California High-Speed Train Project

TECHNICAL MEMORANDUM

Earthwork and Track Bed Design Guidelines
TM 2.6.7

Prepared by:	*Signed document on file*_________ Dominique Rulens	_22 June 09_ Date
Checked by:	*Signed document on file*_________ Jan Zicha	_22 July 09_ Date
Approved by:	*Signed document on file*_________ Ken Jong, PE, Engineering Manager	_22 July 09_ Date
Released by:	*Signed document on file*_________ Anthony Daniels, Program Director	__27 July 09_ Date

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Prepared by PB

for the California High-Speed Rail Authority

System Level Technical and Integration Reviews

The purpose of the review is to ensure:

- Technical consistency and appropriateness
- Check for integration issues and conflicts

System level reviews are required for all technical memoranda. Technical Leads for each subsystem are responsible for completing the reviews in a timely manner and identifying appropriate senior staff to perform the review. Exemption to the System Level technical and integration review by any Subsystem must be approved by the Engineering Manager.

System Level Technical Reviews by Subsystem:

Systems: _Not Required_________________ ____________
Print Name: Date

Infrastructure: _Not Required_________________ ____________
Print Name: Date

Operations: _Not Required_________________ ____________
Print Name: Date

Maintenance: _Not Required_________________ ____________
Print Name: Date

Rolling Stock: _Not Required_________________ ____________
Print Name: Date

Note: Signatures apply for the technical memorandum revision corresponding to revision number in header and as noted on cover.

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ABSTRACT

This technical memorandum provides general guidance on planning and preliminary design considerations for design of earthwork and grading for the California High-Speed Train Project (CHSTP) such that right-of-way needs for the CHSTP can be assessed for the 15% Design level. In addition, this guidance will allow a uniform basis for development of 15% Design level construction cost estimates as it relates to earthwork.

The requirements presented in this technical memorandum consider the standards and best practices used in the construction of earth structures (which have a significant impact on the operations of the line) from high-speed lines around the world. For earthworks and earth structures required for facilities other than high-speed rail infrastructure, or for detail not addressed in this document, the Designers shall follow the requirements of Caltrans Highway Design Manual, Caltrans Standard Specification and American Railway Engineering and Maintenance of way Association (AREMA) Manual of Railway Engineering.

Where improvements are required outside of the CHSTP right-of-way, the requirements of local agency grading and other ordinances shall govern.

Earth retaining systems are an integral part of earthwork design. This technical memorandum identifies the requirements for realization of earth retaining systems. The final type and specific recommendations for the design of earth retaining system will be the responsibility of the Designer.

Earthwork management will also be addressed in this technical memorandum on the aspect of use and re-use of earthwork material according to a material classification defined in this document. The optimization of the alignment's vertical grade in order to excavate suitable, material for re-use or to avoid bad quality material will be a key issue in estimating the cost of earthworks on this project. As demonstrated during the construction of other high-speed lines, the cost of earthworks can reach up to 60% of the total cost of civil works and so optimization can be result in significant cost savings.

This technical memorandum will address the following main topics:

- Material classification and conditions of re-use.
- Design of typical earth structures.
- Typical design for specific earth structures (slope protection, backfill, transition between earth and structures, etc.).

Project-specific guidance geotechnical analyses, design, and geotechnical investigations and testing requirements for design are provided in separate documents. Guidance for drainage, erosion control measures, landscaping and irrigation will be provided in separate technical memoranda.

Material strategy and supply, earthwork movements and haulage distance is defined by the Designer. The program management team will provide coordination between geographic areas in order to equilibrate needs and surplus.

1.0 INTRODUCTION

1.1 PURPOSE OF TECHNICAL MEMORANDUM

This technical memorandum provides general guidance on planning and preliminary design considerations for design of earthwork and grading for the California High-Speed Train Project (CHSTP) such that right-of-way needs for the project can be assessed for the 15% Design level. In addition, this guidance will allow a uniform basis for development of 15% Design level construction cost estimates as it relates to earthwork.

This technical memorandum does not address, in particular, the geometric definition of the project or water and drainage, which are developed in other specific technical memorandums. Some aspects of these subjects will be touched upon in this document but with respect to specifications directly related to the quality of the earthworks. Accessibility requirements for the maintenance of the right-of-way will be provided in a separate document.

1.2 STATEMENT OF TECHNICAL ISSUE

Development of the criteria for determining the geometry and stability of the earthworks on the high-speed train project will provide Designers with a common basis for design and proportioning cuts and fills, which allow for uniformity in assessing both construction impacts and cost estimates.

The general basis of earthworks design, as defined in this document, will follow best practices currently used on the design of high-speed railroad systems. It is possible to use the UIC (International Union of Railways) code that has been issued with the cooperation of Japan, Germany and France. (The Association of American Railroads, Amtrak, and US Department of Transportation are members of the UIC). However, many US legal and customary practices differ significantly from those given in the UIC standards. Many technical issues can be derived from this documentation. More recently, Technical Specifications for Interoperability (TSI) for high-speed railways have been developed by the European Union (EU) to be a set of required standards for all railroad systems in the European Union.

Where specific guidance is not provided, the standards described in the Manual for Railway Engineering of the American Railway Engineering and Maintenance of Way Association (AREMA Manual Volume 1, Chapter 1, Part 1) shall be followed. However, the material presented in the AREMA Manual is defined as “recommended practice” and varies considerably in level of detail and applicability.

The earth structures shall be designed to insure the highest practical geometrical accuracy and stability for the track. These shall also be able to support the heavy dynamic load and the high level of vibration from the high-speed rolling stock running at design speed. This point implies that the bearing capacities and the stiffness levels described in this document shall be reached.

Due to the difficulty to plan heavy maintenance operation on the earth structure supporting operated track without significant impact on operations, the earth structures shall be designed to avoid substantial re-investment for a design life of 100 years.

1.3 GENERAL INFORMATION

1.3.1 Definition of Terms

The following technical terms and acronyms used in this document have specific connotations with regard to the California High-Speed Train system.

Ballast: Crushed rock layer on which the track is laid. The ballast forms part of the superstructure. For this reason, problems relating to the ballast layer and ballast materials are referred to here only so far as they affect the quality of the earthworks and track bed layers.

Backslope: Resultant excavation face located between outer shoulder line and natural ground line.

Blanket: Blanket is a layer of coarse grained material between ballast and subgrade, spread over entire width. It may be required over the formation where the subgrade soil is of poor quality, rainfall is heavy, and traffic density is high, as the absence of blanket in such cases can lead to problems in service.

Cohesive Subgrade: Subgrade constructed with soils having cohesive behavior, 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 behavior. All fine grained soils and GM, GM-GC, GC, SM, SM-SC & SC types of soils exhibit cohesive behavior.

Cohesionless Subgrade: Subgrade constructed with cohesionless, coarse-grained soils, i.e., shear strength is predominantly derived from internal friction of the soil and is termed as cohesionless subgrade. GW, GP, SW & SP types of soils fall in this category.

Cut and Fill: Construction techniques involving excavation or grading followed by placement and compaction of fill material.

Earthwork: A general term applying to cuts, embankments and composite cross sections as well as their environmental mitigations.

Embankment or Fill: Artificial mound of imported material generally made of selected earth, gravel, or stone; built to support the HST when the reference line of the longitudinal profile is above the natural ground.

Foreslope: In fill sections, the resultant slope of the fill that allows to safely support track and road subgrade and that places the subgrade at safe height above the maximum water and flooding level.

Formation: It is a general term referring to the whole of blanket, subgrade, and subsoil.

Formation Top: Boundary between ballast and top of blanket or subgrade (where blanket layer is not provided).

Geosynthetics: Structural elements made of synthetic materials for use in earthworks and track bed layers construction. A distinction is made between:

- Geotextiles: Geosynthetics (woven or non-woven), which may be used for separation, filtering, drainage and reinforcement.
- Geomembranes: Geosynthetics (synthetic or bituminous layer) impermeable to water, which may be used for protection of sensitive subgrade against penetration of surface water or for protecting ground water against pollution.
- Geogrids: Fine or coarse mesh geosynthetics, which may be used for separation and reinforcement.
- Geocomposite: Compound structure made of at least two layers of geosynthetic materials.

Grade, Gradient: The slope of changes in elevation, defined in percentage, as a foot of rise in 100 feet. Sometimes defined in European publications as millimeters of rise in one meter, in which case it is written as $^{o}/_{oo}$.

Interceptor ditches: Above a cut slope, these carry runoff from the watershed served and prevent surface runoff from entering the cut.

Lineside Drains: Line side drains collect and discharge surface water, seepage water and ground water into a controlled outlet. Generally a distinction is made between buried drains, open channels and side ditches.

Prepared Subgrade: The upper part of the subgrade is formed into a prepared subgrade layer, which normally has a cross slope. This layer is made of imported or treated material depending of the quality of the upper part of embankment or the bottom of the cut. Its quality and compactness shall be better than the material below. Its function is to minimize the deformation of the upper part of the embankment or the bottom of the cut and to prevent water that has passed through the sub-ballast layer from penetrating to the earthworks below.

Subgrade: The subgrade is the top of the earthworks on which the sub-ballast layer rests. On an embankment, the subgrade will be formed of imported soil, whereas in a cut, it will be the naturally occurring soil.

Subballast Layer: The sub-ballast is an intermediate layer situated between the ballast and the subgrade layers. It protects the top of the embankment against erosion, ensures a better distribution of loads, and provides a leveled surface suitable for track laying. Sub-ballast is made up of full crushed graduate gravel. This layer is also referred to as the Blanket Layer in the UIC standards.

Subsoil: Soil of natural ground below subgrade.

Slope Value: Slopes are defined as a fraction indicating the number of units of length required to achieve 1 unit of vertical distance, i.e., 2H:1V means the slope raises 1 unit vertically for 2 units of horizontal length.

Ties or Sleepers: Concrete beams laid horizontally on ballast or track bed structure to support and bind rails together at the right gauge.

Track Bed Layers: General term that includes all of the new material imported for the foundation of the track. It includes the ballast and sub-ballast, the following elements when present:

Sub-ballast layer

Prepared subgrade

Geosynthetics

Track Formation: Total width of the track bed layers as shown in Figure 1-1.

Track Formation Level: Surface intended to receive the track bed layers.

Track Foundation: Constitutes ballast, blanket, and subgrade which is placed/exists below track structure to transmit load to subsoil.

Unstable Formation: It is yielding formation with non-terminating settlement including slope failure, which requires excessive maintenance efforts.

Upper Part of Embankment: Top three feet of an embankment. It requires high quality design and construction in order to ensure the appropriate bearing-capacity to receive track bed layers.

Wayside Drainage: Drainage system (buried drains, ditches, precast channel drains) laid to collect and discharge surface water, seepage water, and ground water.

1.3.2 Terminology and Symbols

Earthwork and track formation terms for general, ballastless (slab) and ballasted track structures are illustrated in Figures 1-1 to 1-3.

Figure 1-1 – General Earthwork Terms

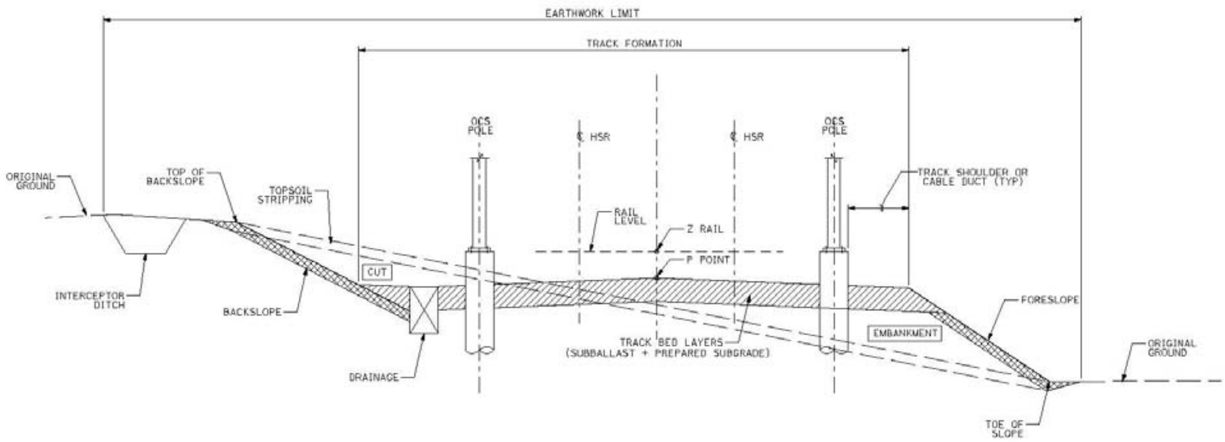


Figure 1-2 – Ballastless Track Formation

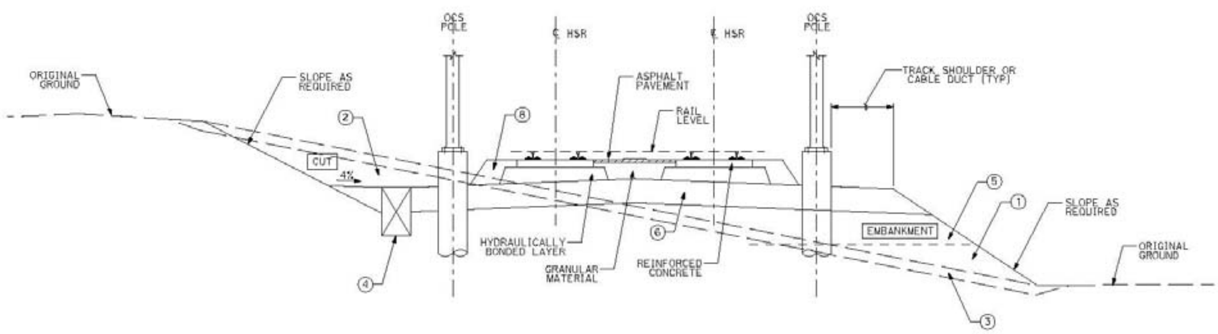
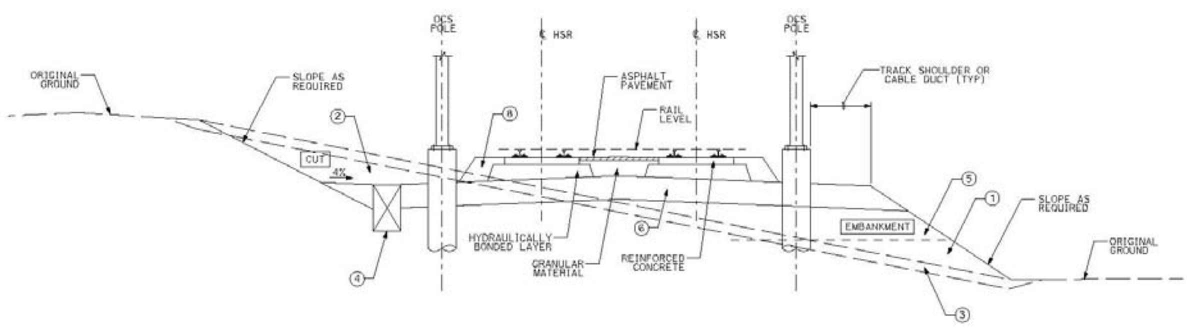


Figure 1-3 – Ballasted Track Formation



LEGEND

(1) EMBANKMENT - FILL	(3) TOPSOIL STRIPPING	(5) UPPER PART OF EMBANKMENT	(7) SUBBALLAST LAYER
(2) CUTTING	(4) DRAINAGE	(6) PREPARED SUBGRADE	(8) BALLAST
	(5) + (6) SUBGRADE	(6) + (7) + (8) TRACK BED LAYERS	

The International Society for Soil Mechanics and Geotechnical Engineering (I.S.S.M.F.E.) recommends the use of the geotechnical, terms definitions and units shown in Table 1-1.

Table 1-1: International Geotechnical Symbols, Terms, Definitions and Units

Symbol	Term	Definition	Unit [(1)]	Comments
I_C(CI)	Consistency Index	Defined by $(W_L - w)I_P$	1	
I_L(LI)	Liquidity Index	Defined by $(w - m_P) / I_P$	1	
I_P(PI)	Plasticity Index	Difference between liquid and plastic limits	-	
W	Moisture Content	Weight of interstitial water divided by weight of solid particles	-	
W_L(LL)	Liquid Limit	Moisture content of a remoulded soil at the transitional point between liquid and plastic states	-	
W_P(PL)	Plastic Limit	Moisture content of a remoulded soil at the transitional point between the plastic and solid states with shrinkage	-	
γ	Bulk unit weight	Total weight of the soil divided by its volume	kN/m^{3}k (pcf)	
γd	Dry unit weight	Weight of solid particles in the soil divided by its volume	kN/m^{3}k (pcf)	
γS	Particle unit weight	Weight of solid particles divided by their volume	kN/m^{3}k (pcf)	
S_R	Degree of saturation	Volume of interstitial water divided by the total volume of voids	1.%	
D, d	Particle size	Size of particle as determined by sieve analysis or sedimentation	n	ASTM D6913 ASTM D653
D_n, d_n	N- percentile particle size	Size at which n% (by weight) of the sample consist of smaller particles	n	ASTM D6913 ASTM D653
C_U	Uniformity Coefficient	Defined by: D_{60} / D_{10} ; d_{60} / d_{10}	1	Some railways use symbol U
C_C	Coefficient of curvature	Defined by $(D_{30})^2 / (D_{60} \times D_{10})$ or $(d_{30})^2 / (d_{60} \times d_{10})$	1	DIN 18196 SN 670120 ASTM D2487 Some railways use symbol C
k	Coefficient of permeability (or hydraulic conductivity)	Rate of flow of water through a unit area of soil when under a unit hydraulic gradient (v / i)	cm/s	
τ_f	Shear strength	Shear strength at failure in the shear plane (at given point)	psf	(kPa)
K_S	Reaction Modulus	Change in vertical stress divided by the corresponding displacement for a given load increment on a rigid plate	psf/ft	

(1) Conventions adopted for the imperial units: ft, s, lb, psf
1: for dimensionless values expressed as a real number (e.g. Sr = 0.93)
% for the same values, which can also be expressed as % (e.g. Sr = 93%)
-: for values which are defined as % (e.g. W_L=45).

Table 1-2: Symbols, Terms and Definitions Used Internationally but not yet Standardized

Symbol	Term	Definition	Comments
	Fines	Portion of a soil finer than a No. 200 (75μm) U.S. standard sieve	ASTM D653
	Particle Shape	Defined by thickness, width and length of each particle	BS 82 BS 5930 CNR B.U.n.95 NF P 18 561
	Hardness of Stone	Resistance to impact and attrition	May be determined by the: • Los Angeles Test ASTM C 535-89 CNR B.U.n. 34 NF P 18 573 • Deval Test NF P 18 577 • Microdeval test CNR B.U.n. 109 NF P 18 572 • Other hardness tests: - BR Ballast specification - DIN 52 115
CBR	California Bearing Ratio	Empirical value of a bearing load expressed as a percentage of a reference bearing load	ASTM D 1883-67 BS 1377: 1975 CNR-UNI n. 10009/1964 NF P 94 078-1 NF P 94 078-2
ρPr (γd)	PROCTOR density	The maximum dry density and water content under standardized conditions of compaction	PROCTOR Standard: AASHTO T 99 ASTM D 698 BS 1377:1975 DIN 18 127 NF P 94 093 SN 670330 PROCTOR Modified AASHTO T 180 ASTM D 1557 BS 1377:1975 DIN 18 127 NF P 94 093 SN 670330
RD	Degree of Compaction	in Percentage	ASTM D1557

Table 1-2: Symbols, Terms and Definitions Used Internationally but not yet Standardized *(Continued)*

Symbol	Term	Definition	Comments
E_{V2}	Modulus of deformation obtained on 2nd loading in the plate bearing test	$E_{V2} = \frac{1.5\, r\, \Delta\sigma}{\Delta s}$ (ksi) With: r: plate radius (in) $\Delta\sigma$: increment of pressure under plate (ksi) Δs: Increment of settlement of plate (in)	DIN 18 134 NF P 94 117.1
Vb	Blue Value	Weight of Methylene blue absorbed by 3.53 oz of fines	NF P 18 592
Vbs	Blue Value of soil 0/D	Weight of Methylene blue absorbed by 3.53 oz of soil 0/D = Vb x f (f = percentage of fines contained in 0/50 soil fraction)	

Acronyms

AREMA	American Railway Engineering and Maintenance-of-Way Association
Authority	California High-Speed Rail Authority
CHSTP	California High-Speed Train Project
CFR	Code of Federal Regulations
FRA	Federal Railroad Administration
SNCF	Société Nationale des Chemins de fer Français (French National Railway Company)
UIC	Union Internationale des Chemins de fer (International Union of Railways – The French abbreviation is also used in English).
TSI / STI	European Technical Specifications for Interoperability
ISO	International Standards Organization
CEN	Comité Européen de Normalisation (European Standards Committee)
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing Materials
SETRA-LCPC	Recommandations du Service d'Etudes Techniques des Routes et Autoroutes et du Laboratoire Central des Ponts et Chaussées

1.3.3 Units

The California High-Speed Train Project is based on U.S. Customary Units consistent with guidelines prepared by the California Department of Transportation and defined by the National Institute of Standards and Technology (NIST). U.S. Customary Units are officially used in the United States, and are also known in the U.S. as “English” or “Imperial” units. In order to avoid any confusion, all formal references to units of measure shall be made in terms of U.S. Customary Units.

Guidance for units of measure terminology, values, and conversions can be found in the Caltrans Metric Program Transitional Plan, Appendice B U.S. Customary General Primer (http://www.dot.ca.gov/hq/oppd/metric/TransitionPlan/Appendice-B-US-Customary-General-Primer.pdf). Caltrans Metric Program Transitional Plan, Appendice B can also be found as an attachment to the CHSTP Mapping and Survey Technical Memorandum.

2.0 DESIGN STANDARDS AND GUIDELINES

2.1 GENERAL

The general basis for design standards will be the most applicable of the experience from building earth structures for high-speed train lines in Europe. The foundation of this experience is delivered in the UIC Code 719 R - *Earthworks and Track-bed Layers for Railway Lines, which* is the basis of this technical memo.

Beyond this basic information, the railway companies that have built high-speed train networks have completed the UIC requirements according to their own experiences and usual methods of design and construction. Some of the background information used in this technical memorandum comes from the *Technical Requirement for Earthworks on High Speed Line* from SNCF (French National Railway) and the HS1 (High-Speed 1) in Great Britain. .

The information derived from European railway operations has been analyzed with an eye toward the "recommended US Practice" as described in the Manual for Railway Engineering of the American Railway Engineering and Maintenance-of-Way Association (AREMA Manual). Notably, there is no divergence in the design philosophy. For detail not addressed in this document, the Designers shall follow the requirements of the AREMA Manual.

For earthworks and earth structures required for facilities other than high-speed rail infrastructure, the Designers shall follow the requirements of Caltrans Highway Design Manual, Caltrans Standard Specification, and American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual of Railway Engineering.

2.1.1 CHSTP Design Considerations

Guidelines in this document are primarily intended for use in preliminary design.

2.1.2 CHSTP Design Parameters

2.1.2.1 Project Specific Technical References

- California High-Speed Train Project TM 0.3 - Basis of Design (current version)

2.1.2.2 Other Technical References

This document references the following standards and operating regulations:

1. ISO: International Standards Organization
2. CEN: Comité Européen de Normalisation (European Standards Committee)
3. AASHTO: American Association of State Highway and Transportation Officials
4. U.S. Army Corp of Engineers Technical and Design Guides
5. ASTM: American Society for Testing Materials
6. BS: Standard of British standards Institute (BSI)
7. CNR-UNI: Consigilio Nazionale dell Ricerche – Ente Natiozane Italiano di Unificazione (Research council - Italian National Standards Organization)
8. DIN: Deutsches Institut für Normung (German Standards Institute)
9. NF: Normes de L'Association Française de Normalisation (AFNOR) (French standards Association).
10. SNCF High-Speed Line Technical Requirements
11. ö,Norm: Norm des Österreichischen Normungsinstituts (Austrian Standards Institute)
12. SETRA - LCPC: Recommandations du Service d'Etudes Techniques des Routes et Autoroutes et du Laboratoire Central des Ponts et Chaussées
13. SN: Norm der schweizer Normenvereinigung (Swiss Standards)
14. UIC Union Internationale des Chemins de fer (International Union of Railways – The French abbreviation is also used in English).

2.2 LAWS AND CODES

Initial high-speed rail design criteria will be issued in technical memoranda that provide guidance and procedures to advance the preliminary engineering. When completed, a Design Manual will present design standards and criteria specifically for the design, construction and operation of the CHSTP railway.

Criteria for design elements not specific to HST operations will be governed by existing applicable standards, laws and codes. Applicable local building, planning and zoning codes and laws are to be reviewed for the stations, particularly those located within multiple municipal jurisdictions, state rights-of-way, and/or unincorporated jurisdictions.

In the case of differing values, the standard followed shall be that which results in the satisfaction of all applicable requirements. In the case of conflicts, documentation for the conflicting standard is to be prepared and approval is to be secured as required by the affected agency for which an exception is required, whether it be an exception to the CHSTP standards or another agency standards.

3.0 ASSESSMENT / ANALYSIS

For a linear infrastructure such as high-speed train lines, the earthwork represents an important portion of the civil in terms of both design and project cost. In terms of design, it is necessary that cut and fill aspects are taken into account in all phases of studies in order to allow for selection of route as well as for technical and financial optimization of the project. Earthworks can represent about 40% to 60% of the cost of civil engineering, according to the morphological, geological and environmental contexts intersected by the project. However, the choice of the “earthworks” option compared to the use of the structure, where technically feasible, allows significant savings for the project.

Successful completion of projects involving large quantities of earthwork requires the ability to balance cut and fill quantities efficiently and to maintain appropriate materials for re-use on-site in order to reduce procurement and transportation costs of imported material. This is achieved by conducting a detailed analysis of the potential for re-use of earthwork early in the project planning phase. The development of an earthworks strategy for the project includes environmental considerations and the concepts of sustainable development, which are particularly important in the design of major linear earthworks projects.

3.1 GENERAL CONSIDERATIONS FOR 15% DESIGN

These evaluations come into play as early as the 15% design and environmental assessment since raising or lowering the vertical alignment can significantly influence the impact of the project on the landscape. It can also result in the development of a different policy for acquiring rights-of-way depending on the potential needs of material borrowing or surplus disposal.

These aspects are taken into account in the early phases of the project, not only to clarify and validate them for later phases, but also to provide guidelines for the testing and geotechnical laboratory standards needed for decision making. The option of iterative analysis of longitudinal profile according to the geological and geotechnical site should be included so that the optimum compromise for the project can be determined.

Another very important aspect is the re-use of materials from the site by treating them with lime and/or hydraulic binders. This allows for re-use of materials like silt, clay, marl, chalk and sand-clay in which natural water conditions are too high to normally permit their re-use. These fully operational techniques in the major earthworks worksite can be very attractive economically and environmentally. However, these need to be incorporated at an early stage in studies of earthworks in order to achieve the appropriate tests and to do economic simulations needed for operational decisions.

The design of earthworks must also include the search for sites close to the alignment that are geologically favorable for extraction of potentially useful materials for the project. The options in terms of earth moving strategy can have a very significant impact on project planning. New quarries, when required, typically impose unavoidable delays due to requirements for permitting and performing impact studies. The use of supplies from existing quarries should be planned in advance and often require storage buffers in order to avoid exceeding the production capacity of the quarries. Such planning also helps mitigate materials price escalation and in ensuring the ability to supply the site without reloading and without planning constraints for the civil worksite.

These elements demonstrate that a materials strategy is a key phase of the project and requires studies and planning at the earliest phases of the project.

3.2 GENERAL REQUIREMENTS FOR EARTH STRUCTURES

3.2.1 Importance of Traceability

Due to the time life of the earth structure and the critical impact of failures on operations, it is important that the operator and maintainer of the high-speed system consider all the necessary elements which can be useful for preventive maintenance and repair. Since it is likely that there will be no access to the individuals responsible for design and construction when follow-up information is required, it is important to record all appropriate data at each stage.

3.2.1.1 Design Record File

The Designer shall produce a summary file named Design Record File (DRF) of the entire project design. This is different from the call for tender files at the end of the design process. This DRF document summarizes the input data of the project, selected sizing, their justification and possibly the history of all the considered possible solutions used prior to dimensioning. It may allow some sizing during construction, taking into account the justification of the original project design. It establishes a list of items whose construction is considered as sensitive and for which should be developed a quality plan to ensure the required performances. This list is specified in the Design Record File and is a component of the commitment of the Designer toward the quality of the project.

3.2.1.2 As-Built File

The Design-Build Contractor shall prepare and provide to the Program Management Team, the As Built File (ABF). This file includes implemented detail design documents, the results of internal and external controls, changes in the project according to the design documents decided during construction and the justification with the corresponding history, and anomalies in the works with the history of their treatment.

3.2.1.3 Maintenance Elements File

Upon receipt by the Authority, the Program Management Team's Maintenance Department produces a Maintenance Elements File (MEF) on the basis of evidence provided by the Designer in the DRF and by the Design-Build Contractor in the ABF. This file, specific for each structure, recapitulates the composition of the earth structure (materials, drainage, specific reinforcements or foundations) and offers a dashboard of its maintenance, and possibly it's monitoring to ensure satisfactory, safe and reliable operation. This file must be transmitted to the Maintenance Manager.

3.2.2 Maintenance, Availability and Durability of Earth Structures

The time life of some components of the superstructure (rails, sleepers, ballast) on a high-speed line is estimated to be ten to twenty years. Concerning the sub-layers and structures in the ground, the potential negative impact on the operations of the high-speed train justifies the need for a one-hundred year design life. During that life cycle, it should be anticipated that no significant maintenance will be undertaken. However, some items associated with the work, such as drainage, vegetation or stone traps may require regular maintenance on an annual to ten year basis. These objectives are achieved by respecting the reference practices of this technical memorandum that are provided in the references portion of this technical memorandum.

3.2.3 Application Field for High-Speed Line Earthworks Design

The design of earthworks concerns the earth structures supporting the high-speed tracks as well as structures located on both sides of the track formation that can influence the operation of the train in case of damage or failure. For example, intrusion protection berms are to be considered if, due to the close distance from the track formation, a slope failure on the berm could provoke material to enter the operating envelope (i.e., the area inside the high-speed train catenary poles).

3.2.4 Stability Calculation and Factor of Safety

The proposed geometry is justified by the slope stability analysis used in soil mechanics and recognized by AASHTO method or US Army Corp of Engineers technical guidance. The method of calculation shall be adapted to the considered failure type.

1. Bishop method for circular failure
2. Disruption method for non circular failure.

The stability calculations apply the principles described in the following paragraphs. These are intended to guide the qualified practitioner in selecting the values of the geotechnical parameters to be taken into account, and verify the qualification of computer calculation coefficient and codes.

3.2.4.1 Requirements Concerning Geotechnical Parameters

Calculations of stability shall be carried out using average values of conservative geotechnical parameters applied to homogeneous areas (strength and density of soil, rocks and embankment). Further, the definition of these parameters and homogeneous areas shall be justified. The values of these parameters shall be derived from the soil investigation on the project and information learned from experience. The choice of parameter values must take into account not only all available information regarding the variation in space (knowledge of geological and geotechnical model), but also the how representative the sampling and testing is, as well as the significance of the test conducted on the sample (taking into account its possible remoulding). The following standards shall be followed:

3.2.4.2 Factor of Safety

A factor of safety of 1.5 shall normally be adopted against slope failure. For high risk category slopes (i.e., slopes supporting buildings, infrastructures, bridges, and amenities), a minimum safety factor of 1.6 shall be achieved.

3.2.4.2.1 Embankments on Soft Ground and Clay

At the end of construction, when pore water pressure dissipates partially, a minimum factor of safety of 1.2 can be allowed to achieve economy but without scarifying safety for long term stability. Minimum factor of safety specified above can be further decreased only in specific cases of instrumented pilot embankments where the factor of safety is monitored during construction. However, in either case, a minimum factor of safety of 1.5 must be ensured for the long term stability.

Before the stability calculations, the values of undrained shear strength determined by field vane shear tests shall be corrected for the effects of anisotropy and strain rate using Bjerrum's correction factor, μ, which depends on the Plasticity of Index (PI) of the clay (Bjerrum, 1972).

As it is not usual to calculate the long-term stability of embankments on soft ground, the evaluation of the effective cohesion is not necessary. The undrained shear strength recorded for over consolidated soil crust that often forms the surface soil is half the undrained shear strength measured with work site rotating auger. It is, however, retained as zero cohesion for fill material (this practice is justified by the risk of cracking of coherent fill materials that makes the material lose the advantage of such cohesion for the stability of the embankment).

In case of construction in stages, the increase of the undrained shear strength Su of the foundation soils due to induced embankment loading shall be considered. There is a unique relationship between the in situ undrained shear strength ratio (Su/σ'_{vc}) and the overconsolidation ratio ($OCR = \sigma'_p/\sigma'_{vc}$) of cohesive soils. For the 15% design level, $Su/\sigma'_{vc} = Su(OCR)^m$ can be used with values of Su and m obtained from the following (Ladd, 1991).

For homogeneous sedimentary clays plotting above Casagrande's A line, Su = 0.22± 0.03.

For silts and organic clays plotting below A line, Su = 0.25 ± 0.05. and m = 0.88 (1-Cs)/Cc where Cs and Cc are equal to the slope of the swelling and virgin compression lines, respectively.

3.2.4.2.2 Natural Slope and Backslope in Cut

Stability of Slopes in Natural Soils

The stability of backslopes in natural soils is generally more critical in drained conditions (long term), so that the calculations are carried out in effective stresses with a pair of parameters (c' and φ'). For new earth structures with steady slopes, it is justified to choose a safety factor of 1.5, because the uncertainty on the parameters of the field is "similar to soft ground conditions.

Stability of Backslope in Rock

Rocks shall not reach the railway track and shall not engage the railway dynamic gauge. Two types of risk to be prevented are:

- The risk of instability of rock masses whose probability of occurrence is difficult to determine. The security is the first element to consider with a comprehensive diagnosis of the mechanisms likely to be involved and an evaluation of the unstable masses.
- The risk of falling rocks that can reach a vulnerable area. This risk is evaluated using structural studies and eventually by trajectory design. .

When the rock in question is subject to rock weathering, it shall be ensured that this alteration does not create a risk of instability within the design life of the high-speed rail line.

In some cases where the rock is altered or likely to deteriorate into loose soil, it may be necessary to evaluate and appraise the stability by conducting a geologic mapping and rock slope stability analyses where the failures are primarily governed by structural discontinuities (bedding planes, joint sets, clay gouges and seams, faults, etc.). This shall be coupled with a complementary study where the failures occur throughout the areas of highly weathered/degraded rock and unstable soils whose mechanical properties are insufficient to withstand gravity. Both types of failure are possible in the same slope and shall therefore be studied.

3.2.4.2.3 Foreslopes for Embankment

For fill materials without cohesion, the foreslopes of embankment if dry are considered as stable when the angle of internal friction φ 'of reworked material is greater than the angle adopted for the slope (i.e., the angle of repose is greater than the angle of the slope).

For fill materials with cohesion (natural soil or soil treated with binders), the slope is determined by local experience or through specific studies in which a safety factor of 1.5 is used for all mechanisms of failure that may affect the track and its facilities. The evaluation of the stability of the slope surface ("surficial stability") will not be based on a safety factor of 1.5, but will be based on the anticipation of a satisfactory drainage, slopes protection and their vegetation to protect against erosion.

Moving train loads may overstress soil mass and would therefore adversely affect the slope stability. Hence, a minimum factor of safety of 1.6 shall be ensured for slope stability of smaller embankments of height up to 12 feet.

In any case, the foreslope of embankment will not exceed 2H:1V.

3.3 DESIGN

3.3.1 General Design Requirements

The Designer shall provide the Authority or designee with all related study documents relating to design.

The design for the earth structures provided by the Designer shall from the preliminary stage, include ways to meet the environmental constraints, to anticipate all possible difficulties, to achieve balanced cut/fill volumes, and to produce optimized structures from the technical, financial, time and environmental point of view. From these perspectives, studies shall:

1. Evaluate the probable ground condition by collecting all possible information on ground investigations already realized on locations close to the considered site and from construction of similar earth structures close to the project
2. Define the geometry of the structure and right-of-way
3. Assess the cost and time of execution of works, especially by sub-contractors
4. Ensure the reliability of the work
5. Achieve well-balanced cut/fill volumes
6. Assess the potential risks during construction and in operation
7. Define performance targets for construction sufficiently explicit so as to allow recognition of the conformity
8. Limit the costs of maintenance during operations.
9. Maximize technical and financial considerations for the structure at each phase: design, construction and maintenance during operation.

3.3.2 Specific Elements to Consider During Design

3.3.2.1 Geological and Geotechnical Investigation and Design

Specific technical memorandums and system requirements are prepared which define the geological and geotechnical investigation and design. These studies will provide a realistic and sufficient description and provide:

1. Local distribution of the geological and structural elements of the area (tectonics, faults, slope failures, pre-historic landslides, potential liquefaction, etc.)
2. Characteristics of nature, status and behavior of the materials pertaining to the project
3. Hydrogeological characteristics of the different intercepted layers

In order to make the most adaptable sizing and design according to the conditions that will be actually encountered by the project, these studies must be translated into a geological, geotechnical and hydrogeological file (GGHF). The GGHF shall contain:

1. The results of an investigation of local, actual conditions including the geological and geo-technical data, as well as difficulties encountered by previous similar projects in construction and operation.
2. The raw results of completed subsurface investigations. This part shall contain enough information to allow an assessment of predictable risks (description of the heterogeneous massifs and of possible fluctuations of hydro-geological parameters, etc.).
3. Analysis of the variability of geotechnical parameters, and the justification of the choice of values adopted by the Design Manager for design, and the corresponding assessment of geological and geotechnical risk.
4. Analysis of hydro-geological studies that may affect the behavior of geotechnical areas (water fluctuations).
5. The elements of design (calculations of stability, settlement, liquefaction potential, etc.) offered by elementary design elements, including a longitudinal profile of geology along the project center line.

The GGHF allows the design manager to take responsibility for the project. It also allows the contractors use of reliable data for their and, where appropriate, suggests calculated and substantiated alternatives and/or derogation.

At the 15% Design level, the geological and geotechnical investigations are limited to the research of existing local data and difficulties encountered by previous similar projects. The research includes hydro-geological data.

3.3.2.2 Meteorological Design

Meteorological studies are performed to provide figures and statistics for use in defining favorable and unfavorable periods for carrying out the work, as well as in assessing the impact of climatic variability on the behavior and implementation of the materials.

This analysis shall be integrated into the risk assessment on the costs and planning of work. The Design Manager will refine meteorological assumptions made for the project work in the DRF(see Section 3.2.1.1) and later the contractor will provide information on the climatic incidents encountered during construction in the ABF (see Section 3.2.1.2).

3.3.2.3 Hydraulic and Drainage Design

Hydraulic and Drainage design is the topic of a separate technical memorandum that will provide key elements for earth structure design such as:

1. Altitude of the Higher Water Level in flooding area
2. Type of protection to install along earth structure in order to avoid erosion
3. Definition and sizing of the culverts and drainage network

If a constructed embankment acts as a dam, it may be subject to provisions of the Water Protection Act. In that case, a technical justification file shall be submitted to the Program Management Team.

3.3.2.4 Hydrogeologic Design

These studies have a dual purpose:

1. To identify the impact of groundwater on the project and its implementation
2. To determine the impact of the project on groundwater and water resources

These studies also determine:

1. The regulatory requirements, including constraints in the study phase
2. The work phase
3. The permanent dispositions and compensatory solutions

All required specific hydro-geological studies and their content shall be suitable for the encountered problem (tracing, modelling of runoff and/or migration of pollutants, simulation of technical solutions, etc.).

3.3.3 Classification of Soils and Subgrades

3.3.3.1 Geotechnical Classification of Soil

3.3.3.1.1 – General

The methods used for classifying soils shall be in accordance to ASTM D2487-06 Classification of Soils for Engineering Purposes (Unified Soil Classification System) and ASTM D2488-06 Description and Identification of Soils (Visual Manual Procedure), unless otherwise stated in this technical memorandum. The commonly used methods described below draw a distinction between:

- Mineral soils (Section 3.3.3.1.2) which may be sub-classified according to:
  - Particle size (Section 3.3.3.1.2 part A)
  - Plasticity (Section 3.3.3.1.2 part B)
  - Sensitivity to water (Section 3.3.3.1.2 part C)
  - Mineral content (Section 3.3.3.1.2 part D)
- Organic soils (Section 3.3.3.1.3)
- Mixed soils (Section 3.3.3.1.4)

3.3.3.1.2- Mineral Soils

A. Classification According to Particle Size

A mineral soil may be identified by its particle size distribution (PSD) curve which is obtained by sieving and/or sedimentation tests. Figure 3-1 shows an example of a PSD curve. The I.S.S.M.F.E. advocates the use of the size limits given in Figure 3-2. Some railways use slightly different limits.

Figure 3-1 – Example of a particle size distribution curve (logarithmic scale of abscissas)

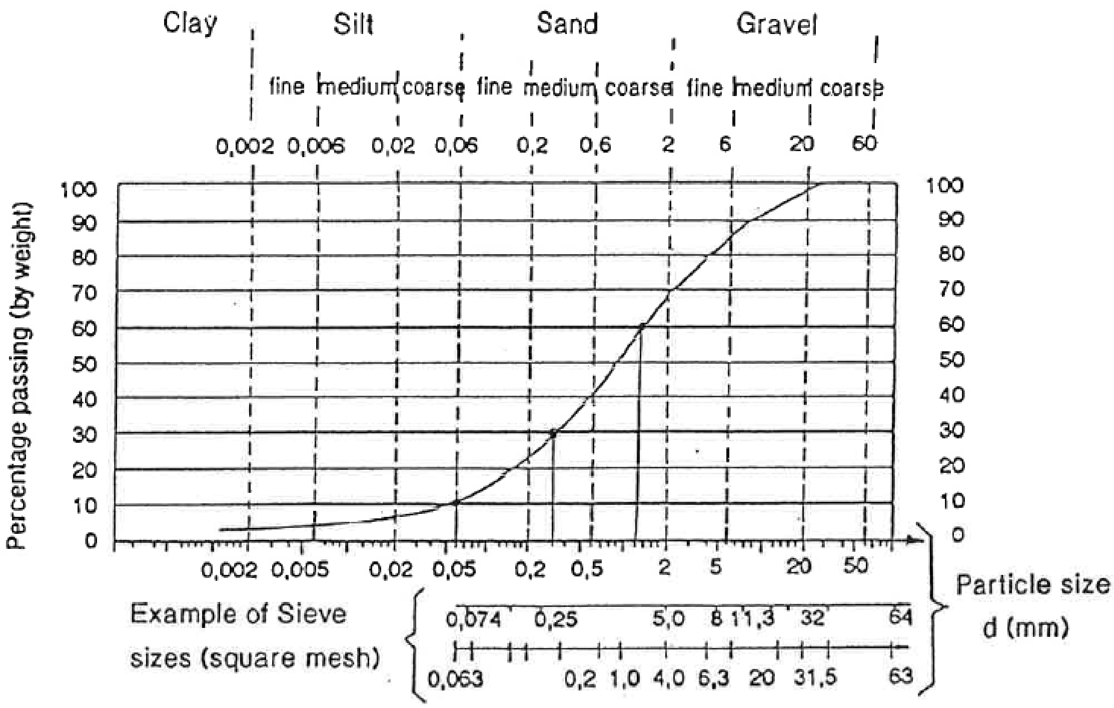


Figure 3-2 – Grain Size Classification (according to I.S.S.M.F.E recommendations of 1973)

Particle Class	Grain Size (mm)
Clay	< 0.002
Silt	0.002 – 0.06
Fine	0.002 – 0.006
Medium	0.006 – 0.02
Coarse	0.02 – 0.06
Sand	0.06 – 2
Fine	0.06 – 0.2
Medium	0.2 – 0.6
Coarse	0.6 - 2
Gravel	2 – 60
Fine	2 – 6
Medium	6 – 20
Coarse	20 - 60
Cobbles	60 - 200
Boulders	> 200

When classifying a mineral soil according to its particle size, this soil is described by the fraction which dominates its behavior, preceded, where appropriate, by adjectives qualifying the other classes represented. The soil represented in Figure 3-1 would therefore be described as "gravelly and slightly silty sand".

Based on the particle size distribution, the following coefficients maybe calculated:

- Uniformity coefficient C_u (defined in Section 1.3.2, Table 1-1)
- Curvature coefficient C_c (defined in Section 1.3.2, Table 1-1)

For the soil shown in Figure 3-1, therefore:

$$C_U = \frac{d60}{d10} = \frac{1.2}{0.06} = 20$$

$$C_C = \frac{(d_{30})^2}{d_{60} + d_{10}} = \frac{(0.3)^2}{1.2 * 0.06} = 1.25$$

The concept of a uniformity coefficient is very important for assessing the quality of granular soils, particularly with respect to:

1. Suitability for compaction.
2. Bearing capacity of the track bed layers closest to the underside of the sleepers.

A granular soil is considered to be well graded when: $C_U > 6$.

It should be noted that for the blanket layer certain railways demand higher values.

In addition, the coefficient of curvature C_C is relatively important, although it is not observed by all railways. A soil is considered to be well-graded when:

$1 < C_C < 3$

both for sandy gravel and for sand.

B. Classification According to Plasticity

For a more meaningful classification of fine cohesive soils the Atterberg limits are generally used (the test is performed on the fraction of the soil in the size range 0 to 0.4 mm). The Atterberg limits are:

- Liquid limit (LL)
- Plastic limit (PL)
- Plasticity Index (PI = LL-PL)

These are used in conjunction with the diagram derived from the Casagrande plasticity chart (see Figure 3-2), to give a further classification of the soil. Even a very small proportion by weight of organic material can affect the classification of fine soils according to the plasticity chart.

C. Classification According to Sensitivity to Water

The sensitivity of clay to water can be characterized by the Methylene blue test (blue value Vb). Similarly, the sensitivity of a soil to water can be characterized by the clay content (Vbs). When Vbs < 0.1, the soil is said to be insensitive to water; when Vbs > 0.2, the soil is sensitive to water.

D. Classification According to Mineral Content

A reference to the mineral content is often added to the classifications (particle size and plasticity).

For example:

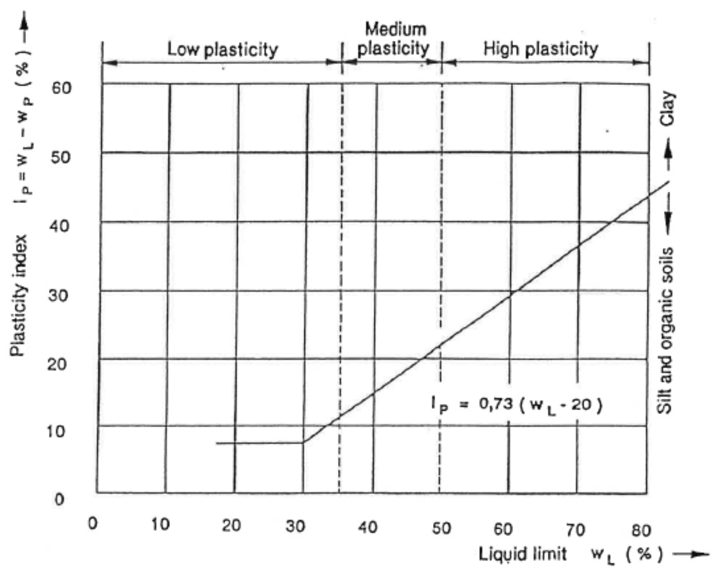
- Quartz sand
- Mica sand
- Olivine sand
- Fine marl, according to the CaCO3 content.

3.3.3.1.3 Organic Soils

Organic soils are the result mainly of the decomposition of vegetable or animal remains (see Figure 3-3). The main groups are: topsoil, peat, organic soils (OH and OL).

Like mineral soils, organic soils can normally be tested for moisture content, liquid limit, plasticity index, strength and compressibility. Topsoil consists mainly of natural and artificial humus mixed in varying proportions with mineral soils. Peat consists of the remains of vegetable matter in varying stages of decomposition and is formed in situ. It is classified according to the degree of decomposition, etc., but the classification system is not provided as it is of little interest for railway applications.

Figure 3-3 – Plasticity Chart for the Classification of Fine Grained Soils (after Casagrande)



Organic soils were deposited under water by sedimentation, and they originate from the decomposition of plant and animal matter and micro-organisms. These are often mixed with sand, clay or rock and have an elastic, spongy texture.

3.3.3.1.4 Mixtures of Mineral and Organic Soils

Mixed soils can be classified according to the Table given in Figure 3-4.

Figure 3-4 – Classification of Mixtures of Mineral and Organic Soils

Description of the soil	Percentage by dry weight of organic content
Mineral soils	≤ 1 %
Soils containing some organic matter	> 1 % et ≤ 5 %
Mixed mineral/ organic soils	> 5 % et < 30 %
Organic oils	≥ 30 %

Note: Some railways use different values.

Soils containing organic matter can also be classified according to plasticity using Figure 3-2.

3.3.3.2 Classification of Subgrade According to Bearing Capacity

To classify a subgrade it is necessary to:

- Determine the quality of each soil type contained in the subgrade(Section 3.3.3.2.1);
- Determine the bearing capacity of the whole system subgrade + prepared subgrade + subsoil (Section 3.3.3.2.2).

3.3.3.2.1 Soil Quality Classes

The quality of a soil depends on the following two factors:

1. The geotechnical properties of the soil; for this purpose the geotechnical classification referred to in Section 3.3.3.1 shall be used.
2. The local hydrogeological and hydrological conditions; these conditions, in as far as they affect the bearing capacity of the soil, can be considered good if:
    - The uppermost layer of soil is above the level at which it maybe adversely affected by the highest natural ground water level (this level shall be assessed assuming unfavorable weather conditions and no drainage),
    - There is no harmful natural transverse, longitudinal or vertical water flow in the subgrade,
    - Rainwater is correctly drained from the subgrade, and the longitudinal or transverse drainage system is in proper working order.

If any of one of these three criteria is not satisfied, the hydrogeological and hydrological conditions must be considered to be poor.

On the basis of the above information it is possible, by referring to Figure 9, to assign a quality class to any given soil using the following 4 SQi quality classes for soils:

SQ 0: “Unsuitable" soils which do not form a suitable subgrade and therefore require improvement (replacement to a certain depth with better quality soil, stabilization with binding agents, use of geotextiles, reinforcement with piles, etc.). For this reason, these soils are not considered when dimensioning the track bed layers.

SQ 1: “Poor" soils which are acceptable in their natural condition subject to adequate drainage being provided and proper maintenance. These soils could be considered for upgrading by means of the appropriate treatment (e.g., stabilization binding agents).

SQ 2: “Average" soils

SQ 3: "Good" soils

Figure 8 – Soil Quality Classes

Soil Type (Geotechnical Classification)	Soil Quality Class
0.1 Organic soils (OH and OL) 0.2 Soft soils containing more than 15% fines [(1),] with a high moisture content therefore unsuitable for compaction. 0.3 Thixotropic soils [(2)] (e.g. quick-clay) 0.4 Soils containing soluble material (e.g. rock salt or gypsum) 0.5 Contaminated ground (e.g. industrial waste) 0.6 Mixed material / organic soils [(2)]	**SQ 0**
1.1 Soils containing more than 40% of fines [(1)] (except for soils classified under 0.2) 1.2 Rocks which are very susceptible to weathering, e.g.: - Chalk with ρ_d < (1.7 t/m^3) 106 pcf and high friability - Marl - Weathered shale	**SQ 1**
1.3 Soils containing 15 to 40% of fines [(1)] (except for soils classified under 0.2) 1.4 Rocks which are moderately susceptible to weathering, e.g.: - Chalk with ρ_d < (1.7 t/m^3) 106 pcf and low friability - unweathered shale 1.5 Soft Rocks, e.g. Microdeval wet (MDE) > 40 and 1.6 Los Angeles (LA) > 40	**SQ 1** [(3)]
2.1 Soils containing from 5 to 15% of fines [(1)] 2.2 Uniform soil containing less than 5% of fines (1) (CU ≤ 6) 2.3 Moderately hard rock, e.g. if 25 < MDE ≤ 40 and 30 < LA < 40	**SQ 2** [(4)]
3.1 Well graded soils containing less than 5% of fines [(1)] 3.2 Hard rock, e.g.: if MDE ≤ 25 and LA ≤ 30	**SQ 3**

1. These percentages are calculated from particle size distribution analysis undertaken on material passing through a 60 mm sieve. The percentage indicated here have been rounded down (practices vary slightly from one railway to another); they may be increased by up to 5% if a sufficiently representative number of samples is taken.
2. Certain railways sometimes include these soils in quality SQ 1.
3. These soils are classified under quality class SQ 2 if the hydrogeological and hydrological conditions are good.
4. These soils are classified under quality class SQ 3 if the hydrogeological and hydrological conditions are good.

3.3.3.2.2 Bearing Capacity Classes for Subgrade

The bearing capacity of the subgrade depends on the:

1. Quality class of the soil which forms an embankment or the natural soil at the base of a cut;
2. Quality and thickness of the prepared subgrade (when this exists).

On the basis of the parameters described above, a distinction can be made between the three following bearing capacity classes:

- P1: poor subgrade – Deformation Modulus ≤ 20 MPa (2.9 ksi)
- P2: average subgrade – Deformation Modulus ≤ 50 MPa (7.25 ksi)
- P3: good subgrade – Deformation Modulus ≤ 80 MPa (11.6 ksi)

Methods of classification used vary from one railway to another. One of the methods is given in Figure 9.

Figure 9 – Determination of the Bearing Capacity of the Subgrade

Quality Class of the Soil	Class of Bearing Required for the Prepared Subgrade	Requirement of Subballast Layer	
		Quality Class	Min. Thickness of Trackbed (in)
SQ 1	P1	SQ1	-
	P2	SQ2	20
	P2	SQ3	15
	P3	SQ3	20
SQ 2	P2	SQ2	15
	P3	SQ3	
SQ 3	P3	SQ3	-

3.3.3.3 Frost Susceptibility of Soils

Soils may be divided into three classes according to their degree of susceptibility to frost:

- not susceptible to frost
- susceptible to frost
- very susceptible to frost

A soil which is not susceptible to frost is one which does not cause unacceptable disturbance to the track geometry as it freezes and thaws.

A soil which is susceptible or very susceptible to frost is one on which lenses of ice (formed under certain conditions of temperature and water availability) cause unacceptable disturbance of the track geometry. For individual grading, the frost susceptibility of a soil can generally be deduced from its particle size (per Figure 3-2) using the table in Figure 10.

Figure 10 – Frost Susceptibility of the various Soils Types

Degree of Frost Susceptibility	Soil Type
Not susceptible to frost	Sand Gravel
Susceptible to frost	Clay
Very susceptible to frost	Silt

In practice it is essential to consider the overall grading. A soil composed mainly of coarse particles (which are unaffected by frost) will become frost-susceptible when the percentage of clay or silt rises above a certain critical level. It is therefore essential to use the concept of a critical percentage of fine particles.

Casagrande's criterion is the best known; it gives the critical percentage of particles with a diameter of d < 0.02 mm (Figure 11) for soils having uniformity coefficients C_U of 5 and 15 respectively. For other values of C_U the critical percentage may be found by interpolation.

Figure 11 – Percentage of fine particles (d < 0.02 mm) according to the Uniformity Coefficient

Uniformity coefficient C_U of the soil under consideration	Critical percentage (by Weight) of particles with a diameter d >0.02mm
5	10
15	3

For a given track, the frost susceptibility also depends on geological conditions, the nature of the constituent soil particles (mineral and chemical composition, shape of the fine particles) and the required quality of track geometry. For these reasons, some railways have adopted other frost-susceptibility criteria. These include the criteria of:

- Beskow, G – Soil Freezing and Frost Heaving, Statens Vaginstitut, Stockholm 1935
- Schaible, L - Frost und Tauschaden an verkehrswegen, W. Ernst und Sohn, Berlin 1957

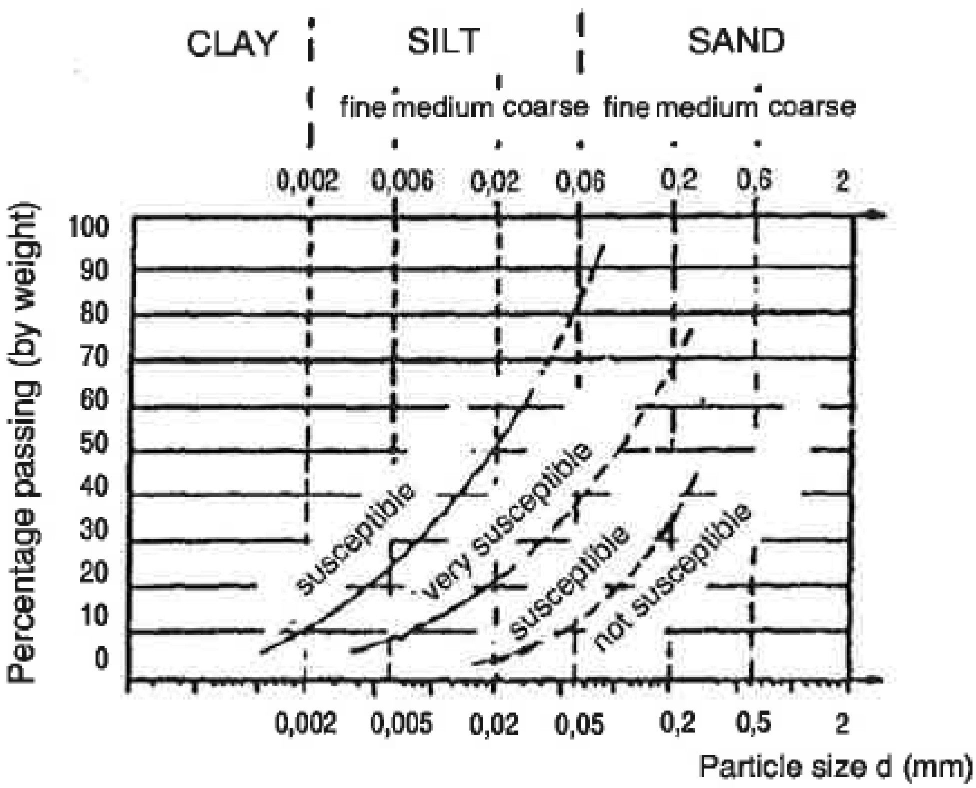
Criteria developed for roads shall not be used unless appropriately adapted.

The degree of frost susceptibility can be estimated by the capillarity of the soil layer. If the capillary rise of water is > 0.7m (23 in), the soil layer can be considered frost susceptible. In track bed layers the capillary rise of water shall be < 0.3m (12 in).

The degree of frost susceptibility can also be estimated through the use of Figure 12. For this purpose, the particle size distribution analysis shall be carried out on that fraction of the test sample which passes through a 2 mm sieve.

The frost susceptibility criteria of soils are not applicable to organic soils.

Figure 12 – Frost Susceptibility of Soils (Estimated on the basis of sieve analysis of fraction passing 2 mm)



3.4 EARTHWORKS AND TRACK BEDS

3.4.1 Suitability of Soils for Re-use

Generally speaking, the project (plan, longitudinal profile) is designed to make maximum use of materials from the site, and to minimize the need for material from temporary or existing quarries and deposits outside the right-of-way while in taking into account the constraints imposed by the environment of the project. The objective for the design of the earth movement is to minimize transport distances. Material which will not be of sufficient quality may be used for landscaping and earth berms at locations where they will not impact the high-speed line operation in case of slope failure or weathering.

3.4.1.1 Body of the Embankments

Generally, the suitability of a soil for re-use can be determined as follows:

1. Soils which cannot be re-used include soils 0.1 to 0.6, 1.1 (if the soil has medium or high plasticity) and 1.2;
2. Soils which can be re-used in certain conditions subject to moisture content, climatic conditions, height of embankment, layer of low quality fill protected by a layer of higher quality material (sandwich construction) soils: 1.1 (if the soil has a low plasticity), 1.3 to 1.5, 2.1 and 2.2;
3. Soils which can always be re-used: 2.3, 3.1 and 3.2.

The upper limit of particle size in any fill is governed by the need to be able to spread and compact it effectively, and is therefore related to the depth of the layer. Normally particles shall not be more than 6 inches (150 mm) diameter; it is also recommended that the maximum particle size is less than half of the thickness of the layer. The maximum particle size of fill used to backfill structures must be less than 4 inches (100 mm). In this case fill shall be laid in thin layers and a small compactor shall be used so as not to disturb the structure. The fill used in the vicinity of masonry of over bridges must not be susceptible to settlement (i.e., soil of quality class SQ3).

For materials with potential evolution over the time by densification (possible collapsing ground, evoluting rocky materials, etc.), specific requirements for implementation shall be defined. In the case of chalk, the requirements shall take into account the possibility of densification, the possibility of moisture contents evolution, and the possibility of crushing under vibration.

The lowest layer of embankments resting on damp ground must be selected from quality class SQ 3 (drainage material). The drainage qualities can be improved by using geotextiles.

3.4.1.2 Prepared Subgrade (Embankment and Cuts)

The categories of materials given in Section 3.4.1.1 are also applicable to the prepared subgrade. However the size of the largest particle shall be either half of the layer thickness or 6 inches (150 mm), whichever is smaller (maximum of 4 inches (100 mm) in the vicinity of structures).

3.4.2 Design and Construction of Earthworks

3.4.2.1 Stability Analysis of Earthworks

3.4.2.1.1 Methods of Analysis

Stability: Resistance to slope failure, both in the short and long term, must be demonstrated by calculations based on the geotechnical and hydrogeological properties of the ground.

Settlement: Settlement predictions shall show not only how fast construction should proceed but also demonstrate that any settlements, which occur after the line is opened, can be rectified by routine track maintenance; if not, one of the alternatives given in Section 3.4.2.1.3 shall be considered.

3.4.2.1.2 Slope Angles

The slopes shall be designed in order to insure their stability and reliability and according to:

- The geotechnical characteristics of the cut grounds in cut, or of the support ground and filled material in embankment.
- The height of the earth structure.
- The particular condition of the site, i.e., the topography, hydrogeology, and natural risks such as seismic factors, possibility of void in the ground, ground sliding, etc.

Considering these points, it appears that the following general configurations are the most used:

Embankments: For soils which are acceptable according to Section 3.4.1.1, a slope of 1.5H:1V or 2H: 1V is normally adopted (some railways adopt 1H:1V or 1.25H:1V in the case of coarse rock fill, also benches or toe walls, etc., may be required). For slopes supported by compressible soft foundation soils (i.e., undrained shear strength between 100 psf and 300 psf), the slope angle will be determined by slope stability analyses.

For 15 % Design level it is proposed to use 2H: 1V slopes. Steeper slope angles may be feasible if justified by stability analyses carried out in subsequent design phases.

Cuts: Slope angles vary according to the type of ground, e.g.:

1. Intact rock not susceptible to weathering and without unfavorable dip or cleavage: a slope of between 45 deg and 90 deg but with a stone trap at the base and benches having a width of about 1/3 of the height of each step produced.
2. Weathered rock subject to degradation and deterioration: Specific considerations to be taken for rock slopes according to the level of geotechnical knowledge and experience on the specified area, substantiated by geological mapping and evaluation of the rock slope stability. Where necessary, surface protection is to be installed to mitigate long term instability.
3. Granular soils: slope of 1.5H:1V to 2H:1V according to the height of the cut.
4. Cohesive soils: slopes typically in the range 1.5H:1V to 2H:1V according to the height of the cut, or even flatter, with benches if required.
5. Pre-historic landslide areas: slope angles to be determined by an extensive evaluation of subsurface conditions and slope stability analyses.

For the 15 % Design level it is proposed to use 2H:1V slopes for soil cuts and 1H:1V for rock cuts. Steeper slope cuts may be feasible if substantiated by slope stability analyses and geologic and geotechnical investigations in the subsequent design levels..

3.4.2.1.3 Sensitive Soils or Unfavorable Hydrogeological Conditions

Some specific technical requirements have to be considered to protect and stabilize sensitive soils and for use where hydrogeological conditions are unfavorable.

Embankments:

1. Replacement of the sensitive soil (this method is the most reliable and shall be used when the depth of soil to be removed is not excessive).
2. Pre-loading for consolidation of the soil underlying the embankment or temporary surcharge of the embankment.
3. Installation of vertical drains or piles.

Where a soil susceptible to water or frost is used to form the body of an embankment it shall be protected by a covering of better quality soil.

In areas susceptible to flooding, the sides of an embankment must be protected with a layer of rock fill or stones with an intermediate granular layer if required.

Cuts:

In ground which is sensitive to frost or water, cut slopes shall be protected by a coarse granular layer. The water can be eliminated by appropriate methods (toe drains, counterfort drains, ditches, filter layers, etc.). Other methods may also be used (surfacing of embankment, nailing, cantilevered or anchored retaining walls, etc.).

In elevated altitude area where freezing conditions are frequent, a frost protection layer has to be included on all slopes in cohesive soil.

3.4.2.2 Construction of Embankment and Prepared Subgrade

Performance of the embankment depends to large extent on the quality of compaction performed during construction. It is essential to ensure proper compaction and precautions/guidelines for this are given as follows:

The compaction method is designed either with the aid of compaction trials, or by using the recommendations established for this purpose in some technical requirements. For example, the technical guide for realization of fill and prepared subgrade from Caltrans and AREMA gives, for each type of soil compactor and moisture content, the thickness of the individual layers to be provided and the compactive effort required. Special arrangements can also be recommended (watering; drainage). This document is recommended and widely used for high-speed line design and construction.

The degree of compaction and minimum deformation moduli, which are specified for each layer, are generally as follows:

Embankment fills:

ρ_d ≥ 90% of the maximum dry density as determined from ASTM D1557-07 where embankment construction exceeds 5 feet in depth. Provide 95% relative compaction as determined by ASTM D1557-07 for the top 5 feet,

EV2 d ≥ 45 MN/m^2 (6.525 ksi) for fine soils, or 60 MN/m^2 (8.7 ksi) for sandy and gravelly soils.

Prepared Subgrade:

ρ_d ≥ 95% of the maximum dry density as determined from ASTM D1557-07,

EV2 d ≥ 80 MN/m^2 (11.6 ksi)

3.4.2.3 Transition between Earthworks and Under Bridges

On the transition between earthworks and structures (e.g. overbridges), suitable measures shall be taken both to reduce differential settlement and to ensure that there is a gradual transition of support stiffness.

Specific guidance will be developed at later stage for the CHSTP.

3.4.2.4 Retaining Walls and Drainage

Where standard roadbed and ballast section back-slopes and/or fore-slopes intersect existing ground lines beyond the existing right-of-way (ROW), retaining walls shall be designed and constructed within the property with diversion ditches or drains provided behind the retaining wall to divert runoff from adjacent properties toward stabilized drainage outfall structures. Where applicable, profiles may be adjusted to minimize earthwork and reduce or eliminate the need for retaining walls.

In order to minimize ROW and excavation requirements, underdrains rather than ditches shall be employed where necessary for drainage. Longitudinal drainage shall be constructed under the high speed rail shoulder. Drainage shall be designed to convey flow from the guideway and adjacent roadway, where the roadway slopes toward the median.

3.4.2.5 Specific Consideration for Maintenance According to the Structure Height

Beyond the stability requirements, and in order to facilitate later maintenance, it is necessary to plan for benches slopes. For cuts with depth greater than 40 feet, it is recommended to plan a 6 feet wide bench with a 6% gradient towards the high-speed line. These benches shall be laid out on average every 30 feet in height (an allowance from 26 to 32 ft can be considered). The bench shall be connected to the natural ground at each end of the cut. If a drainage trench is to be installed on the bench, a road access shall be available on both sides of the cut or on one side but with an area on the other side for vehicle turn.

Similarly, for embankment over 40 feet in height, it is recommended to plan a 6-feet-wide bench with a 6% gradient toward the toe of the slope; laid out in average every 30 feet in height (an allowance from 26 to 32 feet can be considered). These shall also be connected to the natural ground for access.

3.4.3 Composition and Thickness of the Track Bed Layers

3.4.3.1 Typical Track Bed Construction

For construction of a new line it is important to ensure that the track bed layers have the appropriate mechanical characteristics and are of adequate thickness.

Typical track bed structures for various grades of bearing capacity are determined by the possible combinations of the support soil qualities and characteristics of the prepared subgrade, as indicated in Figure 9.

Blanket is a layer of coarse grained material between ballast and subgrade, spread over entire width. The important roles of the blanket layer are:

1. Improving the bearing capacity by modifying the stiffness and achieving a better distribution of transmitted loads on the subgrade soils, thus preventing ballast penetration into the formation.
2. Reduction of induced stresses on the top of subgrade to a tolerable level.
3. To prevent mud pumping and fouling of ballast by upward migration of fine particles from the subgrade.
4. To prevent damage of subgrade by ballast.
5. Shedding surface water from the ballast and drain away from the subgrade.
6. Protection of subgrade against erosion and climatic variations.

The blanket layer, in its most complete form consists of:

1. A sandy gravel sub-ballast layer, the characteristics of which are defined in Section 3.4.5. This layer is present in almost all cases. Certain railways specify it even on rocky subgrade where it serves as a compensation layer and helps to reduce the support stiffness.
2. A "foundation" layer (referred to as prepared subgrade in this document) of well graded sandy gravel, having a grading designed to give good filtering characteristics and allowing construction traffic to run over the area. It is not required on soils of quality class QS3.
3. A filtering layer of sand to be used only with a subgrade of bearing capacity class P1.
4. A geotextile filter used with prepared subgrade P1 and P2, which improves the filtering characteristics of the track bed layers; the geotextile also facilitates construction of the track bed layers without causing rutting of the prepared subgrade in soils QS1or QS2.

3.4.3.2 Determination of the Thickness of the Track Bed Layers

The dimensioning of track bed layers must take into account both the:

- Desirable bearing capacity (defined in this Section);
- Problems of frost protection (defined in Section 3.4.4).

The total thickness (ballast layer + sub-ballast layer) varies according to the:

1. Bearing capacity of the subgrade. It is noted here that the deformation modulus of the layer supporting the sub-ballast layer (top of prepared subgrade) shall be 17.4 ksi.
2. Level of frost protection required.
3. Type of sleeper and the sleeper spacing
4. Traffic characteristics (tonnage supported, axle-load and speed)

Due to the uniform type of train projected to run on the California high-speed train line, the ballast thickness is constant. The dimensions of the track bed layers for the sub-ballast layer and the eventual prepared subgrade are also constant.

The criteria and the optimization of the thickness of the layer will be developed at a later stage.

For 15% design, it is proposed to use an 8 inch thick sub-ballast layer and a 20 inch thick prepared subgrade.

This type of track bed layer is the most general structure used on French high-speed lines and conforms to frost protection and traffic characteristics.

The criteria and the optimization of the thickness of these layers will be developed at a later design stage.

3.4.4 Protection against Frost

To follow

3.4.5 Mechanical Properties of Materials used for Track Bed Layers

This information is not required at the 15% Design level.

3.4.6 Control of Compaction

This information is not required at the 15% Design level.

3.4.7 Drainage of Subgrade

The quality of the drainage and its good functioning for the life of the earth structure is a major factor in the reliability of the track formation. Due to the design life of the high-speed train earthworks (100 years) and the fact that no important investment is planned during this period, the culvert and pipes crossing the high-speed earthworks shall be designed accordingly.

The drainage system shall allow drainage of the surface and subsurface water.

Every cut sections shall be equipped with a drainage functioning only under gravity. An interception ditch may be necessary at the top of the slope according to the catchment area characteristics.

No water coming from outside the cut shall be allowed to run across the cut before it is discharged.

Temporary drainage shall be implemented during construction to avoid flooding of the structure and runoff of spoiled water outside of the work site.

The requirements concerning drainage and hydrology will be presented in a separate technical memorandum.

3.4.8 Special Construction Materials and Procedures

This information is not required at the 15% Design level.

3.5 CONSIDERING CONSTRAINTS FOR PARTICULAR SITES

3.5.1 Soft Support Ground

This information is not required at the 15% Design level.

3.5.2 Reshaped Support Ground

This information is not required at the 15% Design level.

3.5.3 Inflating Support Ground

This information is not required at the 15% Design level.

3.5.4 Crossing of Landfill

This information is not required at the 15% Design level.

3.5.5 Loose Slopes Potentially Unsteady

This information is not required at the 15% Design level.

3.5.6 Rocks Slope Areas

This information is not required at the 15% Design level.

3.5.7 Prehistoric Landslide Areas

This information is not required at the 15% Design level.

3.5.8 Ground with Potential Voids and Subsidence

This information is not required at the 15% Design level.

3.5.9 Seismic Areas

This information is not required at the 15% Design level.

4.0 SUMMARY AND RECOMMENDATIONS

Recommended methodologies for use in advancing the design of Earthwork for the 15% Design level are presented in Section 6.0.

5.0 SOURCE INFORMATION AND REFERENCES

1. Manual for Railway Engineering of the American Railway Engineering and Maintenance of Way Association (AREMA Manual)
2. Certain publications of the UIC: (International Union of Railways) (Acronym is from the French original, Union Internationale des Chemins de Fer)
   - UIC Code 719 R - Earthworks and Track-bed Layers for Railway Lines
3. The European Union's Directive, Interoperability of the Trans-European High Speed Rail System, Technical Specification for Interoperability (TSI), Infrastructure Sub-System
4. Technical Requirement for Earthworks on High Speed Line from SNCF (French National Railway)
5. California Department of Transportation (Caltrans) Design Manuals
6. California Department of Transportation (Caltrans) Standard Specifications
7. U.S. Army Corp of Engineers Technical and Design Guides
8. SETRA - LCPC: Recommandations du Service d'Etudes Techniques des Routes et Autoroutes et du Laboratoire Central des Ponts et Chaussées
9. Ladd, C. C., 1991. "Stability Evaluation During Staged Construction," 22nd Terzaghi Lecture, Journal of the Geotechnical Engineering Division, ASCE, Vol. 117, No. 4, April, pp. 540-615.
10. Bjerrum, L., 1972. "Embankments on Soft Ground," Proceedings, Specialty Conference on Performance of Earth and Earth-Supported Structures, Purdue University, Lafayette, Indiana, ASCE, June 11-14.

6.0 DESIGN MANUAL CRITERIA

6.1 EARTHWORK AND TRACK BED DESIGN

Earthwork evaluation come into play as early as the 15% Design level and environmental assessment since raising or lowering the vertical alignment can significantly influence the impact of the project on the landscape. It can also result in the development of strategies for acquiring rights-of-way depending on the potential needs of material borrowing or surplus disposal, as well as consideration of wetlands mitigation, endangered species, and other environmental concerns impacted by the construction of the high-speed train alignment.

These aspects are taken into account in the early phases of the project, not only to clarify and validate them for later phases, but also to provide guidelines for the testing and geotechnical laboratory standards needed for decision making. The option of iterative analysis of longitudinal profile according to the geological and geotechnical site should be included so that the optimum compromise for the project can be determined.

The design of earthworks must also include the search for sites close to the alignment that are geologically favorable for extraction of potentially useful materials for the project. The options in terms of earth moving strategy can have a very significant impact on project planning. New quarries, when required, typically impose unavoidable delays due to requirements for permitting and performing impact studies. The use of supplies from existing quarries should be planned in advance and often require storage buffers in order to avoid exceeding the production capacity of the quarries. Such planning also helps mitigate materials price escalation and in ensuring the ability to supply the site without reloading and without planning constraints for the civil worksite.

These elements demonstrate that a materials strategy is a key phase of the project and requires studies and planning at the earliest phases of the project.

6.1.1 Definition of Terms

The following technical terms and acronyms used in this document have specific connotations with regard to the California High-Speed Train system.

Ballast: Crushed rock layer on which the track is laid. The ballast forms part of the superstructure. For this reason, problems relating to the ballast layer and ballast materials are referred to here only so far as they affect the quality of the earthworks and track bed layers.

Backslope: In cut sections, the resultant excavation face located between outer shoulder line and natural ground line.

Blanket: Blanket is a layer of coarse grained material between ballast and subgrade, spread over entire width. It may be required over the formation where the subgrade soil is of poor quality, rainfall is heavy, and traffic density is high, as the absence of blanket in such cases can lead to problems in service.

Cohesive Subgrade: Subgrade constructed with soils having cohesive behavior, i.e., shear strength is predominantly derived from cohesion of the soil is termed as cohesive subgrade. All fine grained soils and GM, GM-GC, GC, SM, SM-SC and SC types of soils exhibit cohesive behavior.

Cohesionless Subgrade: Subgrade constructed with cohesionless, coarse-grained soils, i.e., shear strength is predominantly derived from internal friction of the soil and is termed as cohesionless subgrade. GW, GP, SW & SP types of soils fall in this category.

Cut and Fill: Construction techniques involving excavation or grading followed by placement and compaction of fill material.

Earthwork: A general term applying to cuts, embankments and composite cross sections as well as their environmental mitigations.

Embankment or Fill:	Artificial mound of imported material generally made of selected earth, gravel, or stone; built to support the HST when the reference line of the longitudinal profile is above the natural ground.
Foreslope:	In fill sections, the resultant slope of the fill that allows to safely support track and road subgrade and that places the subgrade at safe height above the maximum water and flooding level.
Formation:	It is a general term referring to the whole of blanket, subgrade, and subsoil.
Formation Top:	Boundary between ballast and top of blanket or subgrade (where blanket layer is not provided).
Geosynthetics:	Structural elements made of synthetic materials for use in earthworks and track bed layers construction. A distinction is made between: • Geotextiles: Geosynthetics (woven or non-woven), which may be used for separation, filtering, drainage and reinforcement. • Geomembranes: Geosynthetics (synthetic or bituminous layer) impermeable to water, which may be used for protection of sensitive subgrade against penetration of surface water or for protecting ground water against pollution. • Geogrids: Fine or coarse mesh geosynthetics, which may be used for separation and reinforcement. • Geocomposite: Compound structure made of at least two layers of geosynthetic materials.
Grade, Gradient:	The slope of changes in elevation, defined in percentage, as a foot of rise in 100 feet. Sometimes defined in European publications as millimeters of rise in one meter, in which case it is written as $^{o}/_{oo}$.
Interceptor ditches:	Above a cut slope, these carry runoff from the watershed served and prevent surface runoff from entering the cut.
Lineside Drains:	Line side drains collect and discharge surface water, seepage water and ground water into a controlled outlet. Generally a distinction is made between buried drains, open channels and side ditches.
Prepared Subgrade:	The upper part of the subgrade is formed into a prepared subgrade layer, which normally has a cross slope. This layer is made of imported or treated material depending of the quality of the upper part of embankment or the bottom of the cut. Its quality and compactness shall be better than the material below. Its function is to minimize the deformation of the upper part of the embankment or the bottom of the cut and to prevent water that has passed through the sub-ballast layer from penetrating to the earthworks below.
Subgrade:	The subgrade is the top of the earthworks on which the sub-ballast layer rests. On an embankment, the subgrade will be formed of imported soil, whereas in a cut, it will be the naturally occurring soil.
Subballast Layer:	The sub-ballast is an intermediate layer situated between the ballast and the subgrade layers. It protects the top of the embankment against erosion, ensures a better distribution of loads, and provides a leveled surface suitable for track laying. Sub-ballast is made up of full crushed graduate gravel. This layer is also referred to as the Blanket Layer in the UIC standards.
Subsoil:	Soil of natural ground below subgrade.
Slope Value:	Slopes are defined as a fraction indicating the number of units of length required to achieve 1 unit of vertical distance, i.e., 2H:1V means the slope raises 1 unit vertically for 2 units of horizontal length.

Track Bed Layers: General term that includes all of the new material imported for the foundation of the track. It includes the ballast and sub-ballast, the following elements when present:

- Sub-ballast layer
- Prepared subgrade
- Geosynthetics

Track Formation: Total width of the track bed layers as shown in Figure 1-1.

Track Formation Level: Surface intended to receive the track bed layers.

Track Foundation: Constitutes ballast, blanket, and subgrade which is placed/exists below track structure to transmit load to subsoil.

Unstable Formation: It is yielding formation with non-terminating settlement including slope failure, which requires excessive maintenance efforts.

Upper Part of Embankment: Top three feet of an embankment. It requires high quality design and construction in order to ensure the appropriate bearing-capacity to receive track bed layers.

Wayside Drainage: Drainage system (buried drains, ditches, precast channel drains) laid to collect and discharge surface water, seepage water, and ground water.

6.1.2 Terminology and Symbols

Earthwork and track formation terms for general, ballastless (slab) and ballasted track structures are illustrated in Figures 6-1 to 6-3.

Figure 6-1 – General Earthwork Terms

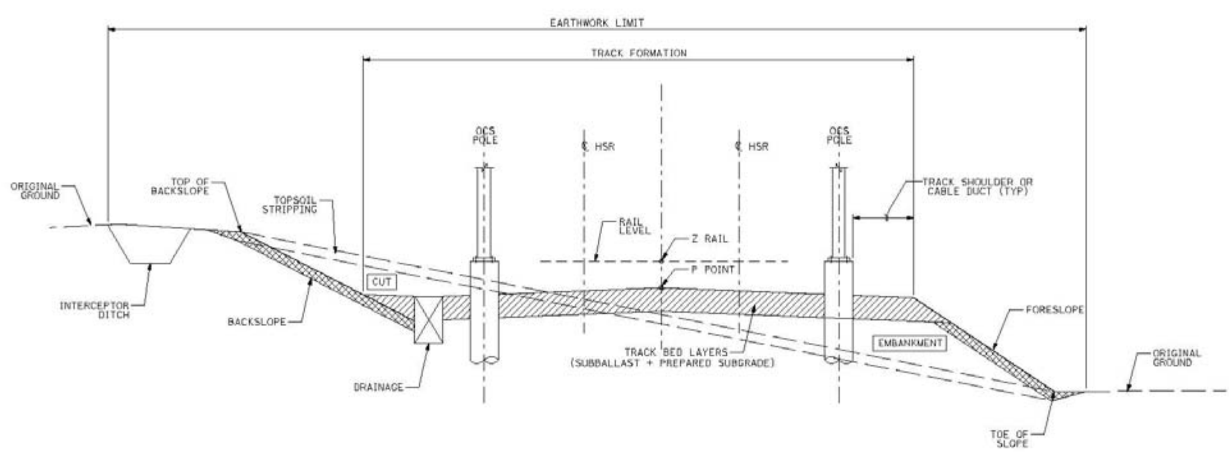


Figure 6-2 – Ballastless Track Formation

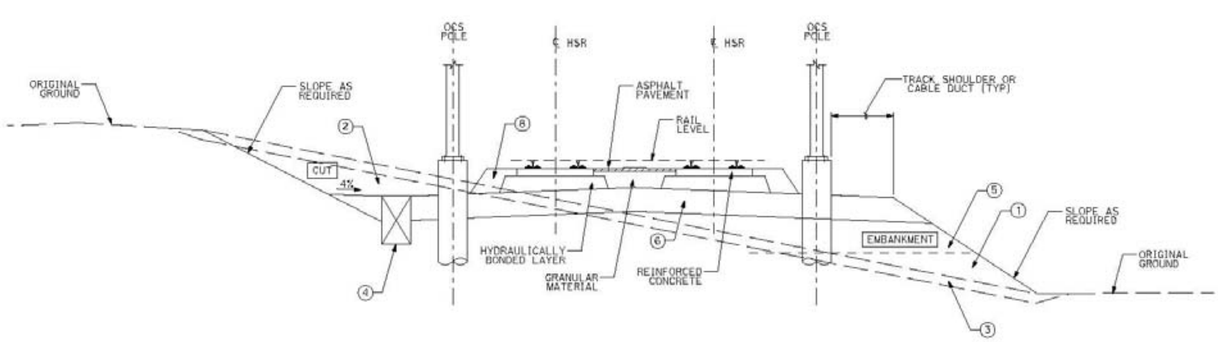
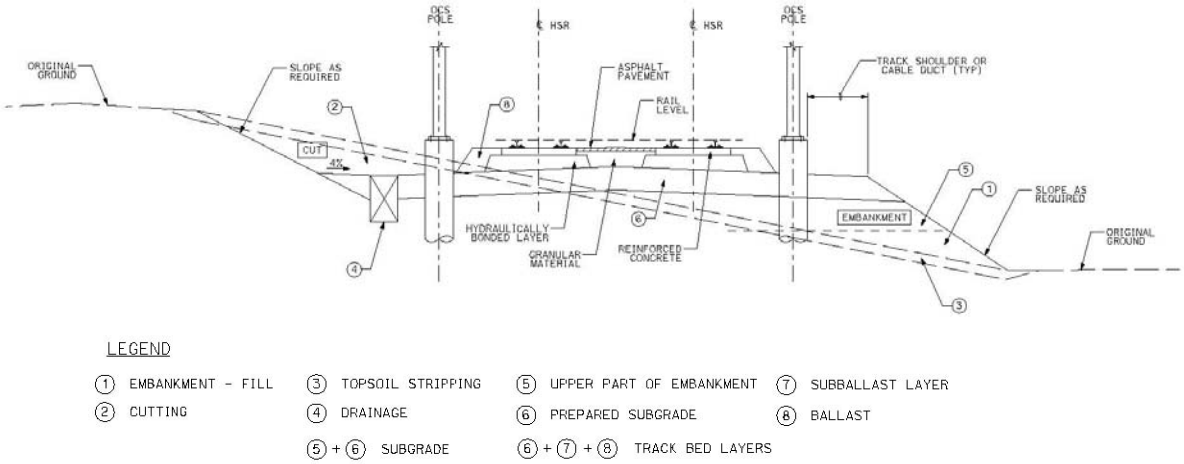


Figure 6-3 – Ballasted Track Formation



The ASTM and International Society for Soil Mechanics and Geotechnical Engineering (I.S.S.M.F.E.) recommend the use of the geotechnical terms, definitions and units presented in Table 6-1.

Table 6-1: International Geotechnical Symbols, Terms, Definitions and Units

Symbol	Term	Definition	Unit [(1)]	Comments
I_C(CI)	Consistency Index	Defined by (W_L –w)I_P	1	
I_L(LI)	Liquidity Index	Defined by (w – m_P) / I_P	1	
I_P(PI)	Plasticity Index	Difference between liquid and plastic limits	-	
W	Moisture Content	Weight of interstitial water divided by weight of solid particles	-	
W_L(LL)	Liquid Limit	Moisture content of a remoulded soil at the transitional point between liquid and plastic states	-	
W_P(PL)	Plastic Limit	Moisture content of a remoulded soil at the transitional point between the plastic and solid states with shrinkage	-	
γ	Bulk unit weight	Total weight of the soil divided by its volume	pcf	
γd	Dry unit weight	Weight of solid particles in the soil divided by its volume	pcf	
γS	Particle unit weight	Weight of solid particles divided by their volume	pcf	
S_R	Degree of saturation	Volume of interstitial water divided by the total volume of voids	1%	
D, d	Particle size	Size of particle as determined by sieve analysis or sedimentation	n	ASTM D6913 ASTM D653
D_n, d_n	N- percentile particle size	Size at which n% (by weight) of the sample consist of smaller particles	n	ASTM D6913 ASTM D653

Table 6-1: International Geotechnical Symbols, Terms, Definitions and Units (*Continued)*

Symbol	Term	Definition	Unit [(1)]	Comments
C_U	Uniformity Coefficient	Defined by: D_{60} / D_{10} ; d_{60} / d_{10}	1	
C_C	Coefficient of curvature	Defined by $(D_{30})^2 / (D_{60} \times D_{10})$ or $(d_{30})^2 / (d_{60} \times d_{10})$	1	DIN 18196 SN 670120 ASTM D2487 Some railways use symbol C
K	Coefficient of permeability (or hydraulic conductivity)	Rate of flow of water through a unit area of soil when under a unit hydraulic gradient (v / i)	cm/s	
τ_f	Shear strength	Shear strength at failure in the shear plane (at given point)	psf	
K_S	Reaction Modulus	Change in vertical stress divided by the corresponding displacement for a given load increment on a rigid plate	psf/ft	

(1) Conventions adopted for the imperial units: ft, s, lb, psf, cm/s
1: for dimensionless values expressed as a real number (e.g. Sr = 0.93)
% for the same values, which can also be expressed as % (e.g. Sr = 93%)
-: for values which are defined as % (e.g. W_L=45).

Table 6-2: Symbols, Terms and Definitions used Internationally but not yet Standardized

Symbol	Term	Definition	Comments
	Fines	Portion of a soil finer than a No. 200 (75 µm) U.S. standard sieve	ASTM D653
	Particle Shape	Defined by thickness, width and length of each particle	BS 82 BS 5930 CNR B.U.n.95 NF P 18 561
	Hardness of Stone	Resistance to impact and attrition	May be determined by the: • Los Angeles Test ASTM C 535-89 CNR B.U.n. 34 NF P 18 573 • Deval Test NF P 18 577 • Microdeval test CNR B.U.n. 109 NF P 18 572 • Other hardness tests: - BR Ballast specification - DIN 52 115

Table 6-2: Symbols, Terms and Definitions used Internationally but not yet Standardized *(Continued)*

Symbol	Term	Definition	Comments
CBR	California Bearing Ratio	Empirical value of a bearing load expressed as a percentage of a reference bearing load	ASTM D 1883-67 BS 1377: 1975 CNR-UNI n. 10009/1964 NF P 94 078-1 NF P 94 078-2
γd (ρPr)	PROCTOR density	The maximum dry density and water content under standardized conditions of compaction	PROCTOR Standard: AASHTO T 99 ASTM D 698 BS 1377:1975 DIN 18 127 NF P 94 093 SN 670330 PROCTOR Modified: AASHTO T 180 ASTM D 1557 BS 1377:1975 DIN 18 127 NF P 94 093 SN 670330
RD	Degree of Compaction	in Percentage	ASTM D1557
E_{V2}	Modulus of deformation obtained on 2nd loading in the plate bearing test	$E_{V2} = \frac{1.5\, r\, \Delta\sigma}{\Delta s}$ (ksi) With: r: plate radius (in) $\Delta\sigma$: increment of pressure under plate (ksi) Δs: Increment of settlement of plate (in)	DIN 18 134 NF P 94 117.1
Vb	Blue Value	Weight of Methylene blue absorbed by 3.53 oz of fines	NF P 18 592
Vbs	Blue Value of soil 0/D	Weight of Methylene blue absorbed by 3.53 oz of soil 0/D = Vb x f (f = percentage of fines contained in 0/50 soil fraction)	

6.2 STABILITY CALCULATION AND FACTOR OF SAFETY

The proposed geometry is justified by the slope stability analysis used in soil mechanics. The method of calculation shall be adapted to the considered failure type.

1. Bishop method for circular failure
2. Disruption method for non circular failure.

The stability calculations apply the principles described in the following paragraphs. These are intended to guide the qualified practitioner in selecting the values of the geotechnical parameters to be taken into account and to verify the qualification of calculation coefficient and codes.

6.2.1 Requirements Concerning Geotechnical Parameters

Calculations of stability shall be carried out using average values of conservative geotechnical parameters applied to homogeneous areas (strength and density of soil, rocks and embankment). Further, the definition of these parameters and homogeneous areas shall be justified. The values of these parameters shall be derived from the soil investigation on the project and information learned from experience. The choice of parameter values shall take into account all available knowledge of geological and geotechnical data, the representative the sampling and testing, and the significance of the tests conducted on samples (taking into account its possible remoulding). The following standards shall be followed:

6.2.2 Factor of Safety

A factor of safety of 1.5 shall normally be adopted against slope failure. For high risk category slopes (i.e., slopes supporting buildings, infrastructures, bridges, and amenities), a minimum safety factor of 1.6 shall be achieved.

A. Embankments on Soft Ground and Clay

At the completion of construction 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. Minimum factor of safety specified above can be further decreased only in specific cases of instrumented pilot embankments where the factor of safety is monitored during construction. However, in either case, a minimum factor of safety of 1.5 must be ensured for the long term stability.

Before the stability calculations, the values of undrained shear strength determined by field vane shear tests shall be corrected for the effects of anisotropy and strain rate using Bjerrum's correction factor, μ, which depends on the Plasticity Index (PI) of the clay (Bjerrum, 1972).

As it is not usual to calculate the long-term stability of embankments on soft ground, the evaluation of the effective cohesion is not necessary. The undrained shear strength recorded for over consolidated soil crust that often forms the surface soil is half the undrained shear strength measured with work site rotating auger. It is, however, retained as zero cohesion for fill material (this practice is justified by the risk of cracking of coherent fill materials that makes the material lose the advantage of such cohesion for the stability of the embankment).

In case of construction in stages, the increase of the undrained shear strength Su of the foundation soils due to induced embankment loading shall be considered. There is a unique relationship between the in situ undrained shear strength ratio (Su/σ'_{vc}) and the overconsolidation ratio ($OCR = \sigma'_p/\sigma'_{vc}$) of cohesive soils. For the 15% design level, $Su/\sigma'_{vc} = Su(OCR)^m$ can be used with values of Su and m obtained from the following (Ladd, 1991).

For homogeneous sedimentary clays plotting above Casagrande's A line, Su = 0.22± 0.03.

For silts and organic clays plotting below A line, Su = 0.25 ± 0.05. and m = 0.88 (1-Cs)/Cc where Cs and Cc are equal to the slope of the swelling and virgin compression lines, respectively.

B. Natural Slope and Backslope in Cut

Stability of Slopes in Natural Soils

The stability of backslopes in natural soils is generally more critical in drained conditions (long term), so that the calculations are carried out in effective stresses with a pair of parameters (c' and φ'). For new earth structures with steady slopes, it is justified to choose a safety factor of 1.5, because the uncertainty on the parameters of the field is “similar to soft ground conditions.

Stability of Backslope in Rock

Rocks shall not reach the railway track and shall not engage the railway dynamic gauge. Two types of risk to be prevented are:

- The risk of instability of rock masses whose probability of occurrence is difficult to determine. The security is the first element to consider with a comprehensive diagnosis of the mechanisms likely to be involved and an evaluation of the unstable masses.
- The risk of falling rocks that can reach a vulnerable area. This risk is evaluated using structural studies and eventually by trajectory design. .

When the rock in question is subject to rock weathering, it shall be ensured that this alteration does not create a risk of instability within the design life of the high-speed rail line.

In some cases where the rock is altered or likely to deteriorate into loose soil, it may be necessary to evaluate and appraise the stability by conducting a geologic mapping and rock slope stability analyses where the failures are primarily governed by structural discontinuities (bedding planes, joint sets, clay gouges and seams, faults, etc.). This shall be coupled with a complementary study where the failures occur throughout the areas of highly weathered/degraded rock and unstable soils whose mechanical properties are insufficient to withstand gravity. Both types of failure are possible in the same slope and shall therefore be studied.

C. Foreslopes for Embankment

For fill materials without cohesion, the foreslopes of embankment if dry are considered as stable when the angle of internal friction φ' of reworked material is greater than the angle adopted for the slope (i.e., the angle of repose is greater than the angle of the slope).

For fill materials with cohesion (natural soil or soil treated with binders), the slope is determined by local experience or through specific studies in which a safety factor of 1.5 is used for all mechanisms of failure that may affect the track and its facilities. The evaluation of the stability of the slope surface ("surficial stability") will not be based on a safety factor of 1.5, but will be based on the anticipation of a satisfactory drainage, slopes protection and their vegetation to protect against erosion.

Moving train loads may overstress soil mass and would therefore adversely affect the slope stability. Hence, a minimum factor of safety of 1.6 shall be ensured for slope stability of smaller embankments of height up to 12 feet.

In any case, the foreslope of embankment will not exceed 2H:1V.

6.3 EARTHWORKS AND TRACK BEDS

6.3.1 Suitability of Soils for Re-use

Generally speaking, the project (plan, longitudinal profile) is designed to make maximum use of materials from the site, and to minimize the need for material from temporary or existing quarries and deposits outside the right-of-way while in taking into account the constraints imposed by the environment of the project. The objective for the design of the earth movement is to minimize transport distances. Material which will not be of sufficient quality may be used for landscaping and earth berms at locations where they will not impact the high-speed line operation in case of slope failure or weathering.

6.3.2 Body of the Embankments

Generally, the suitability of a soil for re-use can be determined as follows:

1. Soils which cannot be re-used include soils 0.1 to 0.6, 1.1 (if the soil has medium or high plasticity) and 1.2;
2. Soils which can be re-used in certain conditions subject to moisture content, climatic conditions, height of embankment, layer of low quality fill protected by a layer of higher quality material (sandwich construction) soils: 1.1 (if the soil has a low plasticity), 1.3 to 1.5, 2.1 and 2.2;
3. Soils that can always be re-used: 2.3, 3.1 and 3.2.

The soil quality depends on the following factors:

1. The geotechnical properties of the soil;
2. The local hydrogeological and hydrological conditions; these conditions, in as far as they affect the bearing capacity of the soil, can be considered good if:
   - The uppermost layer of soil is above the level at which it maybe adversely affected by the highest natural ground water level (this level shall be assessed assuming unfavorable weather conditions and no drainage),
   - There is no harmful natural transverse, longitudinal or vertical water flow in the subgrade,
   - Rainwater is correctly drained from the subgrade, and the longitudinal or transverse drainage system is in proper working order.

If any of one of these criteria is not satisfied, the hydrogeological and hydrological conditions must be considered to be poor.

On the basis of the above information it is possible, by referring to Figure 9, to assign a quality class to any given soil using the following 4 SQ quality classes for soils:

SQ 0: “Unsuitable" soils which do not form a suitable subgrade and therefore require improvement (replacement to a certain depth with better quality soil, stabilization with binding agents, use of geotextiles, reinforcement with piles, etc.). For this reason, these soils are not considered when dimensioning the track bed layers.

SQ 1: “Poor" soils which are acceptable in their natural condition subject to adequate drainage being provided and proper maintenance. These soils could be considered for upgrading by means of the appropriate treatment (e.g., stabilization binding agents).

SQ 2: “Average" soils

SQ 3: "Good" soils

Soil quality classes are defined in Figure 6-4.

Figure 6-4 – Soil Quality Classes

Soil Type (Geotechnical Classification)	Soil Quality Class
0.1 Organic soils (OH and OL) 0.2 Soft soils containing more than 15% fines (1), with a high moisture content therefore unsuitable for compaction. 0.3 Thixotropic soils (2) (e.g. quick-clay) 0.4 Soils containing soluble material (e.g. rock salt or gypsum) 0.5 Contaminated ground (e.g. industrial waste) 0.6 Mixed material / organic soils (2)	**SQ 0**
1.1 Soils containing more than 40% of fines (1) (except for soils classified under 0.2) 1.2 Rocks which are very susceptible to weathering, e.g.: - Chalk with ρ_d < 106 pcf and high friability - Marl - Weathered shale	**SQ 1**
1.3 Soils containing 15 to 40% of fines (1) (except for soils classified under 0.2) 1.4 Rocks which are moderately susceptible to weathering, e.g.: - Chalk with ρ_d < 106 pcf and low friability - unweathered shale 1.5 Soft Rocks, e.g. Microdeval wet (MDE) > 40 and 1.6 Los Angeles (LA) > 40	**SQ 1** (3)
2.1 Soils containing from 5 to 15% of fines (1) 2.2 Uniform soil containing less than 5% of fines (1) (CU ≤ 6) 2.3 Moderately hard rock, e.g. if 25 < MDE ≤ 40 and 30 < LA < 40	**SQ 2** (4)
3.1 Well graded soils containing less than 5% of fines (1) 3.2 Hard rock, e.g.: if MDE ≤ 25 and LA ≤ 30	**SQ 3**

1. These percentages are calculated from particle size distribution analysis undertaken on material passing through a 60 mm sieve. The percentage indicated here have been rounded down (practices vary slightly from one railway to another); they may be increased by up to 5% if a sufficiently representative number of samples is taken.
2. Certain railways sometimes include these soils in quality SQ 1.
3. These soils are classified under quality class SQ 2 if the hydrogeological and hydrological conditions are good.
4. These soils are classified under quality class SQ 3 if the hydrogeological and hydrological conditions are good.

The bearing capacity of the subgrade depends on the:

- Quality class of the soil which forms an embankment or the natural soil at the base of a cut;
- Quality and thickness of the prepared subgrade (when this exists).

On the basis of the parameters described above, a distinction can be made between the three following bearing capacity classes:

- P1: poor subgrade – Deformation Modulus ≤ 2.9 ksi
- P2: average subgrade – Deformation Modulus ≤ 7.25 ksi
- P3: good subgrade – Deformation Modulus ≤ 11.6 ksi

The upper limit of particle size in any fill is governed by the need to be able to spread and compact it effectively, and is therefore related to the depth of the layer. Normally particles shall not be more than 6 inches (150 mm) diameter; it is also recommended that the maximum particle size is less than half of the thickness of the layer. The maximum particle size of fill used to backfill structures must be less than 4 inches (100 mm). In this case fill shall be laid in thin layers and a small compactor shall be used so as not to disturb the structure. The fill used in the vicinity of masonry of over bridges must not be susceptible to settlement (i.e., soil of quality class SQ 3).

For materials with potential evolution over the time by densification (possible collapsing ground, evoluting rocky materials, etc.), specific requirements for implementation shall be defined. In the case of chalk, the requirements shall take into account the possibility of densification, the possibility of moisture contents evolution, and the possibility of crushing under vibration.

The lowest layer of embankments resting on damp ground must be selected from quality class SQ 3 (drainage material). The drainage qualities can be improved by using geotextiles.

6.3.3 Prepared Subgrade (Embankment and Cuts)

The categories of materials given in Section 6.3.2 are also applicable to the prepared subgrade. However the size of the largest particle shall be either half of the layer thickness or 6 inches (150 mm), whichever is smaller (maximum of 4 inches (100 mm) in the vicinity of structures).

6.4 DESIGN AND CONSTRUCTION OF EARTHWORKS

6.4.1 Stability Analysis of Earthworks

6.4.1.1 Methods of Analysis

Stability: Resistance to slope failure, both in the short and long term, must be demonstrated by calculations based on the geotechnical and hydrogeological properties of the ground.

Settlement: Settlement predictions shall show not only how fast construction shall proceed but also demonstrate that any settlements, which occur after the line is opened, can be rectified by routine track maintenance; if not, one of the alternatives given in Section 6.4.1.3 shall be considered.

6.4.1.2 Slope Angles

The slopes shall be designed in order to insure their stability and reliability and according to:

- The geotechnical characteristics of the cut grounds in cut, or of the support ground and filled material in embankment.
- The height of the earth structure.
- The particular condition of the site, i.e., the topography, hydrogeology, and natural risks such as seismic factors, possibility of void in the ground, ground sliding, etc.

Considering these points, it appears that the following general configurations are the most used:

Embankments: For soils which are acceptable according to Section 6.3.2, a slope of 1.5H:1V or 2H: 1V is normally adopted (some railways adopt 1H:1V or 1.25H:1V in the case of coarse rock fill, also benches or toe walls, etc., may be required). For slopes supported by compressible soft foundation soils (i.e., undrained shear strength between 100 psf and 300 psf), the slope angle will be determined by slope stability analyses.

For 15 % Design level it is proposed to use 2H: 1V slopes. Steeper slope angles may be feasible if justified by stability analyses carried out in subsequent design phases.

Cuts: Slope angles vary according to the type of ground, e.g.:

1. Intact rock not susceptible to weathering and without unfavorable dip or cleavage: a slope of between 45 degrees and 90 degrees but with a stone trap at the base and benches having a width of about 1/3 of the height of each step produced.

2. Weathered rock subject to degradation and deterioration: Specific considerations to be taken for rock slopes according to the level of geotechnical knowledge and experience on the specified area, substantiated by geological mapping and evaluation of the rock slope stability. Where necessary, surface protection is to be installed to mitigate long term instability.
3. Granular soils: slope of 1.5H:1V to 2H:1V according to the height of the cut.
4. Cohesive soils: slopes typically in the range 1.5H:1V to 2H:1V according to the height of the cut, or even flatter, with benches if required.
5. Pre-historic landslide areas: slope angles to be determined by an extensive evaluation of subsurface conditions and slope stability analyses.

For the 15 % Design level it is proposed to use 2H:1V slopes for soil cuts and 1H:1V for rock cuts. Steeper slope cuts may be feasible if substantiated by slope stability analyses and geologic and geotechnical investigations in the subsequent design levels.

6.4.1.3 Sensitive Soils or Unfavorable Hydrogeological Conditions

Some specific technical requirements have to be considered to protect and stabilize sensitive soils and for use where hydrogeological conditions are unfavorable.

Embankments:

1. Replacement of the sensitive soil (this method is the most reliable and shall be used when the depth of soil to be removed is not excessive).
2. Pre-loading for consolidation of the soil underlying the embankment or temporary surcharge of the embankment.
3. Installation of vertical drains or piles.

Where a soil susceptible to water or frost is used to form the body of an embankment it shall be protected by a covering of better quality soil.

In areas susceptible to flooding, the sides of an embankment must be protected with a layer of rock fill or stones with an intermediate granular layer if required.

Cuts:

In ground which is sensitive to frost or water, cut slopes shall be protected by a coarse granular layer. The water can be eliminated by appropriate methods (toe drains, counterfort drains, ditches, filter layers, etc.). Other methods may also be used (surfacing of embankment, nailing, cantilevered or anchored retaining walls, etc.).

In elevated altitude area where freezing conditions are frequent, a frost protection layer has to be included on all slopes in cohesive soil.

6.4.1.4 Construction of Embankment and Prepared Subgrade

Performance of the embankment depends to large extent on the quality of compaction performed during construction. It is essential to ensure proper compaction and precautions/guidelines for this are given as follows:

The compaction method is designed either with the aid of compaction trials, or by using the recommendations established for this purpose in the technical requirements. For each type of soil compactor and moisture content, the technical guidance for realization of fill and prepared subgrade will indicate the thickness of the individual layers to be provided and the compactive effort required. Special arrangements can also be recommended (watering; drainage).

The degree of compaction and minimum deformation moduli, which are specified for each layer, are generally as follows:

Embankment fills:

ρ_d	≥	90% of the maximum dry density as determined from ASTM D1557-07 where embankment construction exceeds 5 feet in depth. Provide 95% relative compaction as determined by ASTM D1557-07 for the top 5 feet;
EV2 d	≥	6.525 ksi for fine soils, or 8.7 ksi for sandy and gravelly soils.

Prepared Subgrade:

ρ_d	≥	95% of the maximum dry density as determined from ASTM D1557-07;
EV2 d	≥	11.6 ksi

6.4.1.5 Transition between Earthworks and Under Bridges

On the transition between earthworks and structures (e.g. overbridges), suitable measures shall be taken both to reduce differential settlement and to ensure that there is a gradual transition of support stiffness.

Specific guidance will be developed at later stage for the CHSTP.

6.4.1.6 Retaining Walls and Drainage

Where standard roadbed and ballast section back-slopes and/or fore-slopes intersect existing ground lines beyond the existing right-of-way (ROW), retaining walls shall be designed and constructed within the property with diversion ditches or drains provided behind the retaining wall to divert runoff from adjacent properties toward stabilized drainage outfall structures. Where applicable, profiles may be adjusted to minimize earthwork and reduce or eliminate the need for retaining walls.

In order to minimize ROW and excavation requirements, underdrains rather than ditches shall be employed where necessary for drainage. Longitudinal drainage shall be constructed under the high speed rail shoulder. Drainage shall be designed to convey flow from the guideway and adjacent roadway, where the roadway slopes toward the median.

6.4.1.7 Specific Consideration for Maintenance According to the Structure Height

Beyond the stability requirements, and in order to facilitate later maintenance, it is necessary to plan for benches slopes. For cuts with depth greater than 40 feet, it is recommended to plan a 6 feet wide bench with a 6% gradient towards the high-speed line. These benches shall be laid out on average every 30 feet in height (an allowance from 26 to 32 ft can be considered). The bench shall be connected to the natural ground at each end of the cut. If a drainage trench is to be installed on the bench, a road access shall be available on both sides of the cut or on one side but with an area on the other side for vehicle turn.

Similarly, for embankment over 40 feet in height, it is recommended to plan a 6-feet-wide bench with a 6% gradient toward the toe of the slope; laid out in average every 30 feet in height (an allowance from 26 to 32 feet can be considered). These shall also be connected to the natural ground for access.

6.5 COMPOSITION AND THICKNESS OF THE TRACK BED LAYERS

6.5.1 Typical Track Bed Construction

For construction of a new line it is important to ensure that the track bed layers have the appropriate mechanical characteristics and are of adequate thickness.

Typical track bed structures for various grades of bearing capacity are determined by the possible combinations of the support soil qualities and characteristics of the prepared subgrade, as indicated in Figure 6-5.

Figure 6-5 – Determination of the Bearing Capacity of the Subgrade

Quality Class of the Soil	Class of Bearing Required for the Prepared Subgrade	Requirement of Subballast Layer	
		Quality Class	Min. Thickness of Trackbed (in)
SQ 1	P1 P2 P2 P3	SQ 1 SQ 2 SQ 3 SQ 3	- 20 15 20
SQ 2	P2 P3	SQ 2 SQ 3	15
SQ 3	P3	SQ 3	-

Blanket is a layer of coarse grained material between ballast and subgrade, spread over entire width. The important roles of the blanket layer are:

1. Improving the bearing capacity by modifying the stiffness and achieving a better distribution of transmitted loads on the subgrade soils, thus preventing ballast penetration into the formation.
2. Reduction of induced stresses on the top of subgrade to a tolerable level.
3. To prevent mud pumping and fouling of ballast by upward migration of fine particles from the subgrade.
4. To prevent damage of subgrade by ballast.
5. Shedding surface water from the ballast and drain away from the subgrade.
6. Protection of subgrade against erosion and climatic variations.

The blanket layer, in its most complete form consists of:

1. A sandy gravel sub-ballast layer, the characteristics of which will be defined during a subsequent design phase. This layer is present in almost all cases. Certain railways specify it even on rocky subgrade where it serves as a compensation layer and helps to reduce the support stiffness.
2. A "foundation" layer (referred to as prepared subgrade in this document) of well graded sandy gravel, having a grading designed to give good filtering characteristics and allowing construction traffic to run over the area. It is not required on soils of quality class QS 3.
3. A filtering layer of sand to be used only with a subgrade of bearing capacity class P1.
4. A geotextile filter used with prepared subgrade P1 and P2, which improves the filtering characteristics of the track bed layers; the geotextile also facilitates construction of the track bed layers without causing rutting of the prepared subgrade in soils QS1or QS2.

6.5.2 Determination of the Thickness of the Track Bed Layers

The dimensioning of track bed layers must take into account both the:

- Desirable bearing capacity
- Problems of frost protection

The total thickness (ballast layer + sub-ballast layer) varies according to the:

- Bearing capacity of the subgrade. It is noted here that the deformation modulus of the layer supporting the sub-ballast layer (top of prepared subgrade) shall be 17.4 ksi.
- Level of frost protection required.
- Type of sleeper and the sleeper spacing
- Traffic characteristics (tonnage supported, axle-load and speed)

Due to the uniform type of train projected to run on the California high-speed train line, the ballast thickness is constant. The dimensions of the track bed layers for the sub-ballast layer and the eventual prepared subgrade are also constant.

The criteria and the optimization of the thickness of the layer will be developed at a later stage.

For 15% design, it is proposed to use an 8 inch thick sub-ballast layer and a 20 inch thick prepared subgrade.

This type of track bed layer is the most general structure used on French high-speed lines and conforms to frost protection and traffic characteristics.

The criteria and the optimization of the thickness of these layers will be developed at a later design stage.