California High-Speed Train Project

TECHNICAL MEMORANDUM

Earthwork and Track Bed Design Guidelines
TM 2.6.7

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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.

TABLE OF CONTENTS

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.

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

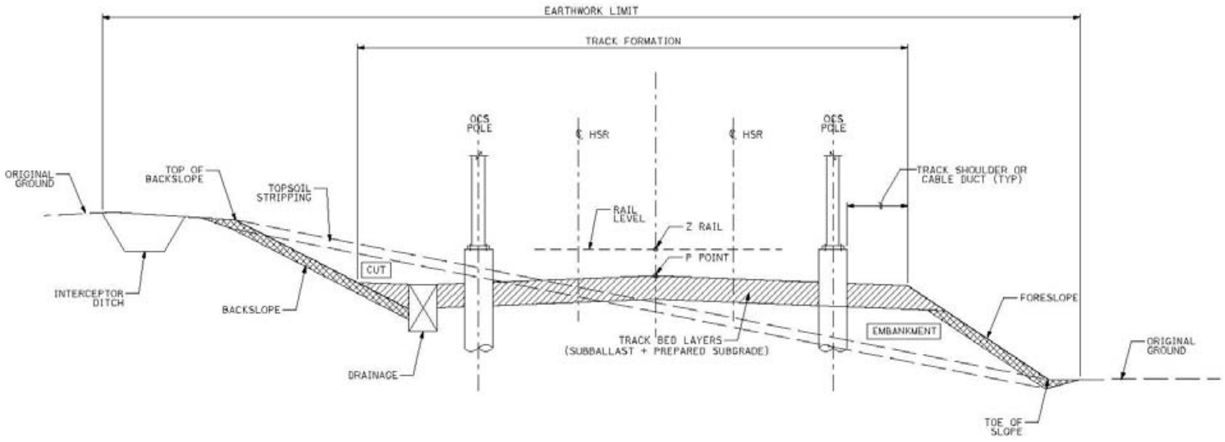


Figure 6-2 – Ballastless Track Formation

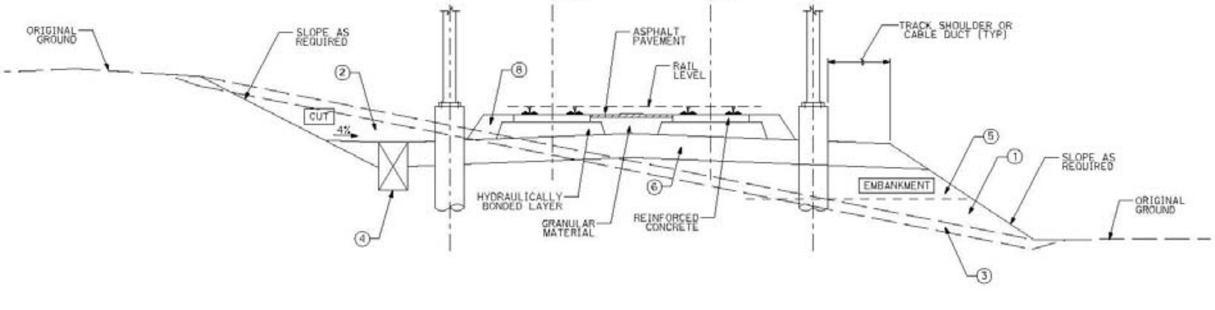
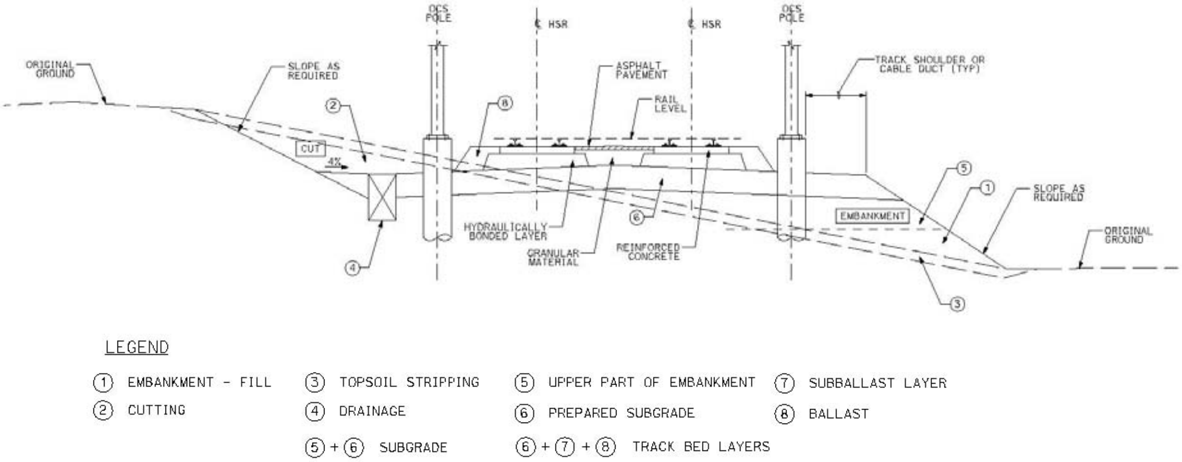


Figure 6-3 – Ballasted Track Formation



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	SQ 1	-
	P2	SQ 2	20
	P2	SQ 3	15
	P3	SQ 3	20
SQ 2	P2	SQ 2	15
	P3	SQ 3	
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.