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GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

Rationalisation of Formation Layer Thickness on Indian Railway Track

Specification No. RDSO/2018/GE: IRS-0004 (D) Part-IV

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Geo-technical Engineering Directorate,
Research Designs and Standards Organisation
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www.rdso.gov.in

25/07/19 ARE/GE SSRE/GE

Rationalisation of Formation Layer Thickness on Indian Railway Track

1.0 Preamble:

1.1 The formation is the platform upon which the track structure is constructed. Its main function is to provide a stable foundation for ballast layer. As the influence of the traffic induced stress extends considerably beyond the depth of the ballast, the formation is a very important sub structure component having significant influence on track performance and maintenance. Replacement/rehabilitation of track formation in service has serious repercussion on traffic and is very costly. Therefore it is necessary that adequately strong formation is built in new constructions to avoid need for rehabilitation in future for the foreseeable/planned traffic needs. Proper formation design and quality control during construction is key for providing stable formation for anticipated traffic needs.

1.2 The instructions given in this document regarding thickness of Formation Layers supersedes instructions given in all earlier Guidelines of RDSO and RDSO letter no. RS/G/108/Heavy Axle Load dated 26.10.2016. The basic instructions (other than those contained in this document) detailed in "RDSO Guidelines for Earthwork in Railway Project GE: G-1 July 2003" and "RDSO Guidelines and Specifications for Design of Formation for Heavy Axle Load GE: G-0014 Nov2009 shall continue to apply.

2.0 Soil Exploration for formation design:

2.1 As formation design will primarily depend upon the type of soil being used in construction. It is essential that soil exploration is done properly for soil classification as laid down in RDSO Guidelines GE: G-1 para 3.0. The results of soil exploration shall be reviewed and finally approved at the level of CAO(C) & Equivalent officers in PSUs as this will be the basis of further design.

2.2 The soil classification shall be done as per IS: 1498-1970. Various soil groups have been combined together in table-1 based on % age fines to formulate the thickness of blanket layer.

Table-1 Description of Soil Quality Class

Soil type	Description w.r.t. % age Fines (size < 75 micron)	Soils as per IS classification confirming to referred Soil type
SQ1	Soil containing fines > 50%	CL, ML, CL-ML, CI, MI, CH, MH
SQ2	Soil containing fines from 12% to 50%	GM, GC, SM, SC, GM-GC, SM-SC
SQ3	Soil containing fines < 12%	GW, GP, SW, SP, GW-GM, GW-GC, SW-SM, GP-GM, GP-GC, SP-SM, SP-SC

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3.0 Requirement of Blanket Layer:

3.1 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 shales and other soft rocks, which become muddy after coming into contact with water.
(ii) Soils conforming to specifications of Blanket material as given in table No. 4 to7.

3.2 For other conditions, the system of layered construction of embankment consisting of blanket layer/prepared sub-grade/sub-grade shall normally be followed.

4.0 Specification and thickness of Formation layers:

4.1 Thickness of Prepared sub-grade and blanket layer has been rationalized based on UIC-719 R calculation for ballast cushion as 350 mm.

Table-2 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 continues upto blanket layer

Table-3 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 continues upto blanket layer

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4.2 Formation for 25 T axle load

Table- 4: Specification and Thickness of Formation Layers for 25 T axle load: Single layer system

Layers	Specification	Thickness
Blanket	(i) C_u > 7 and Cc between 1 and 3. (ii) Fines (passing 75 microns): 3% to 10% (iii) Los Angeles Abrasion value < 40 % (iii) Minimum soaked CBR value ≥ 25, (Soil compacted at 100% of MDD* in lab) (iv) Field Compaction: Min 100 % of MDD* in field trial (v) Minimum Ev_2** = 100 MPa (vi) Size gradation – within specified range (as table-8) or should lie more or less within enveloping curves (as fig.-1) (vii) Filter criteria 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** for SQ3 sub-grade **40 cm** for SQ2 sub-grade **55 cm** for SQ1 sub-grade
Sub-grade/ Embankment Fill Top Layer	SQ1/SQ2/SQ3 soil (SQ1 to be used only with dispensation of PCE/CAO) (i) CBR ≥ 6 (soil compacted at 98% of MDD*) (ii) For SQ1 soil, CBR ≥ 4 (soil compacted at 98% of MDD*) (iii) Field Compaction: min 98% of MDD* (iv) Minimum Ev_2 = 45 MPa (for SQ1) 60 MPa (for SQ2/SQ3)	100 cm
Lower Fill	SQ1/SQ2/SQ3 soil (i) CBR ≥ 3 (soil compacted at 98% 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 (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, (Ref: Annexure – I)

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Table-5: Specification and Thickness of Formation Layers for 25 T axle load: Two layer system

Layers	Specification	Thickness
Blanket	(i) C_u > 7 and Cc 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-8) or should lie more or less within enveloping curves (as fig.-1) (viii) Filter criteria 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** for SQ3 prepared sub-grade **40 cm** for SQ2 prepared sub-grade
Prepared Sub-grade	SQ2/SQ3 (i) CBR ≥ 8 (soil compacted upto 98% of MDD*) (ii) Field Compaction: min 98% of MDD* (iii) Plasticity Index ≤ 12 (iv) Minimum Ev_2 = 60 MPa	**50 cm** over SQ1 fill **35 cm** over SQ2 fill
Sub-grade/ Embankment Fill Top Layer Lower Fill	SQ1/SQ2/SQ3 soil (SQ1 to be used only with dispensation of PCE/CAO) (i) For SQ2/SQ3 soil, CBR ≥ 5, (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) SQ1/SQ2/SQ3 soil (i) CBR ≥ 3 (soil compacted at 97% of MDD*) (ii) Field Compaction: min 97% of MDD*	**50 cm** As per Embankment height
Ground Soil/Sub-soil Strata	(i) Undrained Cohesion of soil (c_u) ≥ 25 KPa (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, (Ref: Annexure – I)

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4.3 Formation for 32.5 T axle load

Table-6: Specification and Thickness of Formation for 32.5 T axle load: Single layer system

Layers	Specification	Thickness
Blanket	(i) C_u > 7 and Cc 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) Size gradation – within specified range (as table-8) or should lie more or less within enveloping curves (as fig.-1) (vii) Min. Ev_2** = 120 MPa (viii) Filter criteria 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)	**45 cm** for SQ3 sub-grade **55 cm** for SQ2 sub-grade **70 cm** for SQ1 sub-grade
Sub-grade/ Embankment Fill Top Layer	SQ1/SQ2/SQ3 soil (SQ1 to be used only with dispensation of PCE/CAO) (i) For SQ2/SQ3 soil, CBR ≥ 6, (ii) For SQ1 soil, CBR ≥ 4 , (Soil compacted at 98% of MDD*) (iii) Field Compaction: min 98% of MDD* (iv) Minimum Ev_2 = 45 MPa (for SQ1) 60 MPa (for SQ2/SQ3)	100 cm
Lower Fill	SQ1/SQ2/SQ3 soil (i) CBR ≥ 3 (soil compacted at 98% 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 (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, (Ref: Annexure – I)

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Table-7:Specification and Thickness of Formation Layer for 32.5 T axle load: Two layer system

Layers	Specification	Thickness
Blanket	(i) C_u > 7 and Cc 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) Size gradation – within specified range (as table-8) or should lie more or less within enveloping curves (as fig.-1) (vii) Min. Ev_2** = 120 MPa (viii) Filter criteria 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)	**45 cm** for SQ3 prepared sub-grade **55 cm** for SQ2 prepared sub-grade
Prepared Sub-grade	SQ2/SQ3 (i) CBR ≥ 8 (soil compacted upto 98% of MDD*) (ii) Field Compaction: min 98% of MDD* (iii) Plasticity Index ≤ 12 (iv) Minimum Ev_2 = 60 MPa	**50 cm** over SQ1 fill **35 cm** over SQ2 fill
Sub-grade/ Embankment Fill Top Layer	SQ1/SQ2/SQ3 soils (SQ1 to be used only with dispensation of PCE/CAO) (i) For SQ2/SQ3 soil, CBR ≥ 5 (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 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 (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, (Ref: Annexure–I)

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Table-8: Grading 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

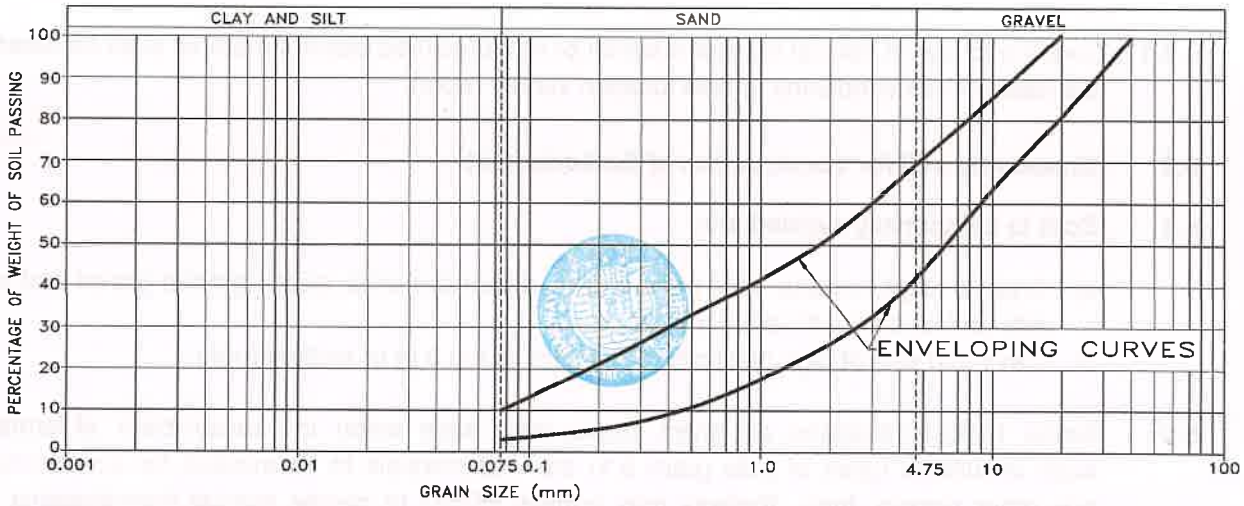

Fig. - 1: Enveloping Curves for Blanket Material:

4.4 Height of Embankment and Formation Layer thickness:

4.4.1 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.

4.4.2 Total thickness of formation layers of 1.5 m (minimum) should be provided of blanket, prepared sub-grade & subgrade/embankment fill uniformly in embankment/cutting for effective stress dispersal.

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

4.4.4 For providing uniform total thickness of formation layer of 1.5 m:

(i) **For Embankment:** If the specification of sub-soil meets the required specification of prepared subgrade upto required depth and below that specification of sub-soil meets the required specification of subgrade upto required depth then there will be no need of excavation, else the excavations will be done as per the requirement. For more clarification a sample case has been explained as Annexure-II.

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(ii) **For Cutting:** If the specification of the sub-soil meets the required specifications of blanket upto the specified depth, then below it the specification of sub-soil meets the specification of prepared subgrade upto specified depth and below that if the specification of sub-soil meet the specification of subgrade upto specified depth then there will be no need of excavation, else the excavations will be done as per the requirement. For more clarification a sample case has been explained as Annexure-II.

4.4.5 The reduction in thickness of formation layer, if required, will be done first in lower fill, then in top layer of subgrade then in prepared subgrade and then in blanket.

4.5 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. (Ref. Appendix-C of GE:G-14). 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.

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

5.0 Unsuitable soil for construction of Embankment:

5.1 Soils to be normally avoided are:

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

5.2 Some typical situations, as given below, may arise when in construction of formation such unsuitable types of soils (para 5.1) are not possible to be avoided for economical or any other reason, then Railway may consult RDSO to decide special investigations and other measures to formulate suitable scheme of construction.

a) Cuttings passing through unsuitable soils (para 5.1), shales and soft rocks which become muddy after coming into contact with water,
b) Construction of embankment on sub-soil of unsuitable types of soils.
c) Use of CH & MH type of soils even in top 3 m of embankment.

6.0 Design of formation, including adoption of single layer or two layer system and use of SQ1 soil 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.

7.0 Use of Geosynthetics in Railway Embankment

7.1 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.

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7.2 Regarding use of Geogrid in Formation Rehabilitation in existing lines, where track parameters gets disturbed frequently, It is recommended to use Geogrid as per RDSO specification for CBR of sub-grade 4 to 8. For sub-grade of CBR less than 4 the cases to be sent to RDSO for approval. Generally geogrid will not be required for subgrade having CBR more than 8. However, if it is required, cases to be referred to RDSO for approval. Non-woven Geotextile just below geogrid at the bottom of ballast may be used where no blanket is available and SQ1 or SQ2 soil exists at the top of formation, to prevent the upward migration of the fine particles from top of formation to the ballast so that clean ballast may not be contaminated.

7.3 To reduce the thickness of the Blanket Layer (which is costly granular material obtained by quarrying or mining) in case of new constructions, on techno-economic considerations and/or to reduce the adverse impact on environment due to quarrying/mining, geogrid can be used as a stabilisation element to form a mechanically stabilised layer.

7.4 Regarding geogrid for use below blanket, in new lines for reduction in specified thickness of blanket layer, use of Geo-grid shall be considered at places where it is economical to use it in combination with blanket as it reduces the requirement of thickness of blanket. Zonal Railways and Construction units must submit the design of reinforced formation layer along with design methodology for use and selection of Geo-grid for approval by RDSO. Zonal Railways and Construction units should consider only those firms which have successfully used the same proposed product in similar application (reduction in bedding layers thickness) at minimum 3 locations, with minimum 3 years' experience at one of the location in India/International, with supporting documents as an evidence for satisfactory performance.

7.5 To prevent upward migration of fines from prepared sub-grade/sub-grade causing contamination of layer on top of it (which reduces the strength & drainage capacity of this layer of better quality material) and also to prevent penetration of coarse particles of layer on top of prepared sub-grade/sub-grade into soft/ fine grained particles of prepared sub-grade/sub-grade a suitable non-woven Geo-textile layer may 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.

8.0 In case of cutting, blanketing shall be provided as per para 4.1 based on type of soil and their CBR values just below the blanket.

9.0 **FIELD COMPACTION TRIAL**: Field compaction trial is carried out to optimize compaction efforts of earthwork while achieving desired level of density based on Lab tests and Relative Density Test. Type of roller to be used for compaction has to be decided depending on type of soil to be compacted in execution of earthwork. For detailed methodology for conducting the Field compaction trial refer: Annexure-IV of GE: G-1.

10.0 **Qualifying and Quality assurance Tests:** Qualifying tests as part of pre-selection of good earth for Blanket, Prepared sub-grade/Sub-grade, Embankment fill 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 as table-9.

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Table – 9: 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) Embankment fill/ Prepared Sub-grade	(i) Soil classification	At site before laying	IS: 1498	Minimum one test for every 5000 cum or change of soil strata whichever is earlier	Soil should not be "unsuitable type" as given in Para 5.1 and should confirm to specification given as per Table 4/5 (25T axle load) &Table 6/7 (32.5T Axle load)
	(ii) CBR		IS: 2720-Part-16		
	(iii) Plasticity Index (Prepared Sub-grade)		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) γ_{max} & γ_{min} (Determined in Relative Density test If fines are upto 5%)		IS:2720-Part-14		
(ii) Finished earthwork					
(Embankment Fill/Prepared Subgrade/Blanket)	(i) Ev_2	Top of every finished surface	DIN 18134 –2012	One test per Km	Acceptance Criteria as specified in table 4 to 7
	(ii) Compaction	Every compacted layer	IS: 2720 (Part-28/29) or NMDG	As note 2	
	(iii) Density Index (Relative Density if fines are upto 5%)	Every compacted layer	IS: 2720 – Part-14		Minimum 70%

Note: 1. 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. For detailed methodology for quality assurances of earthwork refer: Para 7.0 of GE: G-1, July 2003.

2. **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.

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Annexure-I

Deformation Modulus (Ev_2)

(Ref.: DIN 18134 – April 2012)

1.0 Introduction:

Deformation Modulus (Ev_2) 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; from the gradient of the secant between points $0.3x\sigma_{0max}$ and $0.7x\sigma_{0max}$. It is to be determined on top of compacted Blanket layer/Prepared sub-grade/Embankment fill in accordance with DIN: 18134-2012.

1.1 Scope:

This is a field test performed at site and can check the behaviour of the bedding layer i.e. sub-grade/prepared sub-grade and blanket layer. It takes into account bearing capacity of soil as well as deformation condition. The value of Modulus of deformation defines the stiffness of the layers of formation and depends on qualities of all the components, as well as, the quality of workmanship. Modulus of deformation Ev_2 on the top of the blanket layer is a function of:

a) Modulus of deformation of prepared sub-grade/sub-grade
b) Type of soil
c) Thickness of the formation layers
d) Compaction of the formation layers

Since deformation modulus is a function of the four parameters as given above, we can say that higher Modulus of deformation means higher stiffness of bedding layer and so lesser stress, strain and settlement in the sub-grade.

The test should be done for Ev_2 measurement at top of each formation layer e.g. at sub soil, compacted sub-grade/ prepared sub-grade, blanket etc. at the frequency of one test per km length of section.

2.0 Test Procedure

2.1 Apparatus

2.1.1 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.

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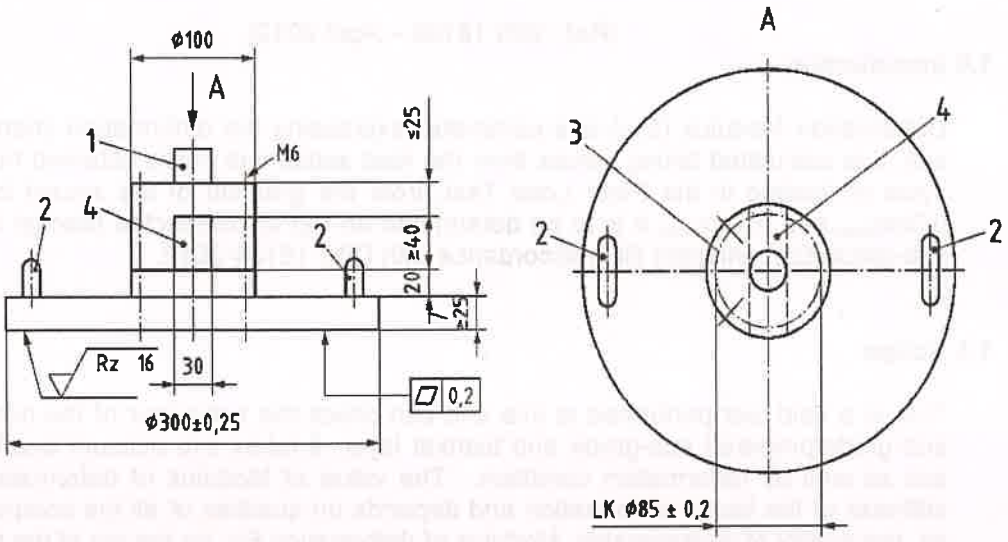
Loading plate

The 300mm dia loading plate shall have two handles (Fig. P1) 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 M6 bolts (distributed equally on hole circle))
4 Measuring tunnel

Fig.- 2: 300mm Dia Loading Plate

2.2.3 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.

2.2.4 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.

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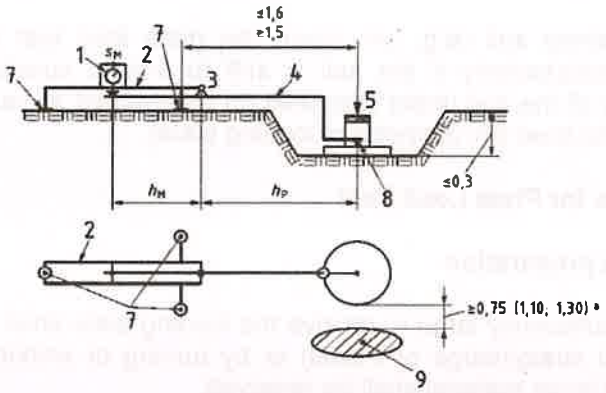
2.2.5 Settlement-measuring device

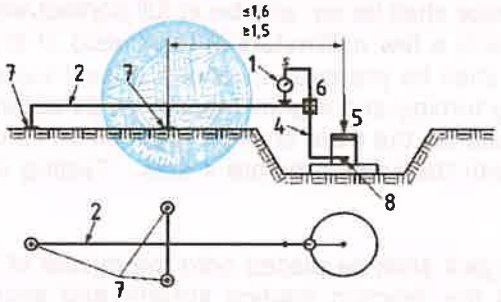
The settlement-measuring device can be with a rotatable contact arm (Fig. P2) or with a contact arm capable of being moved horizontally in axial direction (i.e. with a slide bearing, see Fig. P2).

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	6	Slide bearing
2	Supporting frame	7	Support
3	Fulcrum	8	Stylus
4	Contact arm	9	Area taken up by reaction load system
5	Load		

s_M, s Settlement reading on dial gauge or displacement transducer

Fig.-3 : Settlement Measuring Device

The settlement-measuring device consists of:

2.2.6 A frame supported at three points (see "2" in Fig.P2),
2.2.7 A vertically adjustable, torsion-proof, rigid contact arm (see "4" in Fig.P2),
2.2.8 A displacement transducer or dial gauge (see "1" in Fig.P2).

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. P2).

The h_P: h_M ratio (Fig. P2 a) shall not exceed 2.0. The setting of the assembly shall be capable of being locked so that the hp/h_M ratio does not change during measurement.

The settlement-measuring device shall be capable of measuring the settlement of the

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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.

3.0 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).

4.0 Procedure for Plate Load Test

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.

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.

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.

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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.

4.4 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-T2 &T3).

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 10: 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

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Table 11: Measured values for second loading test

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)
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.

5.0 Evaluation and representation of results

5.1 Load-settlement curve

For each load increment, the average normal stress (σ_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. 2a, 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):

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

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. P3.

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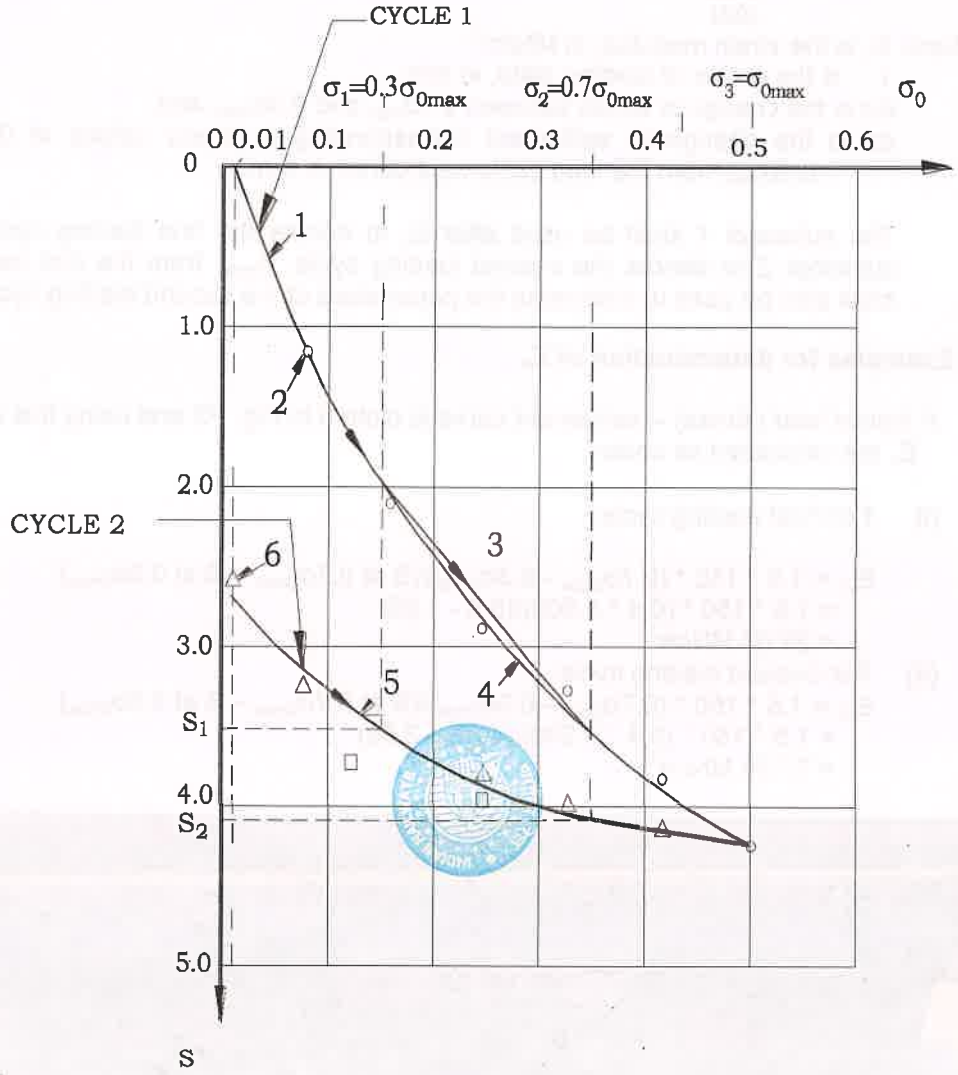

Key

- o Measurement points from the first loading cycle
- □ Measurement points from the unloading cycle
- △ 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 $0.3\sigma_{0max}$ and $0.7\sigma_{0max}$.
- **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
- σ_0 Normal stress in MN/m²

Fig. - 4 : Load (Stress)-Settlement curve

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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:

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

Where: E_v is the strain modulus, in MN/m^2;
r is the radius of loading plate, in mm;
$\Delta\sigma$ is the change in stress between $0.7\sigma_{max}$ and $0.3\sigma_{max}$; and
Δs is the change in settlement corresponding to stress values of $0.7\sigma_{max}$ and $0.3\sigma_{max}$, 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. σ_{0max} from the first loading cycle shall also be used to determine the parameters of the second loading cycle also.

6.0 Examples for determination of E_v

A typical load (stress) – settlement curve is plotted in Fig. P3 and using this curve, values of E_v are calculated as under:

(i) For First loading cycle:

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

(ii) For Second loading cycle:

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

Fig. – 5 : Ev_2 Measuring Equipment

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7. The relation between deformation modulus (Ev_2) vs permissible stress on the formation and settlement of sleeper are given below-

Permissible Contact Pressure and Modulus of Elasticity:

Permissible compressive stress on the formation can be typically estimated using the empirical formula according to Heukelom and Klomp:

$$\sigma_{zperm} = \frac{0.006\ Ev_2}{1+ 0.7 \log n}$$

Where, σ_{zperm} is permissible compressive stress on the formation, Ev_2: Modulus of Elasticity; n= number of load cycles.

Coefficient of Ballast:

Coefficient of Ballast indicates the track sub-structure response in terms of surface pressure between sleeper and ballast, and the vertical settlement under load. Quantitatively, C= 1 N/cm^3, is the value of N/cm^2 surface pressure when the sleeper subsides by 1 cm.

C- Coefficient of Ballast: describes the stiffness of ballasted track. In case of road construction is measured by the plate load bearing tests according to:

C= p/ y (N/cm^3): p- surface pressure under the loaded plate; y- settlement of the loaded plate.

Ballast coefficient is related to modulus of deformation as:

C= 2. Ev_2 / (3.14. r. (1- v^2)),

Where r = radius of the plate and
v = poisson's ratio

Determination of Ev_2 on the top of blanket layer as a design criteria/quality control criteria express right stiffness required to control settlements instead of exclusively relying on thickness of different formation layers.

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Annexure-II

(A) For Embankment

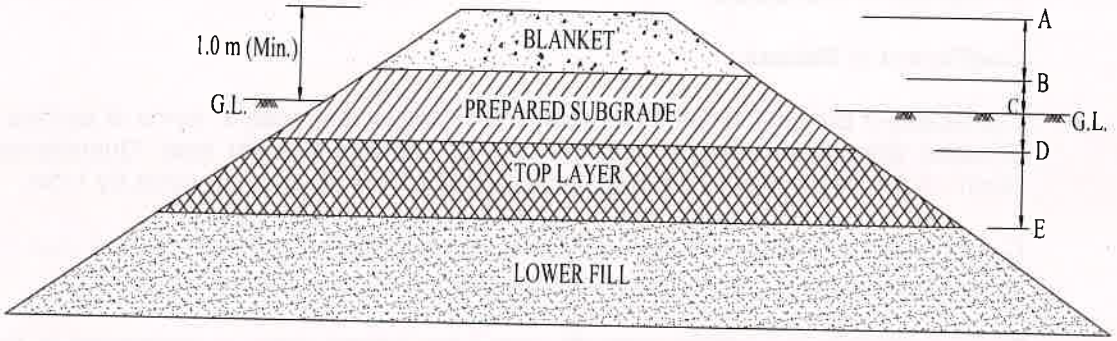

Fig. - 6 : Formation Layers in Embankment

1. If sub-soil CD conforms to the specifications of prepared subgrade and DE part conforms to the specifications of top layer of subgrade and Ev_2 value at top layer (at D) as specified and soil below E conforms to the specifications of lower fill then remaining part of prepared subgrade (BC) for achieving Ev_2 value at top layer (at B) as specified; and blanket layer (AB) of specified thickness is required.

2. If minimum required depth of sub-soil DE conforms to the specifications of top layer of subgrade and Ev_2 value at top layer (at D) as specified and soil below E conforms to the specifications of lower fill then only prepared subgrade and blanket layer of specified thickness are required.

3. If intermediate layer DE upto minimum required depth do not conforms to the specifications of top layer of subgrade and also do not meet Ev_2 value at top layer (at D) as specified, then upper layers should be removed and compacted after replacing intermediate layer with specified quality of soil.

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(B) For Cutting

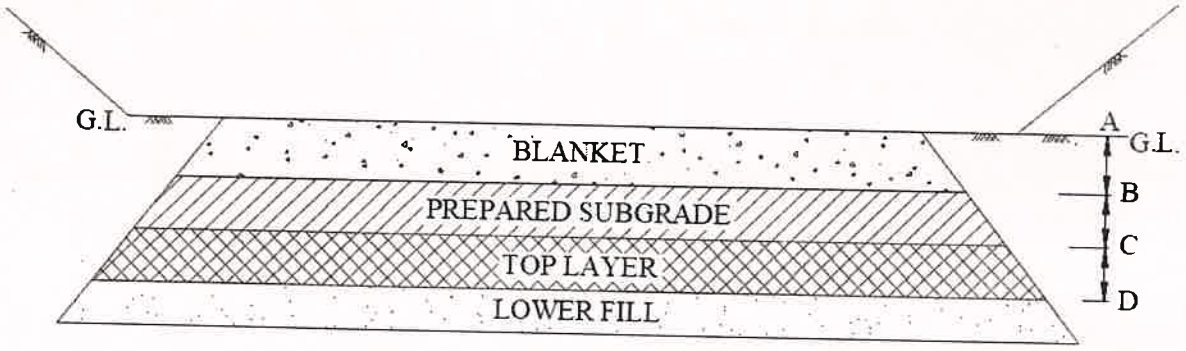

Fig. - 7 : Formation Layers in Cutting

1. If minimum required depth of natural soil AB conforms to specifications of blanket material and Ev_2 value at top layer (at A), as specified; BC part conforms to the specifications of prepared subgrade and Ev_2 value at top layer (at B) as specified; CD part conforms to the specifications of top layer of subgrade and Ev_2 value at top layer (at C) as specified and soil below D conforms to the specifications of lower fill then ballast may be directly laid over it.

2. If minimum required depth of natural soil BC conforms to the specifications of prepared subgrade and Ev_2 value at top layer (at B) as specified; and CD part conforms to the specifications of top layer of subgrade and Ev_2 value at top layer (at C) as specified and soil below D conforms to the specifications of lower fill then only blanket layer of specified thickness is required.

3. If minimum required depth of natural soil CD conforms to the specifications of top layer of subgrade and Ev_2 value at top layer (at C) as specified and soil below D conforms to the specifications of lower fill then only prepared subgrade and blanket layer of specified thickness are required.

4. If any intermediate layer BC and or CD upto minimum required depth do not conforms to the specifications of prepared subgrade and top layer of subgrade respectively and also do not meet Ev_2 value at top layer (at B/C) as specified, then upper layers should be removed and compacted after replacing intermediate layer with specified quality of soil.

5. Adequate drainage system as per existing norms of cutting should be ensured in the excavated portion below GL.

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