Reinforced Soil Behaviour in Railway Application

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ABSTRACT
Although the mechanically stabilized earth walls are widely used in the road and civil industry, there are questions by some with this system in railways application, especially for high-speed railroad construction. One of the uncertainties is due to lack of information about the stress on the structures under dynamic and cyclic load with high frequency, mainly for high speed trains. This article will explain the interaction between the soil and the soil reinforcements in this condition and will present the achievements in the latest research program on Reinforced Earth walls in railway application under dynamic loading and discuss the effect of cyclic loads on the steel strip soil reinforcements. In addition, a project will be briefly presented for high speed train application.

The safety and durability of the structures over time is another big concern for railway organizations. This subject is also discussed here in brief and a procedure is proposed to monitor the durability of the walls with steel reinforcements. Another concern in the design of bridges crossing a railway is the stability of the structures in case of train derailment and impact on walls. Different methods of crash wall construction are discussed to insure the safety and stability of bridges with mechanically stabilized earth abutments.

RÉSUMÉ
Bien que les murs de sol stabilisés mécaniquement soient largement utilisés dans les secteurs routiers et du génie civil, il y a certaines réticences pour leur utilisation dans des applications pour les chemins de fer, particulièrement pour la construction de ligne à grande vitesse. Une des incertitudes vient du manque d'information sur la pression exercée sur les structures sous une charge dynamique et cyclique à haute fréquence, en particulier pour ces trains à grande vitesse. Nous devons mieux comprendre l'interaction entre le sols et les renforcements du sol dans ces conditions. Cet article présente les résultats obtenus dans le dernier programme de recherche sur les murs de Terre Armée dans l'application ferroviaire sous des charges dynaiques et discute des effets des charges cycliques sur les bande de renforcements métalliques. De plus, un projet sera bri`vement présenté pour les train à grande vitesse.

Il a aussi d'autre réticences relativement à la durée de vie en service des murs de sol stabilisés mécaniquement avec des renforcements en acier comme la sécurité et la durabilité des structures dans le temps qui est une grande préocupation pour les organisations ferroviaires. D'autres questionnements concernant l'effet du courant électrique sur les renforcements métalliques sont aussi discuté dans cet article.

1 INTRODUCTION

The construction of several mechanically stabilized earth (MSE) structures for railway projects has significantly increased the knowledge of MSE wall design and its past performance has brought more confidence in utilizing this system in rail application (Figure 1). The challenges encountered in the design of this type of work are greatly influenced by the type of railway and trains.

The experience of utilizing MSE structures for such an application can answer the key issues in each type of rail. The use of reinforced soil walls is more common for roads and civil applications as well as certain rail applications where loads and vibrations caused by train traffic are not significant. The research programs on MSE walls especially for high-speed train applications have helped validate certain design parameters.

In this paper some other pieces of information related to the impact of trains on MSE walls and service life considerations will be addressed.

Figure 1. An MSE wall alongside a railway

2 TYPE OF RAIL LINES

The design of MSE walls varies depending on the type of train and track. In Canada, there are two particularly distinct types of train: the lightweight passenger trains and heavy diesel locomotives. In the case of light trains, the live load is relatively small and in the range of regular highway traffic surcharge. The design of this wall type is well established. However, the long-term settlement should be carefully considered. In the case of heavy rail, the loads are much greater. The structures supporting this type of track in Canada are generally designed for heavy train surcharges, i.e. the Cooper E90 based on AREMA code (American Railway Engineering and Maintenance-of-Way Association), corresponding to a locomotive drive axles weight of 90,000 lbs and an equivalent uniform load of ±100 kPa. The consideration of these surcharges can greatly make a difference in the design of an MSE wall.

There is still no high speed rail in Canada but these are common in Europe and Asia. Research and experimental programs acquire lots of knowledge that can also be applied for trains used in Canada. The high-speed line project SEA Tours - Bordeaux in France (Figure 2) includes a program to monitor the dynamic behavior of Reinforced Earth walls.

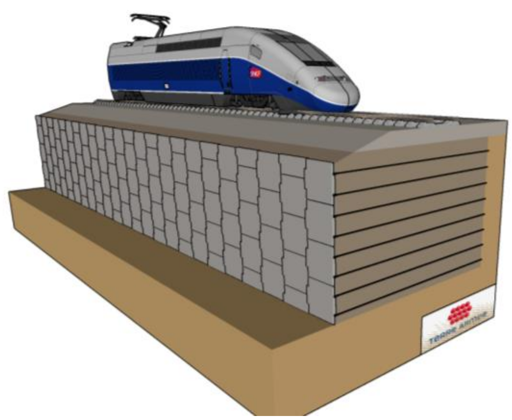

Figure 2. High speed train over a Reinforced Earth wall

3 FRICTION IN MECHANICALLY STABILIZED EARTH WALLS

MSE wall design is based on the principle of friction mobilization between the backfill and the reinforcements thus becoming a composite block. The interaction between the two components is a function of the shape and nature of the soil reinforcement, internal friction and density of the embankment and the vertical stress. A coefficient for soil and reinforcement interaction was determined by laboratory test and it is used for justification of the adhesion criteria in the internal stability of the structure. Structure design is done so that the friction in reinforcing strips resists the lateral pressure exerted by the backfill.

Tests in the field and in the laboratory were conducted to determine the maximum tension line which defines the resistance zone and the active zones within the fill (Figure 3). The active area is shown in dark orange color, located immediately behind the facing. The resistance zone is the area where the friction between high adhesion (HA) reinforcements and the backfill are working against pullout.

In the design of MSE structures, each reinforcement layer is designed for the maximum applied tension and checked whether the safety factor is appropriate. Pull-out resistance of reinforcements is also checked.

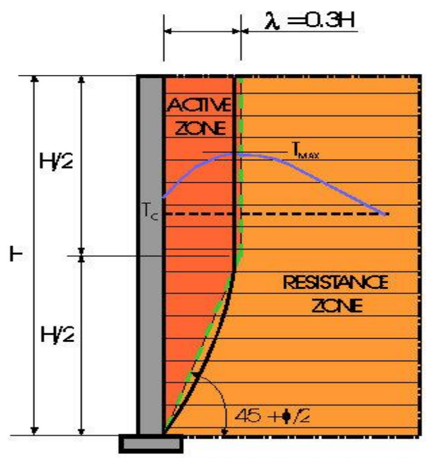

Figure 3. Max tension line, active and resistance zone

3.1 Effects of Vibrations

A train passing on MSE walls causes vibration inside the reinforced volume. The effects of vibration on the soil-strip friction for Reinforced Earth walls with steel strip reinforcements have been the subject of several studies. Here are some of the observations:

First, in an instrumented Reinforced Earth structure subjected to a high number of rail load cycles a reduction in the pull-out resistance was observed in the presence of vibration. However, the study concluded that there is no degradation of soil-strip interaction coefficient but an instant reduction of the vertical stress caused by the vibration is evident (Freitag, N., Bennani, P. and Soyez, L., 2013).

Usually the application of a traffic surcharge temporarily increases the tensile force in the reinforcement due to the increase in the vertical stress. However, the vibration caused during the passage of a train creates the phenomenon of phase shift that occurs between the moment that the tension is at a maximum level and the moment when the vertical stress is at its maximum.

Figure 4 shows the maximum tensile increase in top strip (depth of ± 60 cm) and we can also see the maximum stress. The maximum vertical stress does not occur when the tensile stress is at its peak.

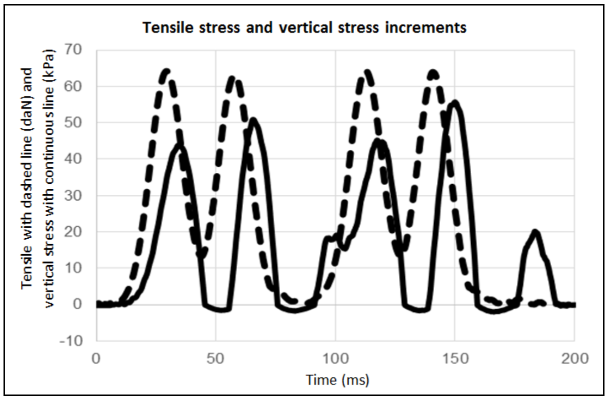

Figure 4. Increment of tensile stress (dashed line) vs vertical stress (continuous line). (Freitag, N., Bennani, P. and Soyez, L., 2013)

According to a modeling made by the finite elements using the software FLAC 2D for SEA line in France, the tensile forces are studied and compared in static and dynamic cases. Indeed, we note on Figure 5 that the overdesign factor for dynamic load decreased to approximately 80% of the one for static load in 200 km/h speed. It is also observed in this study that the variation of dynamic load over static load ratio appears to be negligible at the speed range of 200 km/h to 350 km/h. The effect of dynamic loading during the passage of trains has prompted European code IN 0203 to impose a factor of 1.2 to the tensile stress in the design of soil reinforcements in the reinforced soil mass.

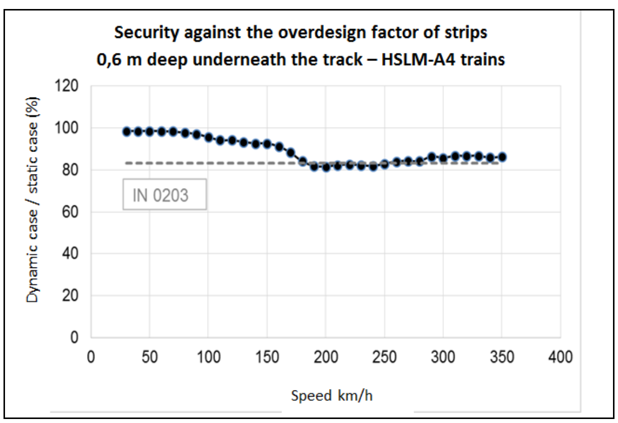

Figure 5. Speed effect on overdesign factor. (Freitag, N., Bennani, P. and Soyez, L., 2013)

The graph above considers a strip that is 0.6 m deep underneath the track. The effect of dynamic load due to passing a train dissipates by depth and is negligible for the deeper strips, as shown in Figure 6. Accordingly the French Standard IN 0203 imposes a factor of 1.2 for tensile forces in the reinforcing strips which are located 1 m below the track level, factor of 1.1 for strips at 3 m depth to 6 m and no factor below 6 m. Besides, the studies have demonstrated that the train induced vibration does not have any effect deeper than 2.35 m and the dynamic effect disappears beyond that depth (Figure 6).

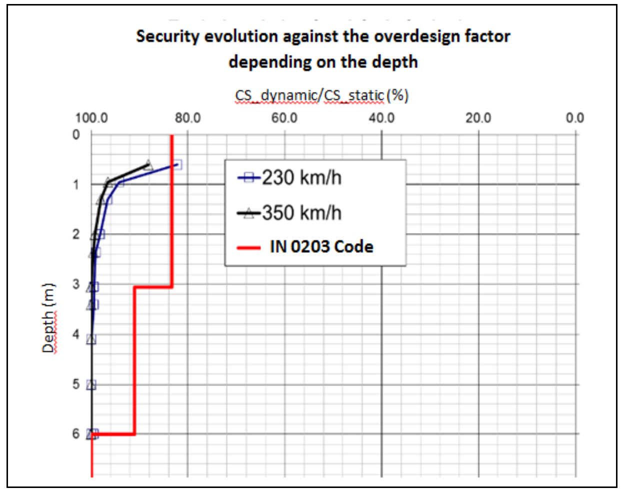

Figure 6. Overdesign factor evolution with depth (Freitag, N., Bennani, P. and Soyez, L., 2013)

3.2 SEA Tours - Bordeaux Project

The high speed trains project SEA Tours - Bordeaux in France contains almost 20 Reinforced Earth walls where trains travel with speeds over 320 km/h. Instrumentation was set up by IFSTTAR (l'Institut français des sciences et technologies des transports) on a wall over 15 m in height with trains traveling at a high speed (Figure 7).

Strain gauges and accelerometers were installed on the reinforcements and also accelerometers were mounted on the concrete panels. These will measure the propagation of vibrations and stresses within the matrix and check the external deformation as well. Data will be collected during the operational phase that is expected to begin in 2016.

As only few MSE walls have been built before to support trains traveling over 300 km/h, this study will provide us information to improve the standards all over the world.

Figure 7. Instrumentation installation

4 CRASH WALLS

In case of train derailment and crashing a MSE retaining wall, the impact applies a significant pressure on the reinforced block. The sliding of the gravity wall can be a mode of failure and needs to be checked in the design of the MSE wall. However the passive pressure mobilized behind the reinforced block, is usually sufficient to resist the sliding of the gravity wall.

The resistance of MSE retaining wall upon an impact is often questioned because of its relatively small facing panel thickness. At the moment of impact, the passive pressure of granular fill inside the reinforced zone is mobilized to support concrete panels. However the panel itself may crush and break under the impact load that could result in the granular material running out. The backfill is a structural component and the loss of material undermines the stability of structure.

In Canada, crash walls are required in MSE walls supporting a bridge over heavy train tracks as well as the retaining walls in close proximity of a railway. These crash walls must have a minimum thickness of 600 mm. However according to the guidelines for the use of a crash wall protecting bridge piers in the AREMA code, the crash wall is generally not required where the MSE abutment wall is located beyond 25 feet (7.6 metres) from the centerline of rail.

Several options exist for the construction of crash walls with reinforced backfill. In the first type of construction method, the MSE wall and the crash wall are designed and built separately. At the crash wall location, the MSE wall is built with a wire mesh facing to retain the lateral earth pressure behind the crash wall. A 600mm thick crash wall is cast in front of it to shield the MSE wall from derailment impact.

Figure 8. MSE wall with CIP crash wall (second method)

In the second method, the cast-in-place crash wall is in fact the MSE wall facing (see Figure 8). This method requires casting of the crash wall prior to backfilling and strip installation. To make the strip connection points, the connectors will be placed into the crash wall when the crash wall is being cast. The wall is backfilled and the soil reinforcements are installed in sequence following the completion of the crash wall. Even with the extra cost in forming, the second method is generally the preferred method by contractors. This method of construction needs assurance that the soil reinforcement has been fully mobilized and also no differential settlement is expected between the reinforced backfill and the cast-in-place wall (Figure 9). The cast-in-place crash walls can be designed with construction joints, e.g. at 3 to 6 m length interval to tolerate differential settlement. For this method to be successful it is important that a well-graded granular material be utilized as backfill to reduce the risk of any backfill compression and internal settlements. It is recommended that the crash wall be 3m or less in height.

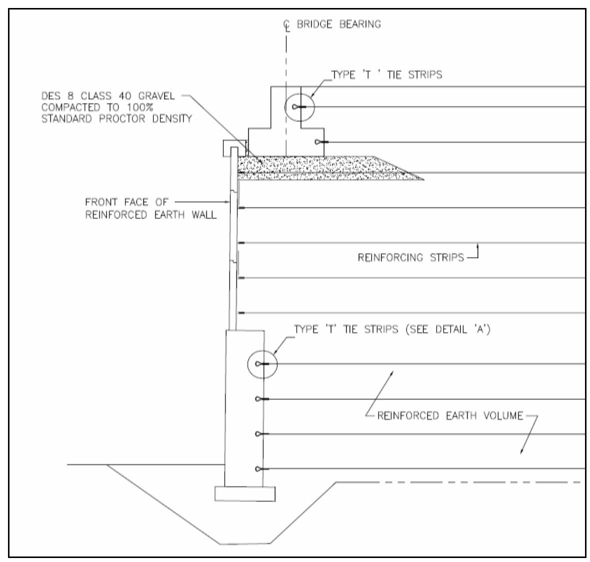

Figure 9. Crash wall section (second option)

The third method involves a combination of standard MSE wall with an approximately one (1) meter zone of soil-cement mix immediately behind the facing panels as shown in Figure 10. This zone is placed during backfilling operation to the required height of crash wall e.g. 3m in height. The granular backfill is usually stabilized with 4% cement in order to avoid backfill loss in case of derailed train crashes the panel facings. The broken panel can be repaired or replaced after the crash while the backfill stays stable behind the broken panel.

This method is has been practiced in countries like Australia and recently was used in a project in Vancouver, Canada.

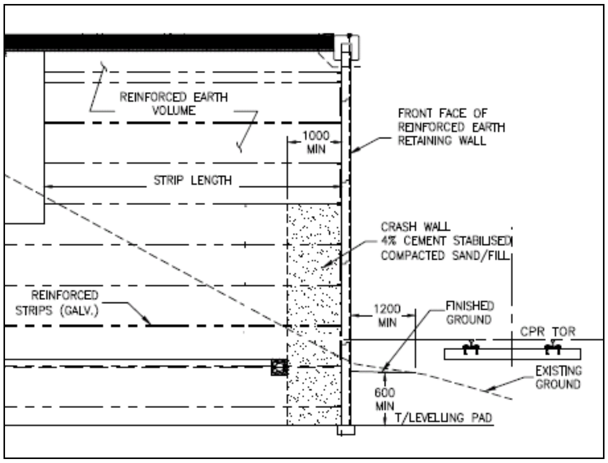

Figure 10. MSE wall with cement stabilized crash wall

5 DESIGN LIFE OF MSE STRUCTURES

The service life of an MSE structure depends on 3 principal factors: the performance of facing, the durability of soil reinforcements, and reliability of reinforcement connection at the facing. For long term service life (>50 years), it is always recommended to use pre-cast concrete panels for the facing. The concrete mix will then be designed for the desired life of the wall. Depending on the location and the environment, the wall designer employs a concrete with additives such as silica fume or fly ash and with some special admixture that enables the concrete to resist the freeze thaw cycle and de-icing salt. The rebar in the concrete can be also specified as galvanised steel, glass fiber reinforced polymer (GFRP) or even stainless steel to prevent the corrosion in concrete reinforcement.

The lifespan of an MSE structure is also based on the strength and durability of soil reinforcements. The section of a steel reinforcement is calculated and selected based on internal stability analysis of the MSE wall considering the defined loading, geometry of the wall and backfill properties. Based on many studies carried out over decades, the standard corrosion rate for steel reinforcements is defined in codes such as AASHTO for controlled environment and select backfill material. Utilizing these studies and guidelines, the wall designers are able to estimate the amount of thickness loss that will take place over the life of the structure. The amount of the thickness loss then will be added (as a sacrificial thickness) to the steel thickness required in the stability analysis. Therefore the strip is designed for the last year of the design life when the sacrificial thickness is corroded and the design thickness is remained.

For structural design, sacrificial thickness shall be calculated for each exposed surface according to AASHTO LRFD 7th edition, assuming that the soil backfill is not aggressive and meets the electrochemical criteria:

- Loss of galvanization=15 micron/year for first 2 years and 4 µ/year for subsequent years
- Loss of carbon steel= 12 µ/year after zinc depletion

Reinforced Earth Company has made several analysis regarding the durability of steel strips and many testing has been done over the years on the strips in controlled conditions in the laboratory and on strip samples extracted from existing and aged MSE walls

Occasionally, for the purpose of structure asset management, a durability monitoring program can be placed. For example in a project for GO Transit at the Snider Diamond rail grade separation in Vaughan, Ontario a method of assessing condition of the soil reinforcement throughout the service life of the project was implemented. Many 1 m test strips were embedded in the wall, behind the test panels. The thickness and weight of the strip coupons had been measured before the placement and the strips were carefully labelled and identified for future extraction. In addition, inspection program for the wall system was developed. Figures 11 through 13 show the test strip placement detail and a couple of picture regarding test strips and test panels.

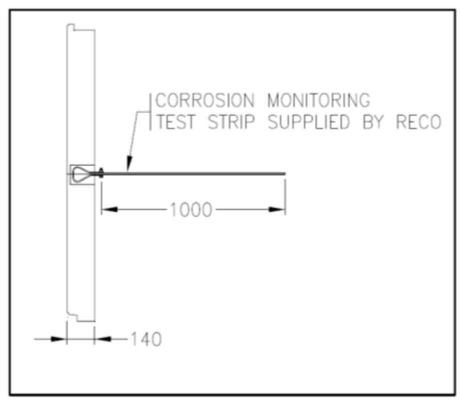

Figure 11. Test strip placement detail

Figure 12. Test strip placement at/behind a test panel

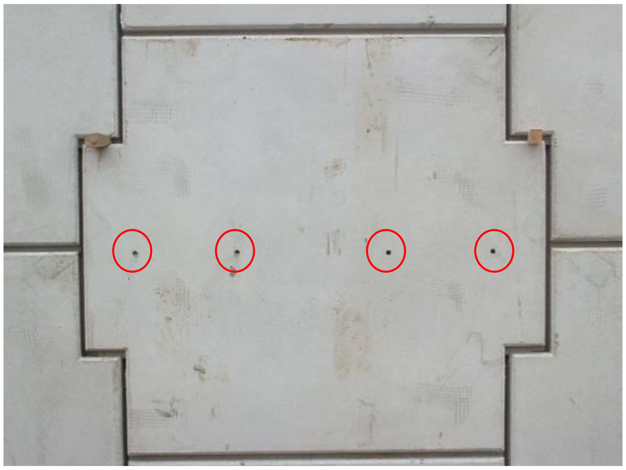

Figure 13. Test strip location marked with a small hole

When the backfill is too aggressive for steel e.g. when the sulphate or chloride content in the available backfill exceeds the limit, the designer can consider extensible reinforcements (geosynthetics). However, the application of extensible reinforcements for MSE walls supporting heavy loads or MSE walls higher than 9m requires complete understanding of the material behaviour and not often recommended. The application of geosynthetic reinforcement must be carefully analysed before using it in rail-supporting applications.

6 CONCLUSION

The use of mechanically stabilized earth walls for railway applications requires some consideration in the design of structures. The effects of vibration during the trains passing is one of the considerations. Accounting for the phase difference between the maximum tension in the reinforcing strips and the vertical stress applied by the vertical load is essential in the design. However, according to the experiments conducted, the reduction of overdesign factor is not directly proportional to the speed of the train and the reduction of overdesign factor with the increase of speed becomes negligible at the speeds exceeding 200km/h. The effect of dynamic loading imposed by a train (phase shift phenomenon) also reduces abruptly with depth and its effect is almost zero beyond 3.0 m underneath the railway. The high-speed train SEA Project in Bordeaux on which several reinforced soil structures have been put in place will certainly improve the knowledge about this phenomenon and the effects of vibration in this type of work.

They are many ways to achieve a safe MSE structure subject to an impact load from a de-railed train. The reinforced soil is very efficient for this kind of application as it is flexible enough to be able to absorb large amount of impact energies without undergoing significant deformation and without needing any major repair. The main consideration is to protect the facade concrete panels that are in fact the most brittle part of the wall.

Different techniques have been invented to address concerns about the impact of trains on MSE walls. Cast-in-place concrete crash walls set up in front of MSE structures at bridges or utilizing a soil-cement mix behind the facing panels can prevent the potential loss of backfill as a result of train impact.

The MSE walls with steel reinforcement can be designed for any service life requirement. It can be considered in the design of reinforcing strips, tie strips and concrete facing. The corrosion rate for the steel strips is well-documented based on the electrochemical properties of the backfill and is commonly used in the wall design. In addition, test strips can be installed inside each MSE wall to ensure a safe structure throughout its service life.

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