TC218 E-exchange

MSE walls supporting railways – Deformation response in high speed rail

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SUMMARY

A) What is the maximum deformation (lateral displacement, total settlement and differential settlement) allowed for MSE walls for rail applications? What is the difference in applications, e.g., light, heavy and high-speed rail?

No current standards that specifically restricts the allowable lateral displacement, total settlement or differential settlement for MSE walls for rail applications.

How deformation and settlement of MSE structures affect track performance has not been fully investigated. The type of foundation for the tracks, proximity, loading, curvature of the tracks, among many other factors would all need to be considered to understand the impact of deformation/settlement.

The capacity to maintain the track geometry over the years is key, and is also linked to the choice of track technology. The criteria are the superimposition of general design standards and owner or project specifications.

Any settlements anticipated in the foundation soils below the MSE wall need to be accommodated in the track performance over the long term. A good geotechnical study that can anticipate settlements will plan on future maintenance operations needed, as has been demonstrated in case studies on railways. The matter of back-to-back wall design can also be a particular challenge in heavy railway design with limited right-of-ways and lateral deformations do need close attention.

Total and differential settlement:

Two components to differentiate:

1) Max total settlement or differential settlement that the MSE system can accommodate: restriction related to the specific MSE system, the reinforcement, the facing elements.

2) Max total settlement or differential settlement of the MSE wall that the rail operations can accommodate to reduce impact to operations and maintenance.
To understand the specific requirements of the rail owners: Track geometry and stability at any time along the service life of the structures.
Rail owners specify the tolerances on the specific project

If guidelines are developed, to clarify that the guidelines are under category 1) and check the values with the specific restriction of each project.

<u>Lateral displacement:</u>

Excessive lateral displacement can contribute to track and rail alignment issues, particularly where the MSE walls are at bridge abutments.

Suggestions used in some projects:

- Where MSE walls support rail embankment and where the back end of the reinforced zones are near the edge of the rail ties (sleepers) to extend the top reinforcement layers completely under the rail ties. These longer reinforcements should help limit progressive lateral displacement of the MSE wall caused by the dynamic train loads. The added reinforcement does not necessarily need to be connected to the main facing if it is just to prevent lateral spread.

- To consider in the analysis mass and stiffness of the MSE wall, relative mass of the trains operating on the track above the MSE wall and reinforcement to determine the number of layers to be extended in each case. Minimum two layers of reinforcement to be extended.

Some information can be found in the following codes and documents:

- **AASHTO: American Association of State Highway Transportation Officials**

  - Settlement and lateral displacement considerations can be found in Sections 11.10.4.1 and 11.10.4.2
  - Differential settlement tolerances based on the facing unit type (block, panels, wire, etc.).
  - Settlements are determined on the basis of differential settlement limitations developed by the fascia panel size and joint width between fascia (the guide varies from 1/100 to 1/600 for joint widths between 6 to 20 mm).
  - Lateral displacement: empirical curve to evaluate lateral displacement for inextensible and extensible reinforcements on the basis of reinforcement length versus wall height.
  - All the above for MSE walls, not specific information to rail applications

  Note: AASHTO is used to supplement railway codes but is actually a highway transportation code

- **EUROCODE**

- **BS8006- 2010: British Standard – Code of practice for strengthened/reinforced soils and other fills.**
  The code covers a wide range of applications including railways.

  - Section 6: Walls and Abutment:
    - Section 6.5.4 Settlement, Table 16: Typical vertical movement capacities required for facing systems and Table 17: Guide to the effects of settlement

Table 16 **Typical vertical movement capacities required for facing systems to cope with vertical internal settlement of reinforced fill**

Structural form	Typical vertical movement capacity of system
Discrete panels	Joint closure of 1 in 150 relative to panel height
Full height panels and blockwalls	Required vertical movement capacity of connections increase with wall height
Semi-elliptical facings	Vertical distortion of 1 in 150 relative to panel height
Geotextile wrap-around facings	No specific limit except for appearance or serviceability considerations

- Section 6.5. 5, Table 18: Construction tolerances commonly achieved for faces of retaining walls and abutments

Table 18 **Construction tolerances commonly achieved for faces of retaining walls and abutments**

Feature	Tolerance
Location of plane of structure	± 50 mm
Verticality	± 5 mm per metre height (1 in 200)
Bulging (vertical) and bowing (horizontal)	± 25 mm in 4.0 m template

NOTE 1 The face of segmental block walls are usually built at a batter often by setting back the face of a row of blocks from the previous layer of blocks. The tolerance for verticality in the table is to be read as the tolerance from the intended designed face batter.

NOTE 2 This is a guide only and structures with greater tolerances can often be satisfactory.

Table 17 **Guide to the effects of settlement**

Maximum differential settlement	Comment
1 in 1000	Not normally significant
1 in 200	Full height panels may be affected by joints closing or opening. Normal safe limit for segmental blockwalls.
1 in 100	Normal safe limit, without special measures, for discrete concrete panel facings
1 in 50	Normal safe limit for semi-elliptical steel face elements. Discrete concrete panels may suffer closed joints if special measures not included
1 in < 50	Soft facings might suffer distortion affecting their retaining ability

NOTE There is no intended firm limit between categories. This is a preliminary guide only.

- Section 8: Embankments with reinforced soil foundations on poor ground
  - Section 8.4.4.2 Acceptable surface deformations
    The degree of acceptable surface deformation may be estimated dependent on the design philosophy for the supporting reinforcement.
    For consideration beneath railway lines, more stringent allowable deflections should be considered; these may be derived from the maximum allowable cross-rail differential movements to prevent a twist fault or derailment.

- **AREMA: American Railway Engineering and Maintenance Association**:
  National code for railways in the USA

- **SUPERTRACK:** Study from Sweden

- **CALTRANS: California Department of Transportation**:
  Rail guidelines for California

- **California High Speed Train Project: Technical Memorandum - Geotechnical & Design Guidelines TM2.9.10**
  - 6.7.7 Settlement and Horizontal Deformation Tolerances
    Settlement issues, especially differential settlement, are of primary concern in the selection of walls. Retaining wall and abutment structures shall be investigated for excessive vertical and lateral displacement, and overall stability, at the service limit state. Tolerable vertical and lateral deformation limits for retaining walls and abutments shall be developed from the structural engineering design and performance criteria based on the function and type of wall, design service life (100 years), and consequences of unacceptable movements to the wall, tracks, and any potentially affected nearby structures, i.e., both structural and aesthetic.

B) Is there a load factor range (in % or direct multiplier) that can be used to increase the vertical stresses in static load to account for analysis of dynamic loading?

Two aspects to consider:

1) **Dynamic loading and the long-term implications of the MSE backfill being subjected to vibrations from rail traffic**

   There are methods to account for dynamic load for rail ballast, but the effect on MSE structures is not well understood and more research would be required.

   Most of the studies for rails are focused on the integrity of the ballast and sub-ballast only. And most of the studies of the MSE walls under dynamic loading have analysed the performance under seismic load but not under rail traffic.

   Note: From experience with walls that support heavy and light rail, no performance issues have been made present and the design methods used at the time with the specific requirements of each project appear to be sufficient to address the design needs.

2) **The potential for Rayleigh waves to develop**

   The use of granular backfill alone seems to be sufficient and with the inclusion of reinforcement we can expect to see the overall Rayleigh wave shear velocity be well above the critical wave velocity due to High speed rail.

   Well compacted granular backfill exhibit shear modulus (hence shear wave velocities) high enough not to cause any issue for even high speeds

   Additional research would need to be conducted.

Some approaches used to consider an amplification factor are:

- **AASHTO Chapter 3:** load factors conditioned to live load (LL), vehicular centrifugal force (CE) and vehicular dynamic load allowance (IM).

  The Fatigue I load combination for the 3 elements is 1.50.

- **American Railway Engineering Association (AREA)**
  For ballast design, to consider the dynamic component of wheel load, the static wheel load shall be multiplied by an influence coefficient generally known as the dynamic amplification factor (DAF). Many factors affect the DAF, including train speed, static wheel load and wheel diameter, unsprung vehicle mass, condition of vehicle and track-ground system, etc.

  The dynamic amplification factor used by (AREA) is:

  $$P_{dyn} = \phi \cdot P$$

  where:

  - P_{dyn} and P are the dynamic and static wheel load (kN), respectively
  - ϕ is the dimensionless DAF, which is given by:

  $$\phi = 1 + (0.0052\ C / D_w)$$

  where:
  - C is the train speed (km/h)
  - D_w is the wheel diameter (m)

  The same DAF should be applied to the wheel load also for designing retaining walls.

- **Amplification factor used without a specific code:**
  To account for dynamic effects, a 1.2 amplification applied on the design tension of the top reinforcing layers, down 3 meters below the tracks, then 1.1 down to 6m.

  Note: This is a conservative approach except for uppermost layers, based on results on an instrumented (steel-reinforced) MSE below high-speed tracks in service now for 3 years in France.

  When considering the amplification factor for dynamic loading, to check if a partial factor for Braking dynamic load has been included or if this needs to be added in the total factor.

C) How much horizontal load can be considered to be transferred to the top of the MSE wall due to vibrations induced by light, heavy and high speed trains respectively? Is there any range or guidance for this? Please reference codes or guidance documents as they pertain including such considerations as rail setback distances, radius of curves and speeds of operation?

Current design guidelines do not address vibratory loads in the design of MSE structures that support light/heavy/high speed rail systems. Project-specific requirements and methods are taken currently to address vibratory loads.

Some approaches used to consider the vibrations are:

- **Conservative load factor:**

  Fatigue load combination for live load (LL), vehicular centrifugal force (CE) and vehicular dynamic load allowance (IM) equal to 1.50.

- **Horizontal load as function of the dynamic wheel load P_{dyn}:**

  In a ballasted railway track, the rails transfer the wheel loads to the supporting sleepers, which are spaced evenly along the rail length. Similarly, sleepers transfer the load from the rail to the wider ballast area. The ballast and sub-ballast layers transmit the high imposed stress at the sleeper/ballast interface to the subgrade layer at a reduced level through spreading.

  Therefore, if the wall supports the railway structure, the vertical load should be evaluated as above, that is spreading the dynamic wheel load P_{dyn} down to the top of the wall. Then the horizontal load can be calculated by multiplying such load by Ka or K0, depending on the type of wall and of reinforcement.

D) What are the main differences, if any, between metallic reinforcement and polymeric reinforcement to absorb the effect of surface vibrations induced by light, heavy and high-speed trains respectively? Could there be any compromise in the long-term performance of the track using metallic or polymeric reinforcement?

There is no compromise in the long-term performance using metallic or polymeric reinforcement if both are correctly designed.

There are good experiences using both types of reinforcements with design considerations made to prevent corresponding corrosion and stray current or excessive creep effects.

Some references:

- Performance of Geosynthetic reinforced walls that support the Hokkaido Shinknsen. *Technical paper: Tatsuoka et al, Geosynthetic-Reinforced Soil Structures for Railways in Japan, Feb 2014.*

- Vibrations effects on displacement of fascia in MSE walls. *Technical Paper: Langcuyan Christine et al, Effects of Surface Vibrations on the Behavior of Panel-Type MSE Walls, 2018 World Congress on Advances in Civil, Environmental and Materials Research.*

- Some examples where Reinforced Soil Structures are used for Railways: List produced by the Australian Rail Track Corporation ARTC in June 2010. https://extranet.artc.com.au/docs/eng/type-approvals/track-civil/earthworks/13_17737.pdf

- Japanese design method of Reinforced Railroad with Rigid Facing RRR, last revision September 2019. Link below of the method in Japanese. http://www.rrr-sys.gr.jp/method.html

E) What are the limits necessary to address prevention of metal losses in metallic reinforcement and reduction factors (installation damage, chemical degradation and/or creep) for polymeric reinforcement in the design life/durability of the MSE walls supporting railways?

Usual limits for durability in steel and geosynthetic reinforcements still apply in rail as for highways.

Durability of the reinforcement is a function of the electro-chemical environment they are placed in, as well as the in-soil temperature range. This is normally covered in design standards and railroad specifications.

Studies have proved that concern with stray currents to railways is associated with proximity to power stations and steel reinforcements continuously connected. However, steel strips in MSE walls are not integrally and continuously connected, therefore stray currents do not result in metal losses.

For geosynthetic reinforcement, installation damage and chemical degradation are function of the soil environment and are considered using reduction factors in the design of the MSW walls. Creep is a function of load and current design methodologies consider a creep factor to determine the allowable design strength for the specific design life of the MSE walls.

Some common additional railway issues that need to be considered in both, steel and geosynthetic reinforcements, are making sure that the owners understand that ballast depth must be sufficient such that any future work done on the rail line does not conflict with the top level of MSE reinforcements. Also, cleaning operations for trains should not result in chemicals washing into the MSE volume and affecting reinforcements.