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COMPARATIVE ANALYSIS OF DESIGN PARAMETERS FOR HIGH-SPEED RAILWAY EARTHWORKS IN DIFFERENT COUNTRIES AND A UNIFIED DEFINITION OF EMBANKMENT SUBSTRUCTURE

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Abstract. This paper compares design specifications and parameters for high-speed railway (HSR) earthworks in different countries (i.e., China, France, Germany, Japan, Russia, Spain and Sweden) for different track types (i.e., ballasted and ballastless), and for different design aspects (i.e., HSR

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embankment substructure, compaction criteria, width of the substructure surface, settlement control, transition section, and design service life). Explanations for differences in HSR implementation among different countries are provided and reference values of the design parameters are obtained. In an attempt to unify different types of HSR substructures around the world, a widely applicable definition of the stratified embankment substructure based on the practices adopted in different countries is proposed. The functions and requirements of each functional layer (i.e., the blanket layer, frost protection layer and filtering layer) are summarized.

Keywords: comparison, design, embankment, high-speed railway, parameter, substructure.

Introduction

High-speed railway (HSR) encompasses a complex reality involving many technical aspects including infrastructure, rolling stock and operations, as well as strategic and cross-sector issues including human, financial, commercial and managerial factors; it has proven to be a flexible system that can be developed under various circumstances and in different contexts and cultures (International Union of Railways [UIC], 2018a). The principal criterion in defining HSR is a commercial operating speed exceeding 250 km/h (UIC, 2016; The Council of the European Union, 1996). The implementation of an HSR project normally includes five phases; i.e., an emerging phase, feasibility phase, design phase, construction phase and operation phase. The design phase is one of the most important stages in HSR implementation. In this phase, definitions of all parameters and technical, architectural and landscaping choices necessary for the execution of works are precisely provided on the basis of applicable standards, rules and regulations, approved preliminary design documents, environmental impact assessments and reliability, availability, maintainability and safety requirements (UIC, 2018b).

Design practices of earthworks differ around the world according to specific regional/national standards. Alamaa (2016) compared regulations for the design of an HSR embankment in three European countries (i.e., France, Germany and Spain), but there has been no systematic and comprehensive comparative study on HSR earthwork design practices at the global scale. There is thus a need to enhance the safety and cost-efficiency of HSR earthworks by summarizing experiences and assimilating advanced technologies. In the present paper, earthwork specifications both in the countries where HSR technologies have been fully developed (i.e., France, Germany, Japan, and China) and in the countries where HSR technologies are developing (e.g., Turkey, Russia and Sweden) are identified, compared and analysed.

The comparison and discussion focus on design parameters, material classification and other factors. The design speed, track type (ballasted or ballastless), traffic type (passenger only or a passenger–freight mix) and other factors are considered in the comparison and analysis. A unified definition of the stratified structure for the HSR embankment substructure is proposed. Since practical parameters of HSR earthworks are collected and summarized for various countries and regions and the railway substructure of an embankment is unified in the present paper, this research can serve as a reference not only for the countries lacking HSR construction experience applying HSR technologies, but also for engineers and researchers willing to develop a clearer understanding of different earthwork practices.

1. Comparative analysis of design parameters of high-speed railway earthworks in different countries

1.1. Design service life of earthworks

The design service life is the expected service life of an earthwork element or how long the element can perform while meeting minimum functional requirements under a particular maintenance regimen. The design service life is determined by the expected working time, maintenance method, environmental conditions and life-cycle cost; it has direct implications for the operational safety and life-cycle cost (Lemer, 1996; Popović, Lazarević, Brajović, & Gladović, 2014). Some countries define design life by elements while others use the system-wide design life. Earthworks are relatively established systems that must perform consistently, as they are difficult to modify or replace. The design service lives of earthworks used in different countries are summarized in Table 1 for reference. The parameters for Spain and Sweden in the table are taken from Smekal (2012) and Alamaa (2016), respectively.

Table 1 shows that the designed service life of earthworks is defined according subdivisional works in some countries, while an extensive value is defined in other countries, and the designed lifespan of main earthworks ranges from 70 to 120 years in different countries. It can be noted that the subgrade, retaining structures, and foundations are defined as the main earthworks in China, but the definition of main earthworks varies from country to country. The objectives of specific requirements towards the lifespan are therefore not exactly equivalent in different countries.

Table 1. Design service life of earthworks in different countries

Country	Design service life
China	For main works: 100 years; For drainage facility and slope protection structure: 60 years
Japan	For main works: 100 years; For drainage facility, slope protection structure, noise barriers and other replaceable structures: usually less than 100 years, adjusted according to the complexity of replacement; Design reference period: 50 years
Germany	120 years
France	For important main works: 100 years; For main works: 70 years
Spain	100 years
Sweden	80 years

1.2. Compaction control criteria for embankment filling

By studying the data of National Railway Administration of P. R. C. (2014, 2016), Japanese Standard (1999), German Institute for Standardization (1988), DB Netz AG (1999), French Standard Association (1998), LGV Technical Reference (2010), PGUPS (2017), International Union of Railways (2008), it has been concluded that the main compaction control indices for fill materials of the subgrade include the compaction coefficient (K) or proctor density (D_{pr}), reaction modulus (K_{30}), second load deformation modulus (E_{v2}), dynamic deformation modulus (E_{vd}) and first load deformation modulus (E_{v2}/E_{v1}).

In most countries, compaction criteria for embankment fillings are determined by factors including design speed, type of track, properties of fill material, filling positions. Having collected and analysed specifications concerning compaction requirements in the above-mentioned standards, these parameters and their limit values are listed in Table 2 for comparative analysis. The definitions of the structural layer will be discussed in Section 3.

It is concluded that the parameters listed in Table 2 can be classified into two categories. The compaction coefficient (K) and proctor optimal density (D_{pr}) are closely related to the porosity of the fill material, which represents the physical compaction state of the filling. K and D_{pr} are measured adopting different testing methods; i.e., K is measured adopting the heavy Proctor test or surface vibration test, while D_{pr} is measured adopting the normal Proctor test. Meanwhile, the reaction modulus (K_{30}), dynamic deformation modulus (E_{vd}), second

Table 2. Different compaction criteria for subgrade in different countries

Country	**Position and material *K***		**Compaction criteria** D_{pr}	K_{30}, **MPa/m**	E_{v2}, **MPa**	E_{vd}, **MPa**	E_{v2}/E_{v1}	
China	Prepared subgrade		≥0.97	–	≥190	–	≥55	–
China	Upper part of embankment	Sandy soils, fine gravelly soil	≥0.95	–	≥130	–	≥40	–
China	Upper part of embankment	Crushed stone, coarse gravelly soil	≥0.95	–	≥150	–	≥40	–
China	Lower part of embankment	Sandy soils, fine gravelly soil	≥0.92	–	≥110	–	–	–
China	Lower part of embankment	Crushed stone, coarse gravelly soil	≥0.92	–	≥130	–	–	–
Japan	Prepared subgrade		≥0.95	–	≥70	–	–	–
Japan	Upper part of embankment		≥0.90	–	≥110[a] ≥70[b]	–	–	–
Japan	Lower part of embankment	Gravel	≥0.87	–	–	–	–	
Japan	Lower part of embankment	Sand	≥0.92	–	–	–	–	
Germany	Prepared subgrade		–	≥1	–	≥120	≥50	–
Germany	Upper part of embankment		–	≥1	–	≥60	≥35	–
Germany	Lower part of embankment	*Mixed Grained Soil* (German Soil Classification Standard)	–	≥1	–	–	≥45	
Germany	Lower part of embankment	*Fine Grained Soil* (German Soil Classification Standard)	–	≥0.97	–	–	≥45	–
France	Prepared subgrade		–	≥1	–	≥80	–	–
France	Embankment	Sandy or gravelly soil	–	≥0.95	–	≥60	–	≤2.2
France	Embankment	Fine soils		≥0.95		≥45		≤2.2
Russia	Prepared subgrade		–	≥1	–	≥120	≥55	–
Russia	Upper part of embankment		–	≥1	–	≥80	≥40	–
Russia	Lower part of embankment		–	≥0.98	–	–	–	–
Turkey	Prepared subgrade		≥0.98	–	–	≥120	≥50	–
Turkey	Upper part of embankment	–	≥0.95	–	–	≥80	–	
Turkey	Lower part of embankment	–	≥0.95	–	–	–	–	

a) ballastless; b) ballasted

load deformation modulus (E_{v2}), and first load deformation modulus (E_{v2}/E_{v1}) are obtained by relating the applied force and corresponding deformation so as to illustrate the mechanical properties of the compacted fill material. Combined parameters chosen from the two categories that represent both the compaction state and mechanical reaction properties are rationally adopted in different countries; i.e., K, K_{30} and E_{vd} in China, K and K_{30} in Japan, D_{pr}, E_{v2} and E_{vd} in Germany, and D_{pr}, E_{v2} and E_{v2}/E_{v1} in France.

The physical meanings of K_{30} and E_{v1} are similar in that they both indicate the deformation modulus derived from the first load results of the static plate load test but with different testing equipment. E_{vd} is obtained from dynamic plate load tests while E_{v1} and E_{v2} are obtained from static plate load tests. Dynamic plate load tests are easier to conduct with smaller and lighter equipment and are thus more suited to sites where minor compaction is permissible; e.g., sidewalk zones and trenches (Mikolainis, Ustinovičius, Sližytė, & Zhilkina, 2016).

1.3. Settlement control criteria

A central problem in HSR embankment engineering is to predict settlements and their development with time (Larsson, Bengtsson, & Eriksson, 1997). Deformation of the embankment mainly comprises elastic and plastic deformations (Sayeed, 2016; Wu & Chen, 2011). Elastic deformation is a recoverable deformation generated by the train load (Trenter, 2001). When the embankment is suitably filled and the ground treatment measures are reliable, the elastic deformation is generally negligibly small. Meanwhile, plastic deformation determines the time allowed for the track laying and the post-construction settlement value of the embankment (Orr & Farrell, 2011). The deformation of earthworks can also be classified as settlement during construction and post-construction settlement by different durations. Train operation safety is closely connected to post-construction plastic deformation (i.e., settlement), so post-construction settlement is strictly controlled within a specific range to ensure riding comfort and safety in different countries (Kang, 2016). Table 3 gives the post-construction settlement limit values used in different countries.

The limit value of post-construction settlement is basically gauged with the consideration of various factors including adjustable range for track deformation, engineering and maintenance costs for settlement control. Table 3 shows that three settlement limitation methods are adopted to control earthwork deformation; i.e., rate limitation, relative limitation (deflection angle) and total limitation methods. Total settlement limitation is specified in each country to control the settlement of ballasted and ballastless tracks. Meanwhile, rate limitation is adopted for the settlement control of ballasted lines in China, Germany, France and Russia and both ballasted and ballastless lines in Japan. Relative limitation is used for the settlement control of normal sections of both ballasted and ballastless lines in Germany, ballastless lines in China, Japan and Russia, and ballasted lines in France. Settlement limitation is used for transition sections of different types of structure in China, Japan and Germany.

Table 3. Post-construction settlement limit values for ballastless or ballasted track in different countries

Country	The settlement limit values	
	Ballastless track	**Ballasted track**
China	Post-construction settlement of normal sections: ≤15 mm. If the settlement of ballastless track is uniform and the radius of vertical curve after the adjustment of rail surface elevation is larger than $0.4v^2$ (v is the design speed, km/h), the allowable post-construction settlement limit value shall be 30 mm. Differential post-construction settlement between different types of structures: ≤5 mm. Deflection angle caused by differential post-construction settlement: ≥1/1000.	For design speed of 250 km/h, post-construction settlement for normal sections: ≤10 cm; post-construction settlement for transition section between earthworks and abutment: ≤5 cm; post-construction settlement rate: 3 cm per year. For design speed of 350 km/h, post-construction settlement for normal section: ≤5 cm, post-construction settlement for transition between earthworks and abutment: ≤3 cm; post-construction settlement rate: 2 cm per year.
Japan	Differential post-construction settlement: ≤0.5–1.0 mm per 100 days. Post-construction settlement for transition between earthworks and abutment: ≤10–30 cm. If ground treatment measures are adopted, post-construction settlement: ≤10 mm per 10 years.	Post-construction settlement limit for Shinkansen: ≤10 cm. Post-construction settlement rate: ≤3 cm per year. Post-construction settlement for transition between earthworks and abutment: ≤5 cm.

Country	The settlement limit values	
	Ballastless track	**Ballasted track**
Germany	Post-construction settlement shall not be greater than fastening adjustment range minus 5 mm. *Relative limitation* Differential post-construction settlement shall ensure track at no point exceeds 1/500 from the reference length, e.g., differential post-construction settlement ≤2 mm within 10 m long section. *Total limitation* Differential post-construction settlement limit is determined by vertical curve radius larger than $0.4v^2$ (*v* is the design speed), i.e., the limit value is 15 mm for a HSR line with the design speed of 300 km/h. *Limitation for transitions* Differential post-construction settlements relative to a fixed track structure between the back wall of the abutment and a given point 30 m from the back wall shall not exceed 20 mm. The gradient of the top of the frost protection layer due to settlement shall not exceed 1:1000.	*Rate limitation* Post-construction settlement rate: ≤12 cm per yaear. *Relative limitation* Differential post-construction settlement shall ensure track at no point exceeds 1/500 from the reference length within a certain maintenance cycle (usually 6–10 years), e.g., differential post- construction settlement ≤2 mm within 10 m long section. *Total limitations* 30 mm total settlements are accepted. Total settlements shall not exceed 3 times the value of the differential settlements after commissioning within a reference length of 40 m.
France	–	*Rate limitation:* Post-construction settlement rate within the first 25-years operation: ≤12 cm per year. *Relative limitation* *Longitudinal differential post- construction settlement:* ≤3 mm between sections located 15 m apart (1:5000); ≤8 mm between sections located 30 m apart (1:1000). *Differential post-construction settlement between two rails:* ≤3 mm at a 3 m long section (1:3750) *Total limitation* Post-construction settlement during design life (100 years): ≤100 mm.

Country	The settlement limit values	
	Ballastless track	**Ballasted track**
Russia	Post-construction settlement of normal section: ≤15 mm. Differential post-construction settlement between different types of structures: ≤5 mm. Deflection angle caused by uneven post-construction settlement: ≤0.25%.	Post-construction settlement within the first 25-years operation: ≤10 cm. Post-construction settlement rate: ≤10 mm per year.
Spain	–	Post-construction settlement: ≤50 mm 100 days after the construction of the superstructure
Turkey	–	Post-construction settlement: ≤5 cm.

1.4. Different types of transition sections

Stiffness variations and relative displacements in a section of transition between different types of structure may lead to a localized dynamic load, greater levels of maintenance and geometric correction, increased costs of maintenance of the railway and changes to line operation (UIC, 2017). Transition sections are built for connection parts where there may be differential settlement and stiffness of the track foundation between earthworks and a bridge, tunnel or other structure beneath the railway track, between different earthwork structures and between regions subjected to different ground treatment measures (Ying & Lie, 2018). Different countries adopt different transition types and give different provisions for transition design. The design provisions of transition sections used in different countries are summarized in Table 4.

Table 4 shows that the shapes of transition are trapezoids or inverted trapezoids in China and France but only trapezoids in Japan. The materials of transition sections are all made from soil (i.e., crushed stone, gravel and sand) and cement whose weight ranges are from 2% to 5%. Additionally, the required length of a transition section in China and Germany is greater than in France.

Table 4. Transition section design requirements in different countries

Country	Length	Shape	Fill material	Comments
China	≥20 m	Trapezoid or inverted trapezoid	Graded crushed stone mixed with cement whose weight is 3% to 5%	Provisions on transition between earthworks and bridge, earthworks and tunnel, embankment and cutting are specified
Japan	–	Trapezoid	Graded crushed stone or cement improved soil, compaction coefficient ≥0.95	–
Germany	≥20 m	Inverted trapezoid or other shape shown in Ril 836	Coarse grained soil mixed with cement whose weight is 2% to 4%	–
France	≥10 m	Trapezoid or inverted trapezoid	Gravel and sand mixed with cement whose weight is 3%	–

2. Worldwide definition of a stratified HSR embankment substructure

The components of a traditionally ballasted railway embankment can be divided into two subcategories: the superstructure and substructure (Bårström & Granbom, 2012). There are basically two categories of superstructure: ballasted and ballastless. A ballasted track uses a ballast layer to support track components and to transfer load. According to Esveld (2001), there are basically two designs principles for ballastless railway superstructures. The German slab track solution and design concept originates from experience in highway design (Esveld, 2001, 2003a; Liu, Zhao, & Dai, 2011a). The reinforcement is placed on the neutral line of the slab and is cast onto a stiff bearing layer (Esveld, 2003b). The other method specifies the reinforcement to be placed on the top and at the bottom of the slab to increase the bending resistance (Esveld, 2001).

The substructure is the foundation of the entire railway structure (Li & Selig, 1995; Selig & Waters, 1994). In an attempt to realize the long-term stability of the structure affected by train loading, precipitation infiltration, dry–wet cycles, and freeze–thaw cycles, the substructure is designed to comply with the strength and stiffness requirements, settlement and seepage control requirements, and other special requirements; e.g., frost protection requirements in a permafrost region.

2.1. Proposal for a unified definition

A review of the literature reveals that the layers of embankment substructure are defined differently in different standards and academic articles, the same embankment substructure layer may be defined differently in different documents, while the substructure layer is defined to illustrate different layers. Substructure layers defined in one country do not match those defined in another as the whole railway structure is different. For a ballasted track railway, Giannakos (2010) defined that the blanket layer is part of the track bed layer and the track bed layer is part of the superstructure. In UIC (International Union of Railways) 719R (2008), however, a blanket layer is not regarded as part of the track bed layer, while it is regarded as part of the substructure, and the sub-ballast layer is defined as the overlap of the track bed layer and embankment substructure. Guler and Aksop (2017) consider a ballasted railway embankment substructure to be a combination of the natural soil, subgrade and sub-ballast.

By studying the documents of the National Railway Administration of P. R. C. (2014, 2016), Japanese Standard (1999), German Institute for Standardization (1988), DB Netz AG (1999), French Standard Association (1998), LGV Technical Reference (2010), PGUPS (2017), Kolos *et al.* (2018), International Union of Railways (2008), it has been found that even though HSR embankment substructures differ among different countries, a unified definition of the embankment substructure suitable

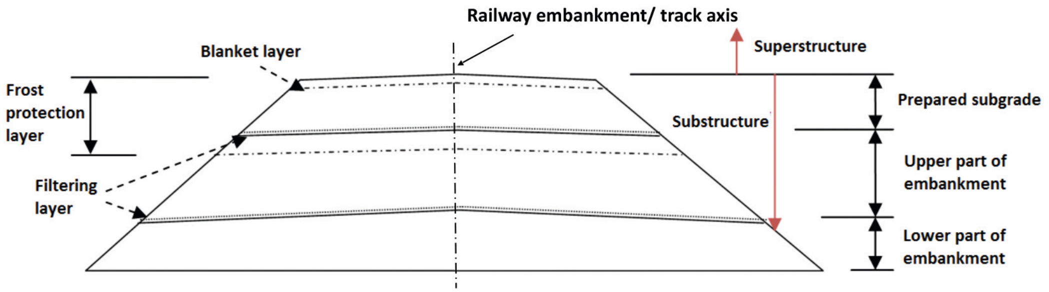

Figure 1. Schematic cross section of a generalized stratified embankment substructure

for depicting ballasted and ballastless track railways can be obtained, as illustrated in Figure 1.

Generally speaking, the railway embankment substructure can be synoptically divided into three main parts – the prepared subgrade, upper part of the embankment and lower part of the embankment – according to our proposed definition. It is noted that functional layers (i.e., the blanket layer, frost protection layer and filtering layer) are included in our proposed stratified structure. These functional layers are explained in detail as follows.

Blanket layer

The blanket layer is generally laid on the top of the prepared subgrade. It provides the functions of concentrated stress reduction, frost protection, water proofing as well as seepage control (Bonnett, 2005). According to the French standards, the thickness of the blanket layer under the ballast is 20 cm or 35 cm (where the fill material is of Class S2 without geotextile). The German standards refer to a blanket layer as a protective layer whose thickness is 40 cm for the ballastless track and 70 cm for the ballasted track. According to the Japanese standards, blanket layers can be made of reinforced concrete, asphalt or graded gravel with respective thicknesses of 30 cm, 15/20 cm and 30 cm. In China, specifications (National Railway Administration of P. R. C., 2014, 2016) on general subgrade structures do not include a blanket layer; however, project tests on the laying of a blanket layer made of asphalt with a thickness of 10–30 cm have been carried out on the Harbin–Qiqihaer HSR (2014), Zhengzhou–Xuzhou HSR (2015), Beijing–Zhangjiakou HSR (2017) and Zhengzhou–Wanzhou HSR (2014).

Frost protection layer

The main role of the frost protection layer is to dewater the subgrade, thus protecting frost-sensitive geomaterials and preventing frost damage (Lichtberger, 2005). In a the seasonally frozen region, the frost protection layer is generally laid with a thickness determined by the frost depth. Materials of the frost protection layer commonly are characterized by high permeability (DB Netz AG, 1999; German Institute for Standardization, 1988; Japanese Standard, 1999; Liu, Niu, Niu, Lin, & Lu, 2011b; National Railway Administration of P. R. C., 2014, 2016). In UIC 719R (2008), the frost protection layer is defined as a specific structural layer above the prepared subgrade. From a boarder perspective, however, all rail substructure layers below the frost penetration depth must be designed so as to be protected against frost during the entire design life; e.g., fill materials are frost-resistance materials. With the reference to other standards and considering functionality, we recommend the frost protection layer be a combination of layers – a blanket layer, prepared layer (or part of it), and upper part of the embankment (or part of it) – below the frost penetration depth, as shown in Figure 1.

Filtering layer

The most vital role of the filtering layer is to prevent intrusion of a filling layer with small grains into an adjacent filling layer with large grains. When grain sizes of two adjacent filling layers are unable to meet the requirement that $D_{15} < 4d_{85}$, a filtering layer is generally employed between them. Geosynthetics are commonly used as the materials for the filtering layers.

2.2. Layer thicknesses of the embankment substructure

The thicknesses of layers of the embankment substructure are determined to meet the deformation and strength requirements considering the defined quality of the fill material and compaction criteria. Owing to the diversity of embankment substructures, fill material compaction criteria and calculation approaches, the thickness of subgrade layers varies from country to country. The fill material and

Table 5. Fill material and thickness of HSR embankment substructure layers in different countries

Country	**Fill material**	**Embankment structure**	**Total thickness of prepared subgrade and upper part of embankment**
China	Prepared subgrade: graded gravel Upper part of embankment: Soil belongs to Group *A* or *B* (National Railway Administration of P. R. C., 2016), or chemically or physically improved soil	Ballasted track: 0.4 m prepared subgrade, 2.3 m upper part of embankment Ballastless track: 0.7 m prepared subgrade, 2.3 m upper part of embankment	Ballasted track: 2.7 m Ballastless track: 3.0 m
Japan	Prepared subgrade: 0.15 m (0.20 m) asphalt concrete layer / 0.3 m reinforced concrete / 0.3 m graded crushed stone + 0.15 m graded gravel Upper part of embankment: Soil belongs to Group *A* (Japanese Standard, 1999)		≥3 m (including track bed layer components)

Country	**Fill material**	**Embankment structure**	**Total thickness of prepared subgrade and upper part of embankment**
Germany (Ballastless)	Prepared subgrade: Soil Belongs to Group *KG* (German Institute for Standardization, 1988), fine grained gravel mixed with sand Upper part of embankment: *Coarse Grained Soil* and *Mixed Grained Soil* (German Institute for Standardization, 1988)	0.4 m blanket layer + 2.1 m subgrade	2.5 m
France (Ballasted)	Prepared subgrade: Embankment: 0.14 m asphalt concrete layer + 0.35 m crushed stone or gravel + 0.35 m gravel mixed with sand Cutting: 0.14 m asphalt concrete layer + 0.7 m gravel mixed with sand Upper part of embankment: ordinary soil		
Russia	Prepared subgrade: sand mixed with crushed stone and gravel Upper part of embankment: non-cohesive and non-expansive soil, e.g., sand mixed with gravel soil	Ballasted track: 0.7 m prepared subgrade, 1.8 m upper part of embankment Ballastless track: 0.4 m prepared subgrade, 1.8 m upper part of embankment	Ballasted track: 2.5 m Ballastless track: 2.2 m

thickness of the embankment substructure in different countries are compared in Table 5.

Table 5 demonstrates that on the whole, the total thickness of the prepared subgrade and upper part of the embankment is more than 2.5 m, while the thickness of the prepared subgrade is more than 0.4 m. A blanket layer is placed at the top of the prepared subgrade in Japan (with a thickness of 0.15–0.3 m), Germany (with a thickness of 0.4 m) and France (with a thickness of 0.14 m), while it is not required in China or Russia.

2.3. Design width of the embankment substructure surface

In most countries, the width of the embankment substructure surface is determined by the design speed, number of lines, type of track, distance between tracks, widening of a curved track, width of the substructure shoulder, requirements for maintenance, type of cable trough

change to "

Table 6. The width of embankment substructure surface excluding widening value of curved track in different countries

Country	The width of substructure surface	
	Single track	Double track
China	Ballastless: 8.6 m Ballasted: 8.8 m	*Ballastless:*8.6 m + distance between centers of tracks *Ballasted:* 8.8 m + distance between centers of tracks 250 km/h: *Ballastless* 13.2 m, *Ballasted* 13.4 m 350 km/h: *Ballastless* 13.6 m, *Ballasted* 13.8 m
Japan	Class I line: 6.9 m	6 m + distance between centers of tracks Shinkansen (260 km/h): 12.4 m Sanyo Shinkansen, Tohoku Shinkansen, Joetsu Shinkansen, Hokuriku Shinkansen (260km/h): 11.6–12.2m
Germany	Berlin-Cologne Line: 9 m	7.6 m + distance between centers of tracks 300 km/h: 12.1 m Berlin-Cologne Line: 13.7 m
France	8.0 m	9.4 m + distance between centers of tracks
Turkey (Ballasted)	7.0 m	14.5 m (250 km/h)

and the foundation of the poles of the overhead contact system and other factors (Cui, 2018). The width of the embankment substructure surface excluding the widening of a curved track in different countries is illustrated in Table 6.

Table 6 shows that the width of the embankment substructure surface mostly ranges from 6.9 m to 9.0 m for a single-track railway and from 11.6 m to 14.5 m for a double-track railway. It has also been found that the width of the embankment substructure surface is usually larger for a ballasted line than for a ballastless line in China but that the widths are identical in Germany; this is because accumulated ballast is designed on the surface, which increases the width of the substructure surface. On the whole, French HSR lines have the widest surface, while Japanese HSR lines have the narrowest. One reason for the narrow surface in Japan is that a trench is usually dug between two lines not only to drain water away but also to obstruct ballast.

Concluding remarks

Important design parameters for HSR earthwork design have been summarized and a comparative analysis has been conducted on their limit values and related specifications in certain countries. The HSR embankment substructure compositions in different countries were sorted for comparison, and a unified definition of the embankment substructure structure that is applicable to different countries was proposed. It is noted that the design parameters of some countries used for comparison in this paper were acquired from national standards while some were obtained from technical specifications of one or several HSR lines. At the same time, we mostly collected and analysed railway construction standards written in different languages. Even though most of the standards have been translated into English, some information may have been lost in translation. Another complication might be that railway organizations refer to the same thing but have different definitions. There is a need for further comparison of the technical and economic rationality of earthwork techniques in different countries and numerical analysis on how each variable affects strain and shear strengths specifically.

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