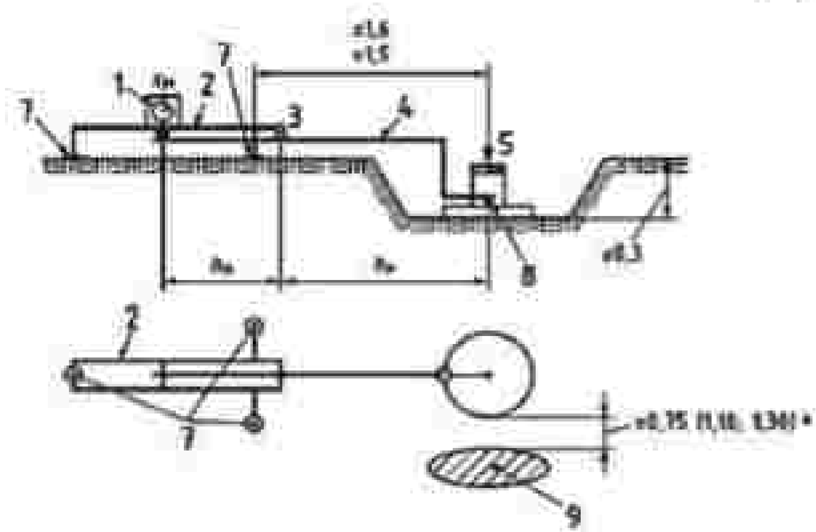
iii) Force-measuring apparatus

A mechanical or electrical force transducer shall be fitted between the loading plate and the hydraulic jack. It shall measure the load on the plate with a maximum permissible error of 1 % of the maximum test load. The stress shall be indicated at a resolution of at least 0.001 MN/m^2.

iv) Settlement-measuring device

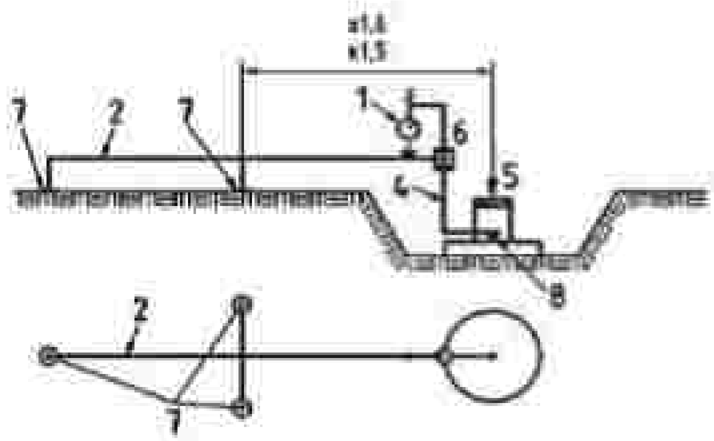
The settlement-measuring device can be with a rotatable contact arm (Fig-H 4) or with a contact arm capable of being moved horizontally in axial direction (i.e. with a slide bearing, see Fig-H 4).

Dimensions in metres



a) Rotatable contact arm according to the "weighbeam principle"; measurement of settlement taking into account the lever ratio $h_P : h_M$

Dimensions in metres



b) Contact arm with slide bearing; measurement of settlement in the lever ratio 1:1

Key

1 Dial gauge or displacement transducer
2 Supporting frame
3 Fulcrum
4 Contact arm
5 Load
6 Slide bearing
7 Support
8 Stylus
9 Area taken up by reaction load system
s_{0i}, s Settlement reading on dial gauge or displacement transducer

Fig-H 4: Settlement Measuring Device

The settlement-measuring device consists of:

(i) A frame supported at three points (see "2" in Fig-H4),

(ii) A vertically adjustable, torsion-proof, rigid contact arm (see "4" in Fig-H4);

(iii) A displacement transducer or dial gauge (see "1" in Fig-H 4).

The distance from the center of the loading plate to the Centre line of the support shall be at least1.5 m and shall not be greater than 1.6 m (see Fig-H 4).

The h_P:h_H ratio (Fig-H 4 a) shall not exceed 2.0. The setting of the assembly shall be capable of being locked so that the h_P/h_H ratio does not change during measurement.

The settlement-measuring device shall be capable of measuring the settlement of the loading plate with a maximum permissible error of 0.04 mm in the measuring range up to 10mm. The indication shall have a resolution of at least 0.01 mm.

Measurement of settlement with alternative measuring devices is permitted if these have at least the same resolution and measure to the same accuracy and are recognized as remaining unaffected by soil deformation occurring as a result of testing.

2.3 Test conditions

In the case of soil which has formed a surface crust, has been softened or has been otherwise disturbed in its upper zone, this disturbed soil shall be removed before the plate load test is carried out. The density of the soil under test shall remain as unchanged as possible.

For fine-grained soil (e.g. silt, clay), the plate load test can only be carried out and evaluated satisfactorily if the soil is stiff to firm in consistency. In case of doubt, the consistency of the soil under test shall be determined at various depths up to a depth "d" below ground level (d= diameter of loading plate).

2.4 Procedure for Plate Load Test

2.4.1 Test area preparation

An area sufficiently large to receive the loading plate shall be leveled using suitable tools (e.g. steel straightedge or trowel) or by turning or working the loading plate back and forth. Any loose material shall be removed.

2.4.2 Setting up the plate loading apparatus

The loading plate shall lie on, and be in full contact with, the test surface. If necessary, a thin bed (i.e. only a few millimeters in thickness) of dry medium-grained sand or gypsum plaster paste shall be prepared to obtain a level surface. The plate shall be bedded on this surface by turning and slightly tapping on its upper face. When using gypsum plaster as bedding material, the plate shall be greased on its underside. Any excess plaster shall be removed with the spatula before it sets. Testing shall not begin until the plaster has set.

The hydraulic jack shall be placed onto the middle of, and at right angles to, the loading plate beneath the reaction loading system and secured against tilting. The minimum clearance between loading plate and contact area of the reaction load shall be 0.75 m. The reaction load shall be secured against displacement at right angles to the direction of loading.

2.4.3 Arrangement of settlement-measuring device

In order to measure settlement, the stylus shall be placed in the center of the loading plate. The distance between the support for the supporting frame and the area taken up by the reaction load shall be at least 1.25 m. The dial gauge or transducer shall be set up so as to be vertical.

When placing the loading plate, care shall be taken to ensure that the stylus of the contact arm can be passed without hindrance into the measuring tunnel in the plinth of the loading plate and positioned centrally on the plate.
The settlement-measuring device shall be protected from sunlight and wind. Care shall be taken to ensure that the device and the reaction loading system are not subjected to vibration during the test.

2.4.4 Preloading

Prior to starting the test, the force transducer and dial gauge or displacement transducer shall be set to zero, after which a load shall be applied corresponding to a stress of 0.01 MN/m^2. The reading of the gauge or transducer shall not be reset to zero until at least 30 s after the preload has been applied.

2.4.5 Loading and unloading

To determine the strain modulus, Ev, the load shall be applied in not less than six stages, in approximately equal increments, until the required maximum stress is reached. Each change in load (from stage to stage) shall be completed within one minute. The load shall be released in 3 stages, to 50%, 25% and approximately 2 % of the maximum load. Following unloading, a further (2^{nd}) loading cycle shall be carried out, in which; however, the load is to be increased only to the penultimate stage of the first cycle (so that the full load is not reached).

When increasing and decreasing the load, 60 s after the previous loading stage has been reached shall elapse before beginning the next stage. The load shall be held constant during this period. The reading shall be recorded at the termination of each loading stage (see Table H-2 & H-3).

To determine the strain modulus, a 300 mm loading plate shall be used and load is increased until a settlement of 5 mm or a normal average stress below the plate of 0.5 MN/m^2 is reached. If the required settlement is reached first, the normal average stress measured at this stage shall be taken as maximum stress.

Table H-2: Measured values for first loading and unloading cycle

Loading stage no.	Load *F (kN)*	Normal Stress σ_0 (MN/m^2)	Dial gauge reading S_m (mm)	Settlement of loading plate S (mm)
0	0.71	0.01	0	0
1	5.65	0.080	0.86	1.15
2	11.31	0.160	1.57	2.09
3	17.67	0.250	2.15	2.87
4	23.33	0.330	2.44	3.25
5	29.69	0.420	2.85	3.80
6	35.34	0.500	3.16	4.21
7	17.67	0.250	2.97	3.96
8	8.84	0.125	2.78	3.71
9	0.71	0.01	1.94	2.59

Table H-3: Measured values for second loading test

Loading stage no.	Load F (kN)	Normal Stress σ_0 (MN/m²)	Dial gauge reading S_m (mm)	Settlement of loading plate S (mm)
9	0.71	0.01	1.94	2.59
10	5.65	0.080	2.42	3.23
11	11.31	0.160	2.65	3.53
12	17.67	0.250	2.84	3.79
13	23.33	0.330	2.99	3.99
14	29.69	0.420	3.10	4.13

If any local inhomogeneity is encountered (e.g. stones, or soil of varying consistency), this shall be recorded.

If, during the loading cycle, a higher load than intended is inadvertently applied, this load shall be maintained and a note made in the test report.

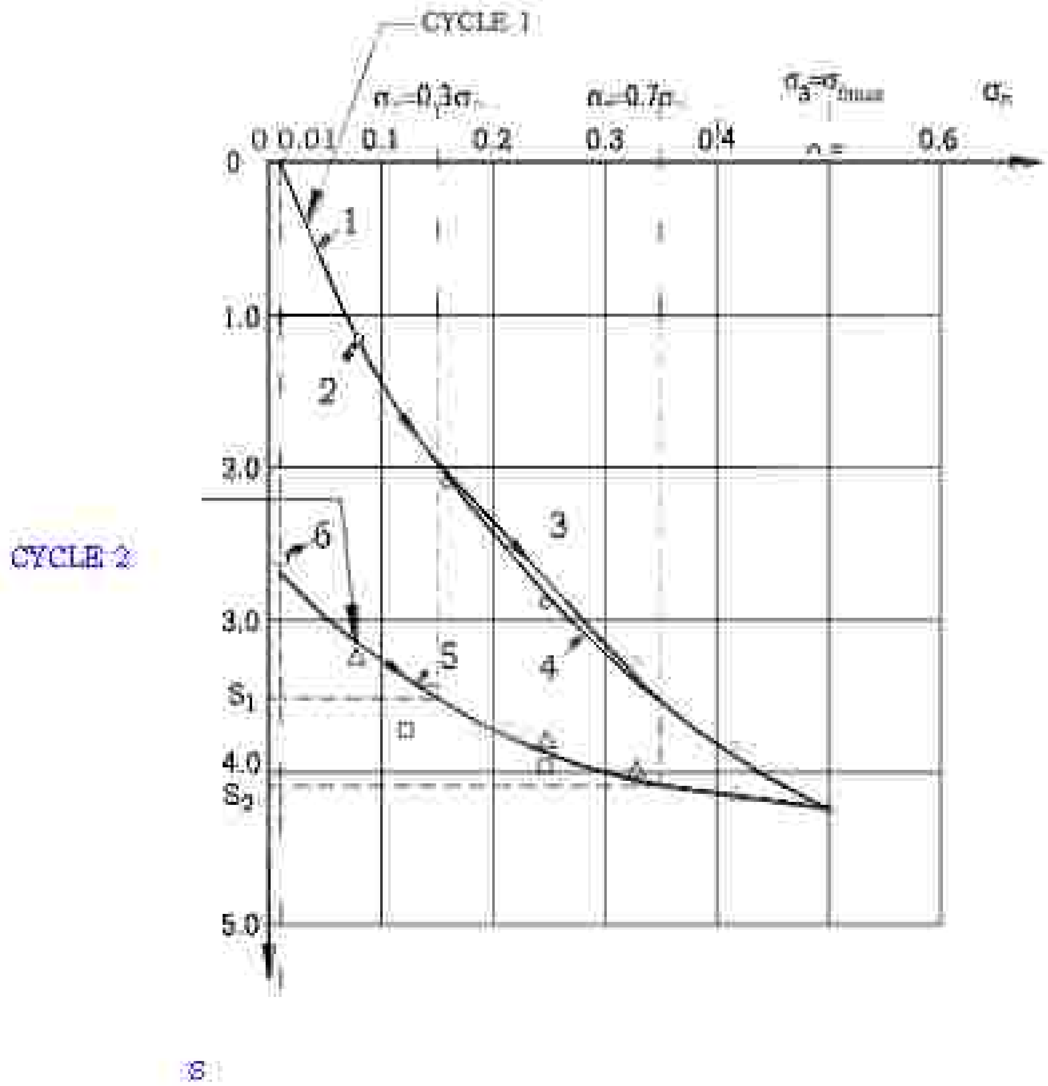
2.5 Evaluation and representation of results

2.5.1 Load-settlement curve

For each load increment, the average normal stress (γ_0) and the associated settlement reading (M) shall be recorded on the dial gauge or displacement transducer. For the assembly shown in Fig. 2b, M shall be taken as the settlement (s) of the plate. For the assembly shown in Fig-H 4, s is to be obtained by multiplying the settlement reading (S_M) by the lever ratio h_P: h_M, in accordance with Equation (1):

$$s = s_M \cdot \frac{h_P}{h_M} \quad (1)$$

A load (mean stress below the plate)-settlement fitting curve shall be drawn for the first loading cycle and second loading cycle as shown in Fig-H 5.



Key

- o Measurement points from the first loading cycle
- □ Measurement points from the unloading cycle
- Δ Measurement points from the second loading cycle
- **1.** Line connecting point (0.01MN/m², 0 mm) and the first point from the first loading cycle
- **2.** First point from the first loading cycle
- **3.** Secant between $0.3\gamma_{0max}$ and $0.7\gamma_{0max}$
- **4.** Quadratic parabola between the first and the last point from the first loading cycle
- **5.** Quadratic parabola between the first and the last point from the second loading cycle
- **6.** First point from the second loading cycle
- s Settlement in mm
- γ_0 Normal stress in MN/m²

Fig–H 5: Load (Stress)-Settlement curve

2.5.2 Calculation of strain modulus, Ev

Calculation of the strain modulus (E_v) from the first and of the second loading cycle shall be based on load-settlement curves, by using following equation:

$$E_v = 1.5 * r * \frac{(\Delta\gamma)}{(\Delta s)}$$

Where: E_v is the strain modulus, in MN/m^2;

r   is the radius of loading plate, in mm;

$\Delta\gamma$ is the change in stress between $0.7\gamma_{max}$ and $0.3\gamma_{max}$; and

Δs is the change in settlement corresponding to stress values of $0.7\gamma_{max}$ and $0.3\gamma_{max}$, from the load settlement curve, in mm.

The subscript 1 shall be used after E_v to denote the first loading cycle, and the subscript 2 to denote the second loading cycle. γ_{0max} from the first loading cycle shall also be used to determine the parameters of the second loading cycle also.

2.6 Examples for determination of Ev

A typical load (stress) – settlement curve is plotted in Fig-H 5 and using this curve, values of E_v are calculated as under:

(i) For First loading cycle:

$E_{v1} = 1.5 * 150 * (0.7\gamma_{0max} - 0.3\gamma_{0max})/(S \text{ at } 0.7\gamma_{0max} - S \text{ at } 0.3\gamma_{0max})$
$= 1.5 * 150 * (0.4 * 0.500)/(3.5 - 1.95)$
$= 29.03\ MN/m^2$

(ii) For Second loading cycle:

$E_{v2} = 1.5 * 150 * (0.7\gamma_{0max} - 0.3\gamma_{0max})/(S \text{ at } 0.7\gamma_{0max} - S \text{ at } 0.3\gamma_{0max})$
$= 1.5 * 150 * (0.4 * 0.500)/(4.08 - 3.50)$
$= 77.58\ MN/m^2$

Fig-H 6: Ev_2 Measuring Equipment

3.0 Measuring in-situ Density and Water Content by Nuclear Moisture Density Gauge

1.0 Apparatus:

1.1 Nuclear Density/Moisture Gauge:

While exact details of construction of the apparatus may vary, the system shall consist of:

Fig.H-7 : Nuclear Gauge

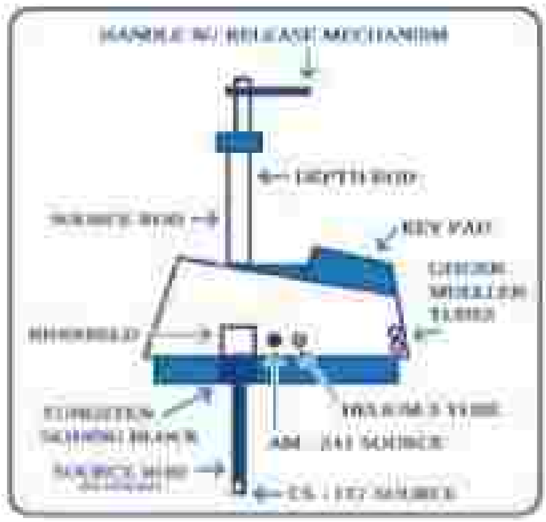


Fig.H-8 : Parts of a Nuclear Gauge

(a) Gamma Source: A sealed source of high-energy gamma radiation, such as cesium or radium.

(b) Gamma Detector: Any type of gamma detector such as a Geiger-Mueller tube(s).

(c) Fast Neutron Source: A sealed mixture of a radioactive material such as americium, radium and a target material such as beryllium, or a neutron emitter such as californium-252.

(d) Slow Neutron Detector: Any type of slow neutron detector such as boron trifluoride or helium-3proportional counters.

1.2 Reference Standard: A block of material used for checking instrument operation, correction of source decay, and to establish conditions for a reproducible reference count rate.

1.3 Site PreparationDevice: Aplate or straight edge or other suitable leveling tool used for levelling the test site to the required smoothness, and in the Direct Transmission Method, guiding the drive pin to prepare a perpendicular hole.

1.4 Drive Pin: A pin of slightly larger diameter than the probe, used to prepare a hole in the test site for inserting the probe:

Fig. H-9 : Site preparation Device with Drive Pin and Hammer etc.

(a) Drive Pin Guide: A fixture that keeps the drive pin perpendicular to the test site.Generally part of the site preparation device.

(b) Drive Pin Extractor: A tool that is used to remove the drive pin in a vertica ldirection so that the pin will not distort the hole in the extraction process.

1.5 Hammer: Heavy enough to drive the pin to the required depth without undue distortion of the hole.

2.0 General

2.1 This procedure covers determination of in-situ density and water content of soil by means of a Nuclear Gauge designed to operate on the ground surface. Most of the gauges normally have combined facilities for determination of density and moisture content both.

2.2 The quality of the result produced is dependent on the competence of the personnel using the gauge and the suitability of the equipment and facilities used.

2.3 Two alternative modes are provided in the gauges:

a) Direct Transmission Mode in which the gamma source rod extends through the base of the gauge in to a pre-formed hole to a desired depth. This is preferred mode for Density Measurement and should be used where possible because of its deeper zone of influence.

b) Backscatter Mode in which the gamma and neutronsource sand the detectors are kept at the surface. Moisture Density can be determined only by using the backscatter mode.

2.4 The presence of moisture inside the gauge cavity will cause malfunctioning of the gauge. Hence, they should be stored in a warm and dry place and not used in the rain.

2.5 Gravel particles or large voids in the source-detector path may be cause higher or lower density measurements. Where lack of uniformity in the soil due to layering, aggregate or voids is suspected, the test site should be excavated and visually examined to determine whether the test material is representative of the in-situ material in general and whether an oversize correction is required, in accordance with practice ASTM D4718.

3.0 Calibration of the Gauge

3.1 Calibration of the gauge should be done by an Accredited Agency or by the Manufacturer of the gauge, in accordance with procedure given in Annex A1and Annex A2 of ASTM:D-6938.

3.2 Gauges shall be calibrated initially and after any repairs that can affect the gauge geometry or the existing calibration. To be within specified tolerances, calibration curves, tables, or equivalent coefficients shall be verified, at periods not to exceed 12 months. If the tolerances cannot be met at any time, the gauge shall be calibrated to establish new calibration curves, tables, or equivalent coefficients. If the owner does not establish a verification procedure, the gauge shall be calibrated at a period not to exceed 12 months.

3.3 Record of calibration shall be maintained, in conformity with procedure given in Annexure- A1 and Annexure- A2 of ASTM:D-6938 and before use of any gauge it should be ensured that the gauge is having valid calibration certificate issued in conformity with stipulated standard.

4.0 Standardization of the Gauge

4.1 Nuclear moisture density gauges are subject to long-term aging of the radioactive sources, which may change the relationship between count rates and the material density and water content. To correct for this aging effect, Standardization of the gauge shall be performed at the start of each day's work and a record of this data should be retained. This procedure shall also be repeated after 8 Hours of continuous use.

4.2 Standardization should be done with the gauge located at least 9 m away from other nuclear moisture density gauges and clear of large masses of water or other items which can affect the reference count rates.

4.3 Standardization Process

(a) Turn on the gauge and allow for stabilization according to the manufacturer's recommendations.

(b) Using the reference standard block, whose serial number matches with the serial number on the gauge, take a reading that is at least four times the duration of a normal measurement period (typically one minute). Use the procedure recommended by the gauge manufacturer to establish the compliance of the standard measurement to the accepted range. Without specific recommendations from the gauge manufacturer, use the procedure given in Para (c) below.

(c) If the values of the current standardization counts are outside the limits set by Eq.1 and Eq.2, repeat the standardization check. If the second standardization check satisfies Eq. 1 and Eq.2,the gauge is considered insatisfactory operating condition.

$$0.99(N_{dc})e^{\frac{-(\ln 2)t}{T_{d(1/2)}}} \le N_{d0} \le 1.01(N_{dc})e^{\frac{-(\ln 2)t}{T_{d(1/2)}}} \quad (1)$$

and

$$0.98(N_{mc})e^{\frac{-(\ln 2)t}{T_{m(1/2)}}} \le N_{m0} \le 1.02(N_{mc})e^{\frac{-(\ln 2)t}{T_{m(1/2)}}} \quad (2)$$

Where

Td (1/2) = the half-life of the isotope that is used for the density determination in the gauge.

Tm (1/2) = the half-life of the isotope that is used for the water content determination in the gauge.

Ndc = the density system standardization count acquired at the time of the last calibration or verification.

Nmc = the moisture system standardization count acquired at the time of the last calibration or verification,

Nd0 = the current density system standardization count,

Nm0 = the current moisture system standardization count,

t = the time that has elapsed between the current standardization test and the date of the last calibration or verification.

ln (2)= the natural logarithm of 2, which has a value of approximately 0.69315,

e = the inverse of the natural logarithm function, which has a value of approximately 2.71828.

4.4 If for any reason,the measured density or moisture becomes suspect during the day's use, another standardization check should be performed.

5.0 Procedure for measurement

5.1 Select a test location where the gauge will be placed at least 600 mm away from any object sitting on or projecting above the surface of the test location. If measurement is to be made at a specific location and the aforementioned clearance cannot be achieved, such as in a trench, follow the gauge manufacturer's correction procedure(s). Keep all other radioactive sources at least 9 m away from the gauge to avoid any effect on the measurement.

5.2 Prepare the test site in the following manner:

(a) Remove all loose and disturbed material and additional material as necessary to expose the true surface of the material to be tested.

(b) Prepare an area to accommodate the gauge by grading or scraping the area to a smooth condition so as to obtain maximum contact between the gauge and material being tested.

(c) The depth of the maximum void beneath the gauge shall not exceed 3 mm. Use native fines or fine sand to fill the voids and smooth the surface with a rigid straight edge or other suitable tool. The depth of the filler should not exceed approximately 3 mm.

(d) The placement of the gauge on the surface of the material to be tested is critical to accurate density measurements. The optimum condition is total contact between the bottom surface of the gauge and the surface of the material being tested. The total area filled should not exceed approximately 10% of the bottom area of the gauge.

5.3 Turn on and allow the gauge to stabilize (warmup) according to the manufacturer's recommendations.

5.4 Direct Transmission Mode

a) Make a hole perpendicular to the prepared surface using the rod guide and drive pin. The hole should be a minimum of 50mm deeper than the desired measurement depth and of an alignment that insertion of the probe will not cause the gauge to tilt from the plane of the prepared area. Care must be taken in the preparation of the access hole in uniform cohesionless granular soils. Measurements can be affected by damage to the density of surrounding materials when forming the hole.

b) Remove the hole-forming device carefully to prevent the distortion of the hole, damage to the surface or loose material to fall in to the hole.

c) Place the gauge on the material to be tested. Lower the probe in to the hole to desired test depth. As safety measure, it is recommended that the probe not be extended out of its shielded position prior to placing it in to the test site.

d) Secure and record one or more sets(s) of one-minute bulk density and water content readings. Read the in-situ bulk density and water content directly.

e) Retract the probe into the housing and check that the radioactive source is safely housed.

5.5 Backscatter Mode:

a) Seat the gauge firmly. Set the gauge in to the Backscatter position.

b) Secure and record one or more set(s) of one-minute density and water content readings.

c) Read the in-situ bulk density and water content.

5.6 Water Content Correction and Oversize Particle Correction:

a) For getting accurate values of water content and bulk density, both of these corrections need to be made when applicable.

b) Prior to using the gauge-derived water content on any new material, the value should be verified. As part of a user developed procedure, occasional samples should be taken from beneath the gauge and comparison testing done to confirm gauge-derived water content values. All gauge manufacturers have a procedure for correcting the gauge-derived water content values.

c) When oversize particles are present, the gauge can be rotated about the axis of the probe to obtain additional readings as a check. When there is any uncertainty as to the presence of these particles it is advisable to sample the material beneath the gauge to verify the presence and the relative proportion of the oversize particles.

d) When sampling for water content correction or oversize particle correction, the sample should be taken from a zone directly under the gauge. The size of the zone is approximately 200 mm in diameter and a depth equal to the depth setting of the probe when using the direct transmission mode; or approximately 75 mm in depth when using the backscatter mode.

6.0 Calculation and expression of Results

In most of the gauges, the Bulk Density, Water Content and Dry Density are calculated and displayed directly. Otherwise, calculate the Dry Density (ρ_d) as under:

$\rho_d = (100 \times \rho) / (100 + w)$

where:

ρ = Bulk Density of the soil determined by Nuclear Gauge

w = Moisture Content of the soil (in %)

If the Nuclear Gauge determines the Water Content of the soil per unit volume of the soil, then the Dry Density is calculated as under:

$\rho_d = \rho - W$

Where,

ρ = wet density

W= Moisture Density i.e. water mass per unit volume of soil

The Moisture Content (in %) "W" can be calculated as: $w = (W \times 100) / (\rho - W)$

7.0 Reporting of Results

The Field Data Records shall include, as a minimum, the following:

(i) Make, model and serial number of the Nuclear Gauge.
(ii) Validity date of Gauge calibration.
(iii) Data for Standardization of the gauge.
(iv) Data/details about daily Verification of gauge Results (see Para 8.0)
(v) Location of test (e.g. Chainage and Lift/Layer No.).
(vi) Visual description of material tested.
(vii) Name of the operator(s).

(viii) Test mode (i.e. Direct transmission or Backscatter) and depth of test.

(ix) Any corrections made in the reported values and reasons for these corrections (i.e. over-sized particles, water content).

(x) Maximum Laboratory Density value.

(xi) Bulk Density measured.

(xii) Water Content in percent.

(xiii) Dry Density Calculated/measured.

(xiv) Degree of Compaction/Percent Compaction.

8.0 Daily Verification of Gauge Results

8.1 At the start of each day's work, the Degree of Compaction (% compaction) should be measured at minimum 3 locations by the Nuclear Gauge and compared with the results given by the conventional methods like Sand Replacement Method or Core Cutter Method at the same locations.

8.2 If the difference in Degree of Compaction (%) at any of the location is more than 6%, the reason for the difference should be examined in detail.

8.3 If the difference in average Degree of compaction (%) of all the locations, ignoring its' sign, is more than 4%, the standardization of the gauge shall be repeated.

8.4 After standardization, the procedure given in Para 8.1 to 8.3 shall be repeated again. If the difference in average Degree of compaction (%) of all the locations, ignoring its' sign, is still more than 4%, the nuclear gauge shall be re-calibrated, to bring the difference in average Degree of compaction (%) of all the locations within 4%.

9.0 Safety Precautions

9.1 These gauges utilize radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Users of these gauges must become familiar with applicable safety procedures and government regulations.

9.2 Effective user instructions, together with routine safety procedures and knowledge of and compliance with Regulatory Requirements, are a mandatory part of the operation and storage of these gauges.

9.3 This procedure does not purport to address all of the safety concerns, if any, associated with its use. The user of this standard should establish appropriate safety and health practices and ensure compliance to all regulatory limitations.

4.0 COMPACTION TEST (Laboratory Method)

[As per IS: 2720 (Part 8)-1983]

Compaction is the process of densification of soil by reducing air voids. The degree of compaction of a given soil is measured in terms of its dry density. The dry density is maximum at the optimum water content. A curve is drawn between the water content and dry density to obtain the maximum dry density and optimum water content. Dry density = M / V (1+w)

Where,

M = total mass of soil

V = volume of soil

w = water content

APPARATUS

1. Cylindrical metal compaction mould
   Capacity: 1000 cc with dia 100 mm + 0.1,
   2250 cc with dia 150 mm + 0.1
   Internal diameter: 100 mm + 0.1, 150 mm + 0.1
   Internal effective height of mould: 127.3 + 0.1 mm
   Collar: 60 mm high
   Detachable base plate
2. Rammer Mass: For Heavy compaction = 4.9 kg, Dia: 50 mm
3. IS sieve: 19 mm & 4.75 mm
4. Oven: Thermostatically controlled to maintain a temperature of 105^0 to 110^0 C
5. Weighing Balance: sensitivity - 1 g for capacity 10 kg,
   0.01g for capacity 200 g
6. Steel straight edge of about 300 mm in length with one edge levelled.
7. Gradation jar
8. Large mixing pan
9. Spatula

Preparation of Sample

1. Break the clods of soil sample as received from the field and remove the organic matter like tree roots, pieces of bark etc. from the sample.
2. Dry the sample in the air. In wet weather, use drying oven but the temperature of the sample should not exceed 60^0 C.
3. Take a representative portion of air-dried soil material and large enough to provide about 6 kg of material passing a 19-mm IS sieve (for soils not susceptible to crushing during compaction, or about 15 kg of material passing a 19-mm IS sieve (for soils susceptible to crushing during compaction)
4. Sieve above material through 19 mm & 4.75 mm IS sieve.
5. Sieve above material through 19-mm IS sieve and if soil retained on this sieve is more than 5%, use mould of 2250 cm^3 and reject soil retained on 19-mm sieve after its proportion of the total sample has been recorded.
6. If percentage retained on 4.75 mm IS sieve is greater than 20, then use mould of 2250 cm^3 otherwise use small mould of 1000 cm^3.
7. Determine the ratio of fraction retained and that passing 4.75 mm IS sieve to to access the density of the soil.

8. Mix the soil sample retained on 4.75 mm sieve and that passing 4.75 mm sieve for further testing.
9. The amount of water to be mixed with air-dried soil at the commencement of the test will vary with the type of soil under test.
   (a) Sandy and gravely soil: a moisture content of 3 to 5 % would be suitable.
   (b) Cohesive soil: Moisture content about 12 to 16% below the plastic limit of the soil should be suitable.
10. With clay of high plasticity or where hand mixing is employed, it may be difficult to distribute the water uniformly through the air dried soil by mixing alone, and it may be necessary to store the mixed sample in a sealed container for a minimum period of about 16 hours before continuing with the test.

PROCEDURE

1. Clean and dry the mould and base plate and apply a thin layer of grease on the inside the mould.
2. Weigh the mould to the nearest 1 gram. Attach the collar to the mould and place on a solid base.
3. Compact the moist soil in to the mould in five layers of approximately equal mass, each layer being given 25 blows from 4.9 kg rammer dropped from a height of 450 mm above the soil. The blows should be distributed uniformly over the surface of each layer.
4. Remove the collar and trim off the excess soil projecting above the mould by using straight edge. Take the weight of mould with compacted soil in it.
5. Remove 100 g of compacted soil specimen for the water content determination.
6. Add water in increment of 1 to 2 % for sandy and gravely soils and 2 to 4 % for cohesive soils
7. Above procedure will be repeated for each increment of water added. The total number of determinations shall be at least four and moisture content should be such that the OMC at which MDD occurs, is within that range.

PRECAUTIONS

1. Ramming should be done continuously taking care of height of 450 mm free fall accurately.
2. The amount of soil taken for compaction should be in such a way that after compacting the last layer, the soil surface is not more than 5 mm above the top rim of the mould.
3. Weighing should be done accurately.

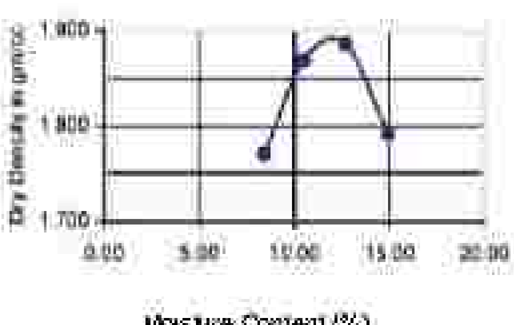


Fig-H 10: Curve for Dry Density V/s Moisture Content

5.0 LOS ANGELES ABRASION TEST FOR BLANKET MATERIAL

(Based on IS: 2386-Part-4)

Purpose: - To determine the Los Angeles abrasion value of Blanket Material.

Apparatus:- -Los-Angeles Machine, Drying Oven, IS sieves of size 10 mm, 6.3 mm, 4.75 mm, 2.36 mm and 1.70 mm.

<u>Preparation of Test sample</u>:-

i) The test sample shall consists of clean material which has been dried in oven at 105-110°C to a constant weight.

ii) The sample shall be sieved through 4.75 mm IS sieve and grading of test sample shall be decided based on percentage passing through it.

Sample passing 4.75 mm IS sieve	**Grading to be adopted for preparation of test sample**
Less than 50%	C
Equal to or more than 50%	D

iii) The sample shall be prepared for the grading 'C' or 'D' [as decided in (ii) above]

Grading	**IS Sieve Size**		**Weight of Sample taken for testing (g)**	
	Passing	**Retained on**		
C	10 mm	6.3 mm	2500	Weight 'A'
	6.3 mm	4.75 mm	2500	
D	4.75 mm	2.36 mm	5000	Weight 'A'

iv) The abrasive charge shall consist of cast iron or steel spheres approx. 48mm diameter and each weighing between 390 and 445g.

The abrasive charge, depending upon the grading of the test sample as follows:

Grading	**Number of Spheres**	**Weight of Abrasive Charges (g)**
C	8	3330±20
D	6	2500±15

Testing Procedure: -

1. The test sample and the abrasive charge shall be placed in the Los Angles Abrasion Machine and the machine rotated at a speed of 20 to 33 revolution / minute. For grading C & D, the machine shall be rotated for 500 revolutions.
2. At the completion of test, the material shall be discharged and sieved through 1.70 mm IS Sieve.
3. The material coarser than 1.70 mm IS Sieve shall be washed, dried in oven at 105-110°C to a constant weight and weighed (Weight 'B').

Calculation:-

1. The proportion of loss between Weight 'A' and 'B' of the test sample shall be expressed as a percentage of the original weight of the test sample.
2. This value shall be reported as:
   Aggregate Abrasion Value (%) = (A-B) x 100/A
   A= Original weight of the Sample
   B= Final weight of the Sample

Precautions:-

1. Avoid loss of any part of sample.
2. Ensure revolutions according to grading.
3. Separate material on completion of test, on appropriate sieve coarser than 1.70mm.

APPENDIX-I

Fitment of Existing Railway Formation

1.0 Introduction

The methodology to assess the fitment of existing formation & requirement for 22.9T/25T axle load operation at 100 kmph & passenger train operations at 160 kmph, is covered in this Appendix.

2.0 Methodology:

The adopted methodology involves determination of induced stress at top of subgrade due to design axle load including dynamic augment for different speeds and makes an arrangement by providing a suitable thickness of blanket layer so that the induced stress at top of subgrade should not exceed the threshold stress of the subgrade soil.

2.1 Assumptions:

i) The induced stress on top of subgrade is calculated by Empirical formula on the basis of various assumptions. References have been taken from IIT/Kanpur Research report no. 1/93, April-1993, "Modern Railway Track" book by C. Esveld. However, the actual stresses may vary, which are measured by instrumentation in the field.

ii) Dynamic Augment (for live load) to be considered for different speed has been calculated assuming an average condition of Track i.e. 'Good' condition.

iii) The permissible stress on the formation has also been calculated using empirical formula. References have been taken from "Modern Railway Track" book by C. Esveld, ORE Report No. D-117, RP-28 and ORE Report No. D-71, RP-12.

iv) Ev_2 value wherever used for calculations, corresponds to the lower limits of different soil quality class and approximate correlation to the different CBR values from ORE report D 117 RP 28 has been used.

v) The CBR of the subgrade soil which is considered in calculation is assumed as minimum CBR value for soil available in top 1.5 - 2.0 m depth of the formation, below the bottom of the ballast.

vi) The thickness of ballast (ballast cushion) used in calculations is total clean ballast cushion of 350 mm.

vii) As per IPWE technical diary 2019-20, passenger locomotive WAP5 has maximum speed of 160 kmph and its axle load is 19.5 T. This is considered for calculation for assessment of requirement for Passenger train operations at 160Kmph.

viii) It is assumed that 30% reduction in blanket thickness requirement can be achieved with application of two layers of geo-grid.

ix) In fitment calculations, it is presumed that there are no persisting problems in sub-soil/subgrade like ground settlement, slope failure etc. in existing formation.

x) In case of stretches where weak/unstable formation exists - Formation rehabilitation measures should be adopted first in pursuance to Para 291 to 295 of IRPWM, before implementation of the recommendations mentioned in Para 4.0.

xi) Other considerations like cess width, slope of embankment etc. for railway formation as per extant policies shall also have to be ensured.

2.2 Calculation of blanket layer thickness:

On the basis of methodology described above & various assumptions, requirement of blanket layer thickness for 22.9T/25 T (Heavy Axle Load) operation upto 100 Kmph and Passenger Train operations upto 160 Kmph has been calculated for different speed and CBR values of soil & are presented below:

2.2.1 22.9 T Axle load:

Table-I 1

Speed → (kmph) / CBR ↓	Thickness of Blanket Layer (mm) Assuming Ballast cushion - 350 mm			
	40	**60**	**75**	**100**
2	550	550	550	600
3	450	450	450	500
4	300	300	300	350
5	150	150	150	200
6	50	50	100	100
7	0	0	0	50

2.2.2 25 T Axle Load:

Table-I 2

Speed → (kmph) / CBR ↓	Thickness of Blanket Layer (mm) Assuming Ballast cushion - 350 mm			
	40	**60**	**75**	**100**
2	600	600	650	650
3	500	500	550	550
4	350	350	400	400
5	200	200	250	250
6	150	150	150	200
7	50	50	100	100

2.2.3 Passenger Trains (for 17T Axle Load/Train 18):

Table-I 3

Speed → (kmph) / CBR ↓	Thickness of Blanket Layer (mm) Assuming Ballast cushion - 350 mm			
	100	**130**	**140**	**160**
2	300	300	300	350
3	200	250	250	250
4	50	100	100	100

2.2.4 Passenger Trains (for 19.5 T Axle Load/WAP-5 loco.):

Table-I 4

Speed → (kmph) / CBR ↓	Thickness of Blanket Layer (mm) Assuming Ballast cushion - 350 mm					
	60	**75**	**100**	**130**	**140**	**160**
2	400	400	450	450	450	500
3	300	300	350	350	350	400
4	150	150	200	200	200	250
5	0	0	50	50	100	100

3.0 Determination of CBR of Subgrade Soil (Sampling & Testing):

i) The soil samples should be collected @ of 4 to 5 locations in a block section. The testing shall be done on a few samples based on the visual examination.

ii) Take out the three soil samples from a location at the depth of 50-100 cm (50 cm depth where embankment height is 1-2 m, assuming ballast penetration if any is less than 30cm) according to sketch-I.(i).
   a) One sample below ballast in the line of rail seat between two sleepers.
   b) One sample on each side of the Cess near the toe of ballast.
   c) Soil samples should not contain pulverised ballast, grass roots etc.

iii) Determine CBR value of soil samples in the Geo-tech lab/soil testing laboratory.

iv) Take the average value of all three CBR values of a location.

v) Based on the determined average value of the CBR of subgrade soil, provision of blanket layer (if required) shall be made, as per the recommendations given in Para 4.0.

4.0 Recommendations for Fitment of Existing Formation:

For operations of 22.9T / 25T axle load at 100 Kmph and Passenger Train (for 19.5T axle load) at 160 Kmph, in existing Railway Formation, the recommendations are as given below (assuming 350 mm ballast cushion and 60 kg Rail Section): -

4.1 Recommendations for 22.9T/25T axle load operation at 100 Kmph:

CBR of Subgrade soil	Recommendation	Remarks
<2	A minimum **1000 mm** thick blanket layer should be provided. Alternatively, thickness of blanket layer can be reduced to 700 mm by provisions of two layers of geogrid one at bottom and another in middle of blanket layer (sketch-I.(ii)).	However, as CBR is low, detailed geotechnical investigation shall also be conducted & if necessary suitable additional measures required as per site conditions/soil investigation should be taken for fitment of existing formation.
≥2 and <4	A **650 mm** thick blanket layer should be provided along with a 350 mm thick layer of better quality soil i.e. soil having CBR ≥ 4. Alternatively, thickness of blanket layer can be reduced to 450 mm by provisions of two layers of geogrid one at bottom and another in middle of blanket layer (sketch-I.(ii)).	
≥4 and <5	A **400 mm** thick blanket layer should be provided.	
≥5 and <8	A **300 mm** thick blanket layer should be provided.	
≥8	No blanket layer is required.	

4.2 Recommendations for Passenger train operations (assuming 19.5 T Axle Load for passenger train/ WAP-5 loco) at 160 Kmph :

CBR of Subgrade soil	Recommendation	Remarks
<2	A minimum **1000 mm** thick blanket layer should be provided. Alternatively, thickness of blanket layer can be reduced to 700 mm by provisions of two layers of geogrid	However, as CBR is low, detailed geotechnical investigation shall also be conducted & if necessary suitable additional measures required as per

	one at bottom and another in middle of blanket layer (sketch-I.(ii)).	site conditions/soil investigation should be taken for fitment of existing formation.
≥ 2 and <4	A **600 mm** thick blanket layer should be provided along with a 350 mm thick layer of better quality soil i.e. soil having CBR ≥ 4. Alternatively, thickness of blanket layer can be reduced to 400 mm by provisions of two layers of geogrid one at bottom and another in middle of blanket layer (sketch-I.(ii)).	
≥4 to <6	A **300 mm** thick blanket layer should be provided.	
≥6	No blanket layer is required.	

4.3 Wherever the blanket layer is to be provided, a suitable non-woven geo-textile layer should be provided below the blanket layer as a separator layer to prevent upward migration of fines from subgrade to blanket layer and penetration of coarse particles of blanket into subgrade.

4.4 The above recommendations are on the basis of 350 mm clean ballast cushion. Wherever it is less, full clean ballast cushion of 350 mm shall be ensured in the section, even where no blanket layer requirement is recommended based on CBR of subgrade.

4.5 Geo-grid and Geo-textile to be used as per RDSO specification no. RDSO/2018/GE: IRS-0004 Pt.-III (Feb 2020) and RDSO/2018/GE: IRS-0004 Pt-I (March 2019) respectively mentioned in **Appendix - C.**

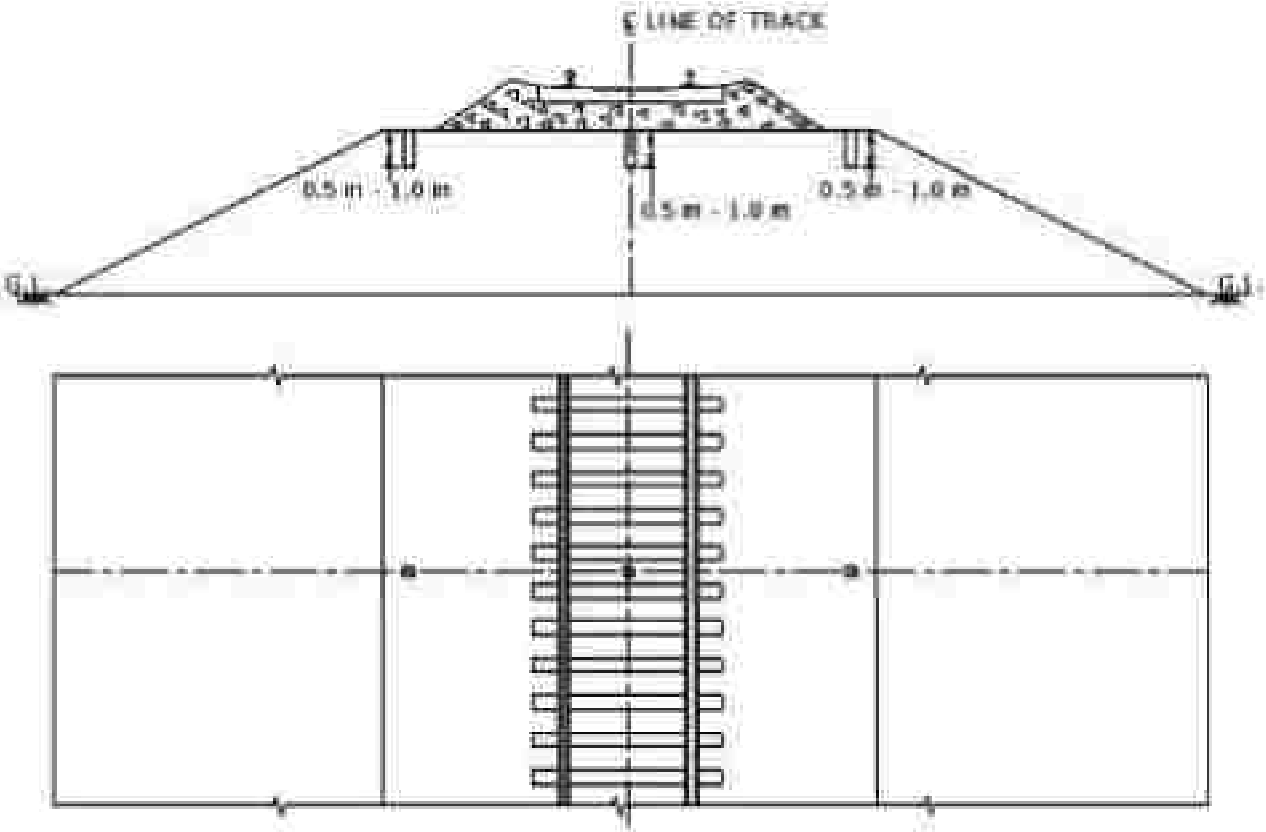
4.6 The above recommendations cover formation related aspects only.

4.7 The formation stretches where the above recommendations are implemented, should be monitored for a period of two year and feedback/suggestions are to be given to RDSO. Based on the feedback of Railways, the above guidelines will be reviewed and improvement suggested (if any) will be incorporated for finalisation accordingly.

4.8 After implementation of above-mentioned recommendations, if any problem arises in the formation the same shall be referred to RDSO. Even otherwise also, subgrade soils with higher CBR values where no blanket requirement has been stated as per para 4.1 & 4.2 above, if any problem is reported in the formation after heavy axle load operation and passenger train at 160 kmph same shall also be reported.

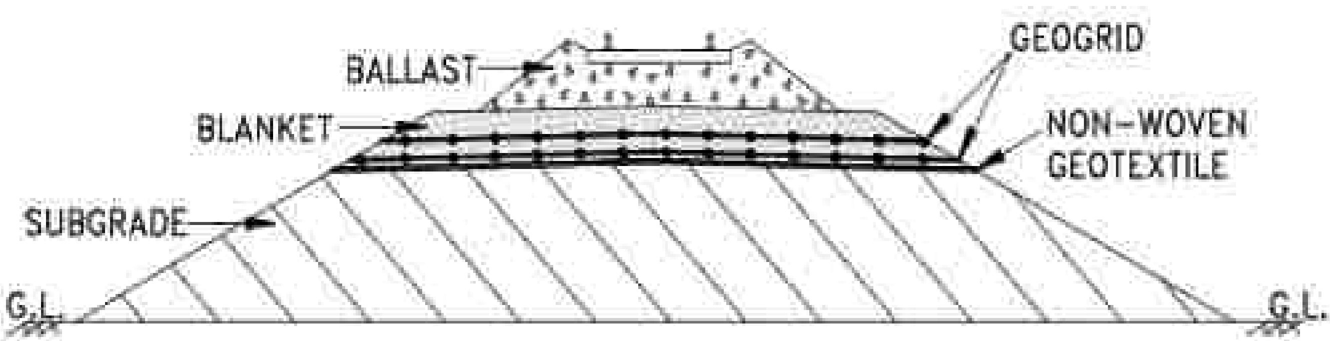
Sketch- I - (i)

LOCATION OF SOIL SAMPLE TO BE COLLECTED



Sketch- I-(ii)

Illustrative diagram for Geo-grid and Geo-textile Application



APPENDIX-J

PROFORMA FOR REPORTING UNSTABLE FORMATION

1. General Details:

Affected Km. From:.. To..

Station between ....

Section ....

Division...

Railway...

	Officer	Name	HQ	Telephone Nos.
1.	CE Construction or concerned CE (Open line)			
2.	CTE			
3.	Sr.DEN (CO)			
4.	Dy. CE or concerned Sr.DEN/DEN			
5.	ADEN/AXEN			
6.	PWI/IOW In-charge			

Reference: By:....................Letter No.................................... Dated:...............................

2. Sectional Details:

Gauge	No. of lines	Max. Permissible Speed	Axle Load	GMT per year	Construction Year	Open to traffic/Year

3. Track Particulars:

Km.	Strength/Curved	Degree	Cant (in mm)	Gradient

4. Track Structure :

Km	Rail			Sleeper			Ballast Cushion mm	
	Section	Year laid	Single/SWR/ LWR	Type	Density	Year laid	Clean	Caked

5. Condition of rails

Type			Percentage
Roaring	Scabbed	Wheel Burnt	

6. Condition of sleepers/fastenings (Tick √ any one)

Good	Fair	Bad

7. Specific deficiencies of track structure:

8. Last deep screening done on:

Month	**Year**

9. Track Quality Index Values of Previous Three Years:

Date of TRC Run	Track Quality Index (TQI)/Composite Track Quality index	Date of OMS Run	Oscillation monitoring System(OMS) data

10. Formation/Cutting Details:

Km	Bank/ Cutting	Max. height/ depth (in m)	Condition of		Condition of Cess and adequacy of width
			Catch Water drain	Side drain	

11. Details of ballast penetration (Attach Cross section of problematic location with ballast penetration profile)

Depth of Ballast Penetration (cm)		
Under left rail	Under right rail	At Centre

12. Details of Erosion control measure, if any

13. Hydrological Characteristics

Average annual rainfall	Erosion of slope during rain (Yes/No)	Position of water table below RL	
		Highest	Lowest

14. Important incidents/problems faced with brief details:

Year of occurrence	Km	Kind of incident	Remarks

Slips/Breach/Raising/Conversion etc.

(Enclose Sketch & brief description)

15. Details of past rehabilitation measures (km-wise)

Km		Type of treatment	Year of execution	Approx. cost	Comments on performance
From	To				

(Enclose separate annexure, if necessary)

16. Details of track attentions in past years, Km-wise (With details)

Year/Km	No. of attentions/year								Remarks
	Km	Km	Km	Km	Km	Km	Km	Km	

17. Speed Restrictions imposed due to unstable formations:

Year/Km	Restriction Imposed			
	1	2	3	4

18. Any proposals for renewals/LWR/CWR: Give brief details

19. Blanket provided: Yes/No

If blanket provided (test results of blanket material to be provided)

20. Type of ground/Formation soil (if not available, relevant tests shall be got done and test reports generated for further analysis as required):

Bank soil/ Cutting	Type of soil	CBR	Remarks
Ground soil			
Formation Soil			

21. Bore log details/report of problematic stretch for sub soil (if not available, bore log should be conducted and report generated for problem analysis, as required):

(Type of Soil & other parameters etc.)

22. Slope stability analysis carried out: Yes/No

If yes, attach the report

23. Maintenance efforts during summers & monsoons, along with brief description of the problem being faced:

24. Any settlement problem of track being faced: Yes/No

If yes, give details

25. Geological details of site (should be made available especially for cuttings related problem & in hilly areas)**:**

26. Details of minor/ major bridge near the problematic location

27. Any rehabilitation carried out using Geosynthetics such as Non-woven Geotextile/Geogrid in past: Yes/No

If yes, give details

28. Any other relevant data/information: Such as consultancy reports rendered by other parties etc.

Signature of Railway Officer
Name:
Designation:

APPENDIX- K

LIST OF EQUIPMENTS FOR FIELD LAB
Table-K.1

S.N.	Description of Equipment	Reference Of I.S. Code (latest version to be used)	UNIT
1	IS set of sieves with base & top lid 20mm,19mm,10mm, 4.75mm, 2mm 600mic, 425mic, 212mic, 75mic,.	IS-460	sets
2	Hand operated sieve shaker for above sieves.		1 no.
3	BALANCE		
	i) Pan balance/Electronic weighing machine - 10 kg capacity (with 1.0 gm Least Count)		1 no.
	ii) Electronic balance - 500 gm capacity (with 0.1 gm Least Count)		1 no.
4	iii) Electronic weighing machine 200grm(LC-0.01g)		2 sets 5 sets
	Field density apparatus complete.	2720-1974 part-XXVIII	2 sets
5	sand replacement	2720-1975 part-XXIX	
	core cutter with dolly	2720 part-8-1983	1 set
6	Heavy Compaction Test apparatus full unit.	2720 part-16-1987	2 sets
7	Laboratory California Bearing Ratio(CBR) Test Apparatus & it's required accessories	2386 part-4	1 no.
8	Abrasion Test Apparatus	IS 2720 Part-5-1985	1 no.
9	Liquid Limit apparatus hand operated with counter & grooving tools.	IS 2720 Part-6-1972	3 no.
10	Shrinkage limit apparatus		4 no.
11	Stainless steel spatula - 25cm long		6 no.
12	Porcelain bowl for LL - 15cm dia.		
13	Aluminium dish with lid – 5cm dia.		2 no.
	Wash bottle - 1 lit. capacity		2 no.
14	500ml capacity		3 no.
15	Glass plate 10mm thick 50x50 cm		3 no.
16	Ground glass 5mm thick 50x50 cm		10 no.
	Enameled trays 45x30cm		10 no.
	20x20cm		10 no.
	&		
	Enameled plates 6inch dia		3 no.
	8 inch dia.		2 no.
17	10 inch dia.		3 no.
18	Frying pans		3 no.
19	Stove janta		1 no.
20	Straight edge 300mm long		2 no.
21	Sample Tube (Size Dia-150mm, Length-450mm)		5 no.

LIST OF EQUIPMENT FOR FIELD LAB
Table-K.2

S. NO.	DESCRIPTION OF EQUIPMENT	REFERENCE OF I.S. CODE (latest version to be used)	UNIT
22	Grain size analyser of fines		
	a)Hydrometer	IS-2720 part-4-1985	2 no.
	b)Thermometer 0 to 50 c		2 no.
	c) Glass cylinder 1000cc capacity with 60mm dia.		5 no.
	d) Nomogram chart		1no.
	e) Stop Watch		1no.
22	Desiccators as IS -6128		2 no.
23	Gallon of 10 litter capacity for distilled water		3 no.
24	Wooden mortar and pestle.		1 no.
25	Specific gravity test apparatus.		2 no.
26	Density bottle-50ml capacity		2 no.
27	Glass cylinder 100 cc capacity (for Free Swell index test)		1 no.
28	Oven- thermostatically controlled to maintain a temperature 105-110c		
29	Relative Density test Apparatus	IS-2720 Part-14-1983	1 no.
30	Standard Penetration Test (SPT) Appratus	IS- 2131- 1981(Reffeed-1997)	1 no.
31	Nuclear Moisture Density Gauge (NMDG) Apparatus		
32	**Note**-Preparation of dry soil samples for various test	Follow IS-2720 Part-1-1983	
33	**Consumable Item**		
34	Sieve brush		
35	Wire brush		
36	Sodium carbonate		
37	Sodium hexa meta phosphate.		
38	Kerosene		
39	Mercury		
40	**Additional Equipment**		
	Hand auger 150mm dia with extension rod		
	Sampling tube 100mm dia. And 450mm length		
41	All machines and equipments should have Calibration Certificate.		

1.0 Soil Classification

(Ref: IS: 1498 – 1970, Reaffirmed 2016)

1.1 Background and Basis of Classification:

The Geotechnical Engineers/Agencies had evolved many soil classification systems, over the world. The soil classification system developed by Casegrande was subsequently modified and named as 'Unified Classification' system. In 1959, Bureau of Indian Standards adopted the Unified classification system as a standard, which was revised in 1970. According to BIS classification system, soils are primarily classified based on dominant particle sizes and its plasticity characteristics. A soil particle mainly consists of following four size fractions:

- Gravel : 80 – 4.75 mm
- Sand : 4.75mm – 0.075mm (75 micron)
- Silt : 75 – 2 micron
- Clay : less than 2 micron

Particle size distribution of a soil is determined by a combination of sieving and sedimentation analysis as per procedure detailed in IS: 2720 (Part 4) – 1985 (Reaffirmed 2015) and its plasticity characteristics are determined by Liquid Limit and Plastic Limit as per procedure detailed in IS:2720 (Part 5) –1985 (Reaffirmed 2015).

1.2 Symbols used in Soil Classification:

Symbols and other soil properties used for soil classification are given below:

Primary Letter

G: Gravel
S: Sand
M: Silt
C: Clay
O: Organic soil
P: Peat

Secondary Letter

W: well-graded
P: poorly graded
M: with non-plastic fines
C: with plastic fines
L: of low plasticity
I : of medium plasticity
H: of high plasticity

Other soil parameters required for soil classification:

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

1.3 Based on above, soils encountered in India are classified as under (as per IS Code):

1.3.1 Coarse grained soils:

GW-Well graded gravels, gravel-sand mixtures; little or no fines
GP-Poorly graded gravels or gravel-sand mixtures; little or no fines
GM-Silty gravels, poorly graded gravel-sand-silt mixtures

GC-Clayey gravels, poorly graded gravel-sand-clay mixtures
SW-Well graded sands, gravelly sands; little or no fines
SP – Poorly Graded Sands or gravelly sands; little or no fines
SM-Silty sands, poorly graded sand-silt mixtures
SC-Clayey sands, poorly graded sand-clay mixtures

1.3.2 Fine grained soils:

ML-Inorganic silts and very fine sands rock flour, silty or clayey fine sands or clayey silts with none to low plasticity
CL-inorganic clays, gravelly clays, sandy clays, silty clays, lean clays of low plasticity
OL-Organic silts and organic silty clays of low plasticity
MI-Inorganic silts, silty or clayey fine sands or clayey silts of medium plasticity
CI-Inorganic clays, gravelly clays, sandy clays, silty clays, lean clays of medium plasticity
OI-organic silts and organic silty clays of medium plasticity
MH-Inorganic silts of high compressibility, micaceous or diatomaceous fine sandy or silty soils, elastic silts
CH-Inorganic clays of high plasticity, fat clays
OH- Organic clay of medium to high plasticity
Pt-Peat and other highly organic soils with very high compressibility.

Table-L.1 Coarse grained soils

Soil Particle	Gradation		Mixed Soils(s)
	Well Graded	Poorly Graded	Silt & Clay
Sand	SW	SP	SM, SC
Gravel	GW	GP	GM, GC

Table – L.2 Fine grained soils

Soil Particle	Plasticity/compressibility		
	Low	Medium	High
Clay	CL	CI	CH
Silt	ML	MI	MH
Organic	OL	OI	OH & Peat

Soils having dual symbol: GW-GM, GW-GC, GP-GM, GP-GC, SW-SM, SP-SM, SP-SC & CL-ML

1.4 Limiting gradation curve for separating liquefiable and non-liquefiable soil is as given below for reference:

Poorly graded sand and gravel with Cu < 2.0, should not be used in earthwork for the banks to safeguard against liquefaction. Generally, most liquefiable soils as falling in gradation zone as indicated in the Fig-L1 & having coefficient of uniformity, Cu < 2 shall not be used. Potentially liquefiable soils as falling in gradation zone as shown in Fig-L1 should be specifically examined and designed to prevent possibility of any liquefaction.

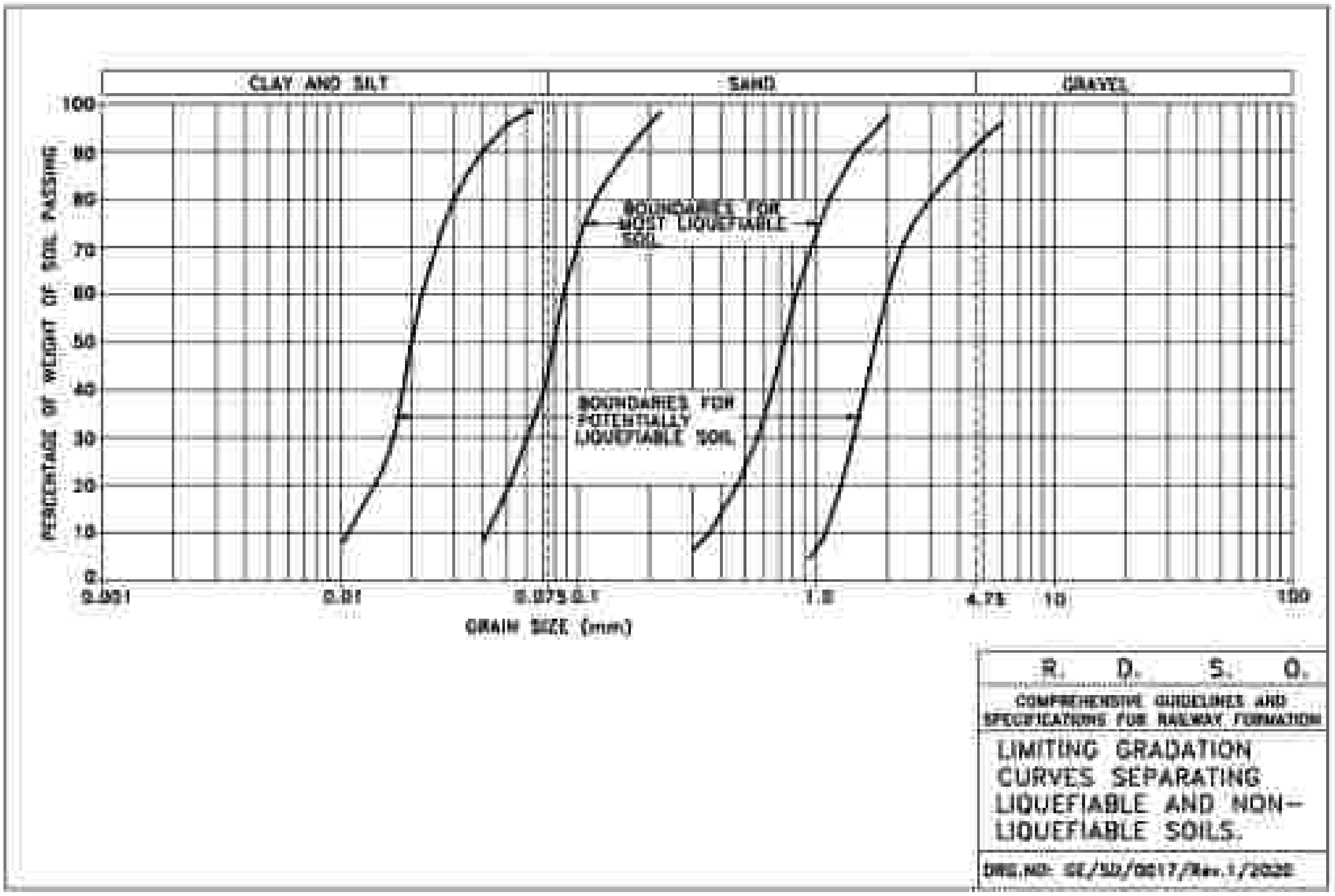


Fig-L1: Limiting Gradation Curves Separating Liquefiable and Non-Liquefiable Soils

APPENDIX- M

CHECKLIST FOR CERTIFICATION OF QUALITY OF EARTHWORK IN RAILWAY PROJECTS

(NEW LINES/ DOUBLING/ GAUGE CONVERSION PROJECTS)

(As per Guideline & Specification for Railway Formation No. RDSO/2020/GE: IRS-0004, June 2020)

1.0 GENERAL INFORMATION:

i) Name of the Project :

ii) Length of the Project :

iii) New Line/Doubling/Gauge Conversion :

iv) Section & Length being certified :

2.0 SOIL EXPLORATION:

(As per Chapter 1 of RDSO/2020/GE: IRS-0004)

(i) Is soil survey carried out as per para 1.2 of Chapter 1 of RDSO/2020/GE: IRS-0004. :

(ii) Reference of record/report of soil exploration :

(iii) Any problematic soils encountered in soil exploration such as soft soil, Organic clays & silts etc. :

(iv) Whether results of soil exploration taken into account in project formulation and alternatives explored. :

(v) Whether geological investigations carried out in case of hilly terrain. :

(vi) Reference of record/report of geological investigation :

(vii) Reference if any, to RDSO for proof checking & consultancy report submitted by private agencies. :

3. FIELD COMPACTION TRIALS

(As per para 6.2.3 (c), Chapter 6 of RDSO/2020/GE: IRS-0004)

(i) Whether field trials conducted :

(ii) Details of field trial (indicate) :

(a) Classification of soil :

(b) Type of roller used and its weight :

(c) Optimum thickness of layer achieved :

DY.CE/

(d) Optimum number of passes of the roller used :

(e) Field moisture content :

(f) Maximum attainable field dry density :

(iii) Whether field compaction trial taken into account in execution. :

(iv) Reference of record of field trials :

(v) Reference of record of field compaction trails (maintained as given in Annexure III, IV, V & VI) :

4. QUALITY CHECK OF EARTH WORK
(As per Para 6.2.8, Chapter 6 of RDSO/2020/GE: IRS-0004)

(i) Whether GE Field Laboratory has been set up at site for quality check. :

(ii) Whether equipment available in the GE Lab is as per Annexure –VIII (attached). :

(iii) Dates of inspection of GE Lab by CE/Con based on which item Nos (i) & (ii) above is certified. :

4.1 BORROW MATERIAL
(As per para 7.3.1, Chapter 7 of RDSO/2020/GE: IRS-0004)

(i) Type of fill material (indicate classification as per IS-1498): used in the earth work.

(ii) Is soil suitable for embankment (As per Para 3.7 of Chapter 3 of RDSO/2020/GE: IRS-0004) :

(iii) Frequency of testing at site to assess the suitability of fill materials (As per Table 7.2 Chapter 7 of RDSO/2020/GE: IRS-0004) :

(a) Total quantum of earthwork involved :

(b) Minimum number of test required (at least one test at every change of subgrade/ Prepared subgrade material subjected to minimum of one test per 5000 cum) :

(c) Number of tests actually done :

(iv) Maximum size of materials used in the bank in case of cobbles/boulders/rock etc. :

DY.CE/

(v) Is it certified that record of quality of fill material has been maintained as given in format in Annexure VII (A), attached record of testing is preserved in the reference :

4.2 BLANKET MATERIALS

(As per para 7.3.2, Chapter 7 of RDSO/2020/GE: IRS-0004)

(i) Source of blanket material :

(ii) Type of blanket material used (Natural/Mechanically Crushed/ Blended) :

(iii) Whether quality of blanket material selected in conforming to specification as given in para (As per table 3.3, 3.4, 3.5 & 3.6, Chapter 3 of RDSO/2020/GE: IRS-0004) :

(iv) Thickness of blanket layer

(a) Type of sub-grade (in top 1m) :

(b) Thickness required (As per table 3.3, 3.4, 3.5 & 3.6, Chapter 3 of RDSO/2020/GE: IRS-0004) :

(c) Thickness actually provided :

(d) Deviation from prescribed thickness, if any :

(v) Frequency of testing to assess the suitability of blanket material (As per Table 7.2, Chapter 7 of RDSO/2020/GE: IRS-0004) :

(a) Total quantum of blanket material involved in cum :

(b) Minimum number of test required (at least one test per 5000 cum) :

(c) Number of tests actually done :

(vi) Reference of record of testing where quality of blanket material has been maintained as given in format in Annexure VII (B) attached. :

4.3 QUALITY CONTROL CHECKS ON FINISHED EARTHWORK

(As per Para 7.4, Chapter 7 of RDSO/2020/GE: IRS-0004)

4.3.1. For Soil

(i) Frequency of tests for degree of compaction (As per Table 7.2, Chapter 7 of RDSO/2020/GE: IRS-0004) :

(a) Total area of earth work involved (Cumulative for every layer in Sqm.) :

DY.CE/

(b) Minimum number of density test required (at least one per 200 sqm for top one metre of subgrade and one per 500 sqm for balance) :

(c) Number of density test check actually done :

(d) Number of test where degree of compaction is less than 98% of MDD :

(e) Action taken in case of (d) :

(ii) Reference of record where report of checking of degree of compaction has been preserved as given in format in Annexure VII (C) (enclosed) :

(iii) Soil used as subgrade (SQ1/SQ2/SQ3) :

(iv) Ev_2 Value on top of subgrade (As per Table 7.2, Chapter 7 of RDSO/2020/GE: IRS-0004) :

(v) Compaction at top layer of subgrade(As per Table 7.2, Chapter 7 of RDSO/2020/GE: IRS-0004) :

4.3.2 For Ballast

Ballast Cushion Thickness :

4.3.3 For Blanket

(i) Frequency of tests for degree of compaction / Relative Density done (As per Table 7.2, Chapter 7 of RDSO/2020/GE: IRS-0004) :

a) Total area of blanket involved :

b) Minimum number of density test required (at least one par 200 sqm for every blanket layers) :

c) Number of density check actually done :

d) Number of test where degree of compaction is less than 98% of MDD or 70% of Relative Density (Relative Density should be calculated if fines in the soil are less than 5%) :

e) Action taken in case of (d) :

(ii) Reference of record where report of checking of degree of compaction has been maintained as given in format in Annexure VII (D) attached. :

(iii) Compaction of blanket layer (100% of MDD(As per Table 7.2, Chapter 7 of RDSO/2020/GE: IRS-0004) :

(iv) Blanket material specification test Report : Y/N

(v) Blanket thickness (Single layer/ Two layer) :

(vi) Ev_2 Value on top of blanket layer (As per Table 7.2, Chapter 7 of RDSO/2020/GE: IRS-0004) :

DY.CE/

4.3.4. Prepared Subgrade (As per table 3.4 &3.6 of RDSO/2020/GE: IRS-0004)
(**For Two Layer Formation system only**)

(i) Prepared sub grade specification and test report : Y/N
(ii) Soil used as prepared sub grade (SQ2/SQ3) :
(iii) Prepared sub grade thickness :
(iv) Compaction of Prepared Sub-grade :
(v) EV2 Value on top of Prepared Sub-grade :

4.3.5. Formation level (As per para 7.6, Chapter 7 of RDSO/2020/GE: IRS-0004)

(i) Has it been ensured that finished top sub grade level is within ± 25 mm of designed level and finished top of blanket layer is within +25 mm from designed level and top of formation is level without ruts of low pocket. :
(ii) Reference of level book maintained to ensured Item (i) above :

4.3.6 Cross Slope (As per para 7.7 of RDSO/2020/GE: IRS-0004) :

4.3.7. Side Slope (As per para 7.8 of RDSO/2020/GE: IRS-0004) :

4.3.8. Formation System (As per para 3.1 of RDSO/2020/GE: IRS-0004)
Single layer/ Two layer :

4.3.9. Formation width (As per IRSOD latest version) :

4.3.10 Cess Width (90cm Min.) :
(As per Para 3.3 (a) of RDSO/2020/GE: IRS-0004)

4.3.11 a) Provision of Berm (for more than 6m High embankment): Y/N

b) Berm Width (2.0m Min.)
(As per Para 5.1.2 of RDSO/2020/GE: IRS-0004 :

5.0 SLOPE STABILITY FOR EMBANKMENT/ CUTTING
(As per chapter 5 of RDSO/2020/GE: IRS-0004)

(i) Maximum height of bank (at chainage) :
(ii) Maximum depth of cutting (at chainage) :
(iii) Designed side slope in bank/cutting as per slope stability analysis (attach profile duly approved) :
(iv) Agency which carried out slope stability analysis :
(v) Actual side slope provided in bank/cutting at site (attach profile duly approved) :

6.0 EROSION CONTROL MEASURES
(As per para 8.3, Chapter 8 of RDSO/2020/GE: IRS-0004)

(i) Type of soil used in earth work :
(ii) Chainage where erosion control measures required : Y/N

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(iii) Chainage where erosion control measures planned :

(iv) Type of erosion control measures provided chainage wise:

7.0 Slope Protection Measures

(Ref: RDSO Guidelines for Cuttings in Railway Formations, GE: G-2)

(i) Slope protection measures required : Y/N

(ii) Slope protection planned :

(iii) Slope protection provided :

8.0 Drainage system (As per para 6.2.6, Chapter 6 of RDSO/2020/GE: IRS-0004)

(i) Drainage system required : Y/N

(ii) Catch water Drain System Planned :

(iii) Catch water Drain System Provided :

(iv) Side drain planned :

(v) Side drain Provided :

9.0 CUTTINGS (Ref: Para 8.4, Chapter 8 of RDSO/2020/GE: IRS-0004 & GE: G-2)

(i) Details of cutting as per **Annexure –1** enclosed :

(ii) Attach copy of designed & approved cutting profiles :

(iii) Details of deviation, if any, to recommendation of Geologist investigation. :

10.0 BACKFILL BEHIND BRIDGE ABUTMENT/WING WALLS/ RETURN WALL

(As per Para 6.2.5, Chapter 6 of RDSO/2020/GE: IRS-0004)

(i) Details of backfill behind bridge approach **Annexure –II** enclosed. :

11.0 GE LAB AT SITE (Para 6.2.8, Chapter 6 RDSO/2020/GE: IRS-0004)

(i) Organization

a) In Charge :

b) Total Staff strength with particular :

c) Qualification and training of personnel :

(ii) Period for which lab at site was in operation :

(iii) Total number of tests carried out at site :

(iv) Reference of record of tests :

(v) Equipments (As per Annexure VIII attached) :

12.0 GENERAL SITE DETAILS

(i) Pond/Ditches/ Borrow pits along the Alignment (distance from toe of bank) (As per para. 3.6, Chapter 3 of RDSO/2020/GE: IRS-0004) :

DY.CE/

(ii) Rain cuts on slope : Y/N (if Y chainage)

(iii) Cracks on formation and slope : Y/N (if Y chainage)

(iv) Details of benching in case of doubling :

(v) Minimum center to center distance between tracks :

DYCE/

13.0 BRIEF DETAILS OF DEVIATIONS

S. No.	Nature of Deviations	Approved by	Reference of approval.
1.			
2.			
3.			
4.			

It is certified that the earthwork and blanketing from chainage ------ to chainage ------ i.e. ------km have been done strictly as per prescribed specification, stipulated in (as per RDSO Guideline & Specification No. RDSO/2020/GE: IRS-0004) under my active administrative and technical control except minor deviations as stated in para. 13.0 above for which approval of the component authority has been obtained and necessary precautions for ensuring safety on the account of deviation have been taken.

Chief Engineer (Con)

ANNEXURE-I

DETAILS OF CUTTING

Location Chainage/Km	Max Depth of Cutting	Geological investigation carried out	Details of Beam provided (Not less than 4-5m)	Type of Rock/ soil strata	Side slope		Side Drain		Catch Water Drains				Other measures taken like gabions, R/walls, etc.
					Designed (Y/S)	Actual at site	Designed	Provided	Required	Designed	Provided	Katcha /Lined	

ANNEXURE-II

BACK FILL BEHIND BRIDGE ABUTMENT

Bridge No.	Boulder Shape	Boulder Size	Packing of Boulders	Thickness of Boulder packing	IS classification of back fill in triangular zone	Weep holes	Any special treatment like toe pitching, toe wall etc.

ANNEXURE- III

FIELD COMPACTION TRIAL OBSERVATIONS & COMPUTATION SHEETS
COMPACTION EQUIPMENT DATA

Project..................... Location......................... Date......................

Item		Roller - 1	Roller -2	Roller -3
Type of Roller				
Gross weight (tonnes)				
Drum Dimension (Roller Type)	Width (mm)			
	Diameter (mm)			
Foot (Sheep foot Type)	Type			
	Number			
	Length (mm)			
	Area (mm^2)			
Contact Area (cm^2) (Sheep foot/ Pneumatic Tyred/Vibratory Plate Type)				
Tyre Inflation Pressure(Kg/cm^2)				
Nominal Amplitude(mm)				
Frequency(Hz)				
Dynamic Force(Kg)				
Operational Speed(Kmph)				
Static Linear Loads(Kg/cm)				
Contact Pressure(Kg/cm^2)				

LIST OF EQUIPMENT FOR FIELD TRIALS/MONITORING

S. No.	Equipment	No. Reqd.	No. available
1.	Field density apparatus complete: a)Sand replacement b) Core cutter with dolly and hammer	 4 Sets 4 Sets	
2.	Balance: a)Electronic balance – 20 kg capacity (with 2.0 gm Least Count) b)Electronic balance – 500 gm capacity (with 0.1 gm Least Count)	 1 Set 1 Set	
3.	Straight edge 300mm long	4 Nos.	
4.	Frying Pan	1 No.	
5.	Containers plastic (about 500g capacity)	8 Nos.	
6.	Enamel plates: 6 inch dia. 8 inch dia. 10 inch dia.	10 Nos. 5 Nos. 3 Nos.	
7.	Uniform clean sand (Ottawa Sand) (bags of 50 Kg)	10 Bags	
8.	Measuring tape (3M/5M)	1 No.	
9.	Measuring tape (15 M/30M)	1 No.	
10.	Kerosene oil stove	1 No.	

Signature of
Monitoring Official ________________
Name________________________
Designation __________
Date ___________________________

Signature of
Project Official ______________________
Name_______________________________
Designation ____________________
Date ___________________________

ANNEXURE- IV

FIELD COMPACTION TRIAL OBSERVATION
TABLE- 1

Project ______________________________ Date ______________________

Location ___________________________________

Strip No.	Location on the ramp	Moisture content before watering				Moisture content after adding the water			
		Container No.	Weight of wet soil.(gms)	Weight of dry soil.(gms)	Moisture content (%)	Container No.	Weight of wet soil.(gms)	Weight of dry soil.(gms)	Moisture content (%)
1	2	3	4	5	6	7	8	9	10
J	1								
	2								
	3								
	4								
K	1								
	2								
	3								
	4								
L	1								
	2								
	3								
	4								
M	1								
	2								
	3								
	4								

Signature of Monitoring official___________________
Name______________________________________
Designation__________________________________
Date ________________________

Signature of Project Official_______________________
Name_______________________
Designation___________________________________
Date ________________________

ANNEXURE - V

FIELD COMPACTION TRIAL OBSERVATION
TABLE- 2

Project ______________________ Location: ______________________ Date ____________
STRIP No. ____________ OMC ____________ % MDD ____________ gms/cc Volume of core cutters: ____________ C.C.

No.of roller passes	Location of the Ramp	In-situ bulk density					Moisture content				Dry density of soil	Percent of MDD	Remark
		Core cutter No.	Wt. Of empty core cutter (gm)	Wt. of wet soil with core cutter (gm)	Wt. of wet soil (gm)	Bulk density of soil (gm/cc)	Containe r No.	Wt. of wet soil (gms)	Wt. of dry soil (gms)	Moisture content (%)			
1	2	3	4	5	6	7	8	9	10	11	12	13	14
4	1												
	2												
	3												
	4												
6	1												
	2												
	3												
	4												
8	1												
	2												
	3												
	4												
10	1												
	2												
	3												
	4												
12	1												
	2												
	3												
	4												
14	1												
	2												
	3												
	4												

Signature of monitoring official ____________
Name ____________
Designation ____________
Date ____________

Signature of project official ____________
Name ____________
Designation ____________
Date ____________

ANNEXURE- VI

FIELD COMPACTION TRIAL-COMPUTATION SHEET
TABLE- 3

Project________________ Location____________________________

S. No	Lift thickness (mm)	Moisture content %	Dry density of soil(gm/cc) Nos. of the roller passes						Remarks
			4	6	8	10	12	14	
1.	225								
2.	300								
3.	375								
4.	450								

Computed by___________________________ Checked by __________________

Name ________________________________ Name_________________________

Designation___________________________ Designation____________________

Date _________________________ Date__________________________

ANNEXURE- VII

A) DETAILS OF BORROW SOIL / FORMATION SUBGRADE / PREPARED SUBGRADE

S. no	Date of taking sample	Location layer Ch./Km	Soil type				Soil classification	LL	PL	PI
			Gravel %	Sand %	Silt %	Clay %				
1	2	3	4	5	6		7	8	9	10

CBR value	Whether of dispersive nature	Suitable/ Non suitable	Signature and name of Engineer's representative	Signature and name of contractor representative	Remarks
11	12	13	14	15	16

B) QUALITY OF BLANKET MATERIAL

1. Type of material: Manufactured/Naturally available
2. Source location:

S.no	Date of taking sample	Location of laying	Soil type			C_u	C_c	Abrasion Value
			Gravel %	Sand %	Fines passing 75 micron sieve %			
1	2	3	4	5	6	8	9	10

CBR value	Signature and name of Rly official	Signature and name of contractor	Remarks
11	12	13	14

(C) PROFORMA FOR FIELD COMPACTION RECORD

Chainage / km from ...... to ....

Soil Classification:

Height of bank: OMC:

Type of roller being used: Lab. MDD/ Field Trial MDD:

CORE CUTTER METHOD

Date of Laying	Layer no.	location coordinate for check	Placement moisture content (%)	No. of passes	Wt. of core cutter+ wet soil (W_s) (g)	Wt. of core cutter (Wc) (g)	Wt of wet soil (W_s - W_c) (g)	Vol. of core cutter (V_c) (cc)	Bulk density, $\gamma_b = \frac{(W_s - W_c)}{Vc}$ (g/cc)
1	2	3	4	5	6	7	8	9	10

Moisture content of compacted layer (w) (%)	Dry Density(γ_d) = γ_b / 1+w *100 (g/cc)	Degree of compaction (%)	Sig. and name of Rly officer	Sig. and name of contractor	Remarks
11	12	13	14	15	16

Note: *1. In case of compaction of blanket material, percentage of fines should also be mentioned in a column.*

2. Determination of Dry Density, (γd) of soil in above table is done as per IS: 2720 Pt 29 – 1975 (latest version) titled as Determination of Dry Density of Soils In-Place By The Core-Cutter Method

(D) PROFORMA FOR FIELD COMPACTION RECORD

Chainage /km from ...... to.........

Soil Classification: Height of embankment:

SAND REPLACEMENT METHOD

Location	Bulk density of sand, (γ_s) g/cum	Wt of wet soil from hole, W_w (g)	Wt of Cylinder + Sand, before pouring W_1 (g)	Wt of sand + Cylinder after pouring W_2 (g)	Mean weight of sand in cone W_3 (g)	Wt of sand in hole W_b = W1 - W2-W3	Bulk Density of soil $\gamma_b = (W_w / W_b) * \gamma_s$
1	2	3	4	5	6	7	8

Moisture content of soil (w), %	Dry Density of soil $\gamma_d = \gamma b/1+w$	Relative Density I_D	Sign. and name of Rly Official	Sign and name of contractor	Remarks
9	10	11	12	13	14

Ref: IS: 2720 (Pt 28)1974 (latest version)
(Determination of dry density (γ_d) of soils in-place, by the sand Replacement method)

Note: ***1. Density Index (Relative Density) shall be find out as per IS 2720 (Part 14) – 1963 – (latest version).***
2. The density index, Id (relative density) expressed as a percentage should be calculated as follows:

Relative density (ID) = $\gamma_{max} (\gamma_d - \gamma_{min}) / \gamma_d (\gamma_{max} - \gamma_{min}) \times 100$

γ_{max} (from lab as per IS 2720 (Part 14) ....

γ_{min} (from lab as per IS 2720 (Part 14) ....

γ_d determined in field as shown in above table by the sand Replacement method.

ANNEXURE – VIII

LIST OF EQUIPMENTS FOR FIELD LAB
Table-1

S N.	Description of Equipment	Reference of I.S. Code (latest version to be used)	UNIT
1	IS set of sieves with base & top lid	IS-460	
	20mm,19mm,10mm, 4.75mm, 2mm		sets
	600mic, 425mic, 212mic, 75mic,.		
2	Hand operated sieve shaker for above sieves.		1 no.
3	BALANCE		
	i) Pan balance/Electronic weighing machine - 10 kg capacity (with 1.0 gm Least		1 no.
	Count)		1 no.
	ii) Electronic balance - 500 gm capacity (with 0.1 gm Least Count)		
4	iii) Electronic weighing machine		2 sets
	200grm(LC-0.01g)		5 sets
	Field density apparatus complete.	2720-1974 part-XXVIII	2 sets
5	sand replacement	2720-1975 part-XXIX	
	core cutter with dolly	2720 part-8-1983	1 set
6	Heavy Compaction Test apparatus full		2 sets
	unit.	2720 part-16-1987	
7	Laboratory California Bearing Ratio(CBR)		1 no.
	Test Apparatus & it's required accessories	2386 part-4	
8	Abrasion Test Apparatus	IS 2720 Part-5-1985	1 no.
9	Liquid Limit apparatus hand operated with		3 no.
	counter & grooving tools.	IS 2720 Part-6-1972	
10	Shrinkage limit apparatus		4 no.
11	Stainless steel spatula - 25cm long		6 no.
12	Porcelain bowl for LL - 15cm dia.		
13	Aluminium dish with lid – 5cm dia.		2 no.
	Wash bottle - 1 lit. capacity		2 no.
14	500ml capacity		3 no.
15	Glass plate 10mm thick 50x50 cm		3 no.
16	Ground glass 5mm thick 50x50 cm		10 no.
	Enameled trays 45x30cm		10 no.
	20x20cm		10 no.
	&		
	Enameled plates 6inch dia		3 no.
	8 inch dia.		2 no.
17	10 inch dia.		3 no.
18	Frying pans		3 no.
19	Stove janta		1 no.
20	Straight edge 300mm long		2 no.
21	Sample Tube (Size Dia-150mm, Length-450mm)		5 no.

LIST OF EQUIPMENT FOR FIELD LAB
Table-2

S. NO.	DESCRIPTION OF EQUIPMENT	REFERENCE OF I.S. CODE (latest version to be used)	UNIT
22	Grain size analyser of fines		
	a)Hydrometer	IS-2720 part-4-1985	2 no.
	b)Thermometer 0 to 50 c		2 no.
	c) Glass cylinder 1000cc capacity with 60mm dia.		5 no.
	d) Nomogram chart		1no.
	e) Stop Watch		1no.
22	Desiccators as IS -6128		2 no.
23	Gallon of 10 litter capacity for distilled water		3 no.
24	Wooden mortar and pestle.		1 no.
25	Specific gravity test apparatus.		2 no.
26	Density bottle-50ml capacity		2 no.
27	Glass cylinder 100 cc capacity (for Free Swell index test)		1 no.
28	Oven- thermostatically controlled to maintain a temperature 105-110c		
29	Relative Density test Apparatus	IS-2720 Part-14-1983	1 no.
30	Standard Penetration Test (SPT) Appratus	IS- 2131- 1981(Reffeed-1997)	1 no.
31	Nuclear Moisture Density Gauge (NMDG) Apparatus		
32	**Note**-Preparation of dry soil samples for various test	Follow IS-2720 Part-1-1983	
33	**Consumable Item**		
34	Sieve brush		
35	Wire brush		
36	Sodium carbonate		
37	Sodium hexa meta phosphate.		
38	Kerosene		
39	Mercury		
40	**Additional Equipment**		
	Hand auger 150mm dia with extension rod		
	Sampling tube 100mm dia. And 450mm length		
41	All machines and equipments should have Calibration Certificate.		

APPENDIX- N

LIST OF RELEVANT I.S. CODES

Table-L.1

SN	I.S. CODE NO.	DISCRIPTION
1.	IS: 2720 -1983 Part-1 (Reaffirmed 2010)	Methods of test for soils. Preparation of dry soil samples for various tests.
2.	IS: 2720-1973 Part-2 (Reaffirmed 2015)	Determination of water content Methods of test for soils.
3.	IS: 2720-1980 Part-3 Section 1 (Reaffirmed 2011)	Methods of test for soils. Determination of specific gravity. Fined grained soils
4.	IS: 2720-1980 Part-3 Section 2 (Reaffirmed 2011)	Methods of test for soils. Determination of specific gravity. Section 2 Fine, Medium and coarse-grained soils.
5.	IS: 2720-1985 Part-4 (Reaffirmed 2015)	Methods of test for soils. Grain size analysis.
6.	IS: 2720-1985 Part-5 (Reaffirmed 2015)	Methods of test for soils. Determination of liquid and plastic limits.
7.	IS: 2720-1972 Part –6 (Reaffirmed 2011)	Methods of test for soils. Determination of shrinkage factors.
8.	IS: 2720-1980 Part-7 (Reaffirmed 2011)	Methods of test for soils. Determination of water content-dry density relation using light compaction.
9.	IS: 2720-1983 Part-8 (Reaffirmed 2015)	Methods of test for soils. Determination of water content-dry density relation using heavy compaction.
10.	IS: 2720-1992 Part-9 (Reaffirmed 2011)	Methods of test for soils Determination of dry density –moisture content relation by constant weight of soil method.
11.	IS: 2720-1991 Part-10 (Reaffirmed 2010)	Methods of test for soils. Determination of unconfined compressive strength.
12.	IS: 2720-1993 Part-11 (Reaffirmed 2011)	Methods of test for soils. Determination of the shear strength parameters of a specimen tested in unconsolidated undrainedtriaxial compression without the measurement of pore water pressure.
13.	IS: 2720-1981 Part-12 (Reaffirmed 2011)	Methods of test for soils. Determination of shear strength parameters of soil from consolidated undrainedtriaxial compression test with measurement of pore water pressure.
14.	IS: 2720-1986 Part-13 (Reaffirmed 2011)	Methods of test for soils. Direct shear test
15.	IS: 2720-1983 Part-14 (Reaffirmed 2015)	Methods of test for soils. Determination of density index (Relative density) of cohesionless soils.

16.	IS: 2720-1965 Part-15 (Reaffirmed 2011)	Methods of test for soils. Determination of consolidation properties.
17.	IS: 2720-1987 Part-16 (Reaffirmed 2011)	Methods of test for soils. Methods of test for soil. Laboratory determination of CBR.
18.	IS: 2720-1986 Part-17 (Reaffirmed 2011)	Methods of test for soils. Laboratory determination of permeability.
19.	IS: 2720-1992 Part-18 (Reaffirmed 2011)	Methods of test for soils. Determination of field moisture equivalent.
20.	IS: 2720-1992 Part-19 (Reaffirmed 2011)	Methods of test for soils. Determination of centrifuge moisture equivalent.
21.	IS: 2720-1992 Part-20 (Reaffirmed 2011)	Methods of test for soils. Determination of linear shrinkage. (with amendment No. 1)
22.	IS: 2720-1977 Part-21 (Reaffirmed 2016)	Methods of test for soils. Determination total soluble solids.
23.	IS: 2720-1972 Part-22 (Reaffirmed 2015)	Methods of test for soils. Determination of organic matter.
24.	IS: 2720-1976 Part-23 (Reaffirmed 2010)	Methods of test for soils. Determination of calcium carbonate.
25.	IS: 2720-1976 Part-24 (Reaffirmed 2015)	Methods of test for soils. Determination of cation exchange capacity.
26.	IS: 2720-1982 Part-25 (Reaffirmed 2015)	Methods of test for soils. Determination of silica sesquioxide ratio.
27.	IS: 2720-1987 Part-26 (Reaffirmed 2011)	Methods of test for soils. Determination of pH value.
28.	IS: 2720-1977 Part-27 (Reaffirmed 2015)	Methods of test for soils. Determination of total soluble sulphate.
29.	IS: 2720-1974 Part-28 (Reaffirmed 2015)	Methods of test for soils. Determination of dry density of soils in -place by the sand replacement method.
30.	IS: 2720-1975 Part29 (Reaffirmed 2015)	Methods of test for soils. Determination of dry density of soils in- place by the core cutter method.
31.	IS: 2720-1980 Part-30 (Reaffirmed 2011)	Methods of test for soils. Laboratory vane shear test.
32.	IS: 2720-1990 Part-31 (Reaffirmed 2010)	Methods of test for soils. Field determination of california bearing ratio.
33.	IS: 2720-1971 Part-33 (Reaffirmed 2010)	Methods of test for soils. Determination of the density in- place by the ring and water replacement method.
34.	IS: 2720-1972 Part-34 (Reaffirmed 2010)	Methods of test for soils. Determination of dry density of soil in- place by rubber balloon method.
35.	IS: 2720-1974 Part-35 (Reaffirmed 2010)	Methods of test for soils. Part-35 Measurement of negative pore water pressure.
36.	IS: 2720-1987 Part-36 (Reaffirmed 2010)	Methods of test for soils. Part-36 Laboratory determination of permeability of granular soils (constant head).

37.	IS: 2720-1976 Part-37 (Reaffirmed 2011)	Methods of test for soils. Part-37 Determination of sand equivalent value of soils and fine aggregates.
38.	IS: 2720-1976 Part-38 (Reaffirmed 2011)	Methods of test for soils. Part-38 Compaction control test (Hilf method).
39.	IS: 2720-1977 Part-39 Section 1 (Reaffirmed 2011)	Methods of test for soils. Direct shear test for soils containing gravel. Section 1 Laboratory test.
40.	IS: 2720-1979 Part-39 Section 2 (Reaffirmed 2011)	Methods of test for soils. Direct shear test for soils containing gravel. Section 2 in-situ shear test.
41.	IS: 2720-1977 Part-40 (Reaffirmed 2011)	Methods of test for soils. Determination of free swell index of soils.
42.	IS: 2720-1977 Part-41 (Reaffirmed 2011)	Methods of test for soils. Measurement of swelling pressure of soils.
43.	IS: 2810-1979 (Reaffirmed 2011)	Glossary of terms relating to soil dynamics.
44.	IS: 4434-1978 (Reaffirmed 2011)	Code of practice for in-situ vane shear test for soils.
45.	IS: 4968-1976 Part 1 (Reaffirmed 2011)	Method of subsurface sounding for soils. Part I Dynamic method using 50mm cone without bentonite slurry.
46.	IS: 4968-1976 Part 2 (Reaffirmed 2011)	Method of subsurface sounding for soils. Part II Dynamic method using cone and bentonite slurry.
47.	IS: 4968-1976 Part 3 (Reaffirmed 2011)	Method of subsurface sounding for soils. Part III Static cone penetration test.
48.	IS: 5249-1992 (Reaffirmed 2015)	Method of test for determination of in-situ dynamic properties of soils.
49.	IS: 460-1985 Part 1 (Reaffirmed 2013)	Specification of test sieves. Wire cloth test sieves.
50.	IS: 460-1985 Part 2 (Reaffirmed 2013)	Specification of test sieves. Perforated plate test sieve.
51.	IS: 460-1985 Part 3 (Reaffirmed 2011)	Specification of test sieves. Part III Methods of examination of apertures of test sieves.
52.	IS: 1498-1970 (Reaffirmed 2011)	Classification and identification of soils for general engineering purposes.
53.	IS: 1607-2013	Methods for test sieving.
54.	IS: 4616-1968 (Reaffirmed 2017)	Specification for Sheep Foot roller.
55.	IS: 5421-2013	Glossary of terms relating to test sieves and tests sieving.
56.	IS: 5500-2004 (Reaffirmed 2015)	Vibratory Roller – General Requirements
57.	IS: 5501-1969 (Reaffirmed 2017)	Specification for pneumatic tyred roller.
58.	IS: 5502-1988 (Reaffirmed 2017)	Specification for smooth-wheeled diesel road roller.

59.	IS: 1888-1982 (Reaffirmed 2011)	Method of load test on soils.
60.	IS: 1892-1979 (Reaffirmed 2011)	Code of practice for site investigations for foundations. (With amendment no. 1)
61.	IS: 2131-1981 (Reaffirmed 2011)	Method for standard penetration test for soils.
62.	IS: 2132-1986 (Reaffirmed 2011)	Code of practice for thin walled tube sampling of soils.
63.	IS: 10074-1982 (Reaffirmed 2010)	Specification for compaction mould assembly for light and heavy compaction test for soils.
64.	IS: 10077-1982 (Reaffirmed 2010)	Specification for equipment for determination of shrinkage factors.
65.	IS: 10379-1982 (Reaffirmed 2010)	Code of practice for field control of moisture and compaction of soils for Embankment and sub-grade.
66.	IS: 10837-1984 (Reaffirmed 2010)	Specification for moulds and accessories for determination of density index (relative density) of cohesionless soils.
67.	IS: 11196-1985 (Reaffirmed 2010)	Specification for equipment for determination of liquid limit of soils-cone penetration method.
68.	IS: 11229-1985 (Reaffirmed 2010)	Specification for shear box for testing of soils.
69.	IS: 11209-1985 (Reaffirmed 2010)	Specification for mould assembly for determination of permeability of soils.
70.	IS: 4081-2013	Code of Safety for Blasting and Related Drilling Operations
71.	IS: 3764-1992 (Reaffirmed 2012)	Code of Safety for Excavation Work
72.	IS: 2386 Part 4 – 1963 (Reaffirmed 2016)	Methods of test for aggregates for concrete – Mechanical Properties
73.	IS: 15869	Open weave Coir Bhoovastra specification
74.	IS: 15872	Application of Coir Geotextile
75.	IS: 14986 (Reaffirmed 2018)	Guidelines for Application of Jute Geotextile for Rain Water Erosion Control in Road and Railway Embankments and Hill Slopes

Note: Latest version of IS codes shall be referred to.

APPENDIX- O

भारत सरकार (GOVERNMENT OF INDIA)
रेल मंत्रालय (MINISTRY OF RAILWAYS)
रेलवे बोर्ड (RAILWAY BOARD)

No. 2011/CE-II/Form/Spec   New Delhi, dated 18.09.2020

Executive Director/GE
RDSO
Lucknow

Sub: Comprehensive Guidelines and Specification for Railway Formation
Ref: RDSO's letter no. GE/GEN/185/Vol-I dated 02.07.2020

Vide letter under reference above, the final draft of "Comprehensive Guidelines and Specifications for Railway formation" has been forwarded by RDSO for Board's approval.

Having considered the various recommendations of RDSO regarding the above Guidelines, Competent Authority has approved the above final draft for adoption in Zonal Railways with following decisions on specific issues referred by RDSO:-

SN	Specific issues/provisions of the guidelines	Board's decision
(i)	Fitment of existing railway formation for 22.9T/25T axle load operations for speed upto 100 kmph and passenger train (19.5T axle load) operation for speed upto 160 kmph assuming 350 mm ballast cushion and 60 kg rail section (Appendix-I)	Approved.
(ii)	Provisions for Gauge conversion/doubling/Cess repair work in case of existing formation (Chapter-9)	Approved.
(iii)	Methods of Formation Rehabilitation (Chapter 10)	Approved.
(iv)	Erosion control of slopes (Chapter 8)	Approved.
(v)	Quality control of Earthwork (Chapter 7)	Approved with following modification. • The note marked as "*" of Table 7.2 to be modified as under: "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." • In Para 7.4.1.c, in case of PSU, existing provision of Equivalent authority for acceptance criteria shall continue.

SN	Specific issues/provisions of the guidelines	Board's decision
(vi)	Modified checklist of certification of quality of Earthwork in Railway Projects (Appendix-M)	Approved.
(vii)	Para 2.2 (i) for suitability of subsoil	Approved.
(viii)	Para 2.3.5 for Ground Improvement for expansive soils	Approved.
(ix)	Para 2.4.1 for Use of Geo-composite drain	Approved.
(x)	Para 2.4.4 for Geo-synthetics encapsulated Stone column	Approved.
(xi)	Para 3.4 for Cross Slope of Formation	Approved.
(xii)	Para 3.7 for Soils to be normally avoided	Approved.
(xiii)	Table 3.3 to 3.6 regarding filter criterion	Approved.
(xiv)	Chapter 4 regarding applications of geo-synthetics in railway formation and Appendix C- specification of geo-synthetic products	Approved.
(xv)	Para 5.1 regarding requirement of flatter slope	Approved.
(xvi)	Para 5.1.1 & 5.1.2 regarding provision of berm	Approved.
(xvii)	Appendix B of Illustrative Examples for providing minimum thickness of Formation Layers	Approved.
(xviii)	Newly added test procedures for Nuclear Moisture Density Gauge	Approved.
(xix)	Appendix J regarding Proforma for Reporting Unstable Formation	Approved.

RDSO shall circulate the final draft to Zonal Railways/PSUs. Zonal Railways/PSUs shall take necessary action for adoption of above guidelines and for closely monitoring the implementation for a period of two years and to furnish feedback/suggestions to RDSO for improvement, if any.

North Central Railway & Western Railway are nominated for field validation for fitment of existing formation for passenger train operations at 160 kmph and South Eastern Railway & East Coast Railway for field validation for fitment of existing formation for 22.9t/25t axle load operation at 100 kmph.

Any deviation to above guidelines/specifications based on logic/local conditions can be permitted with approval of PCE/CAO(C) only.

7-09-2020

(Pradeep Nagar)
Director Civil Engg. (Plg.)
Railway Board

Copy for necessary action to:
(i) PCEs/All Zonal Railway
(ii) CAO(C)/All Zonal Railway
(iii) MD/KRCL, RVNL, IRCON, DFCCIL, RITES, MRVC.