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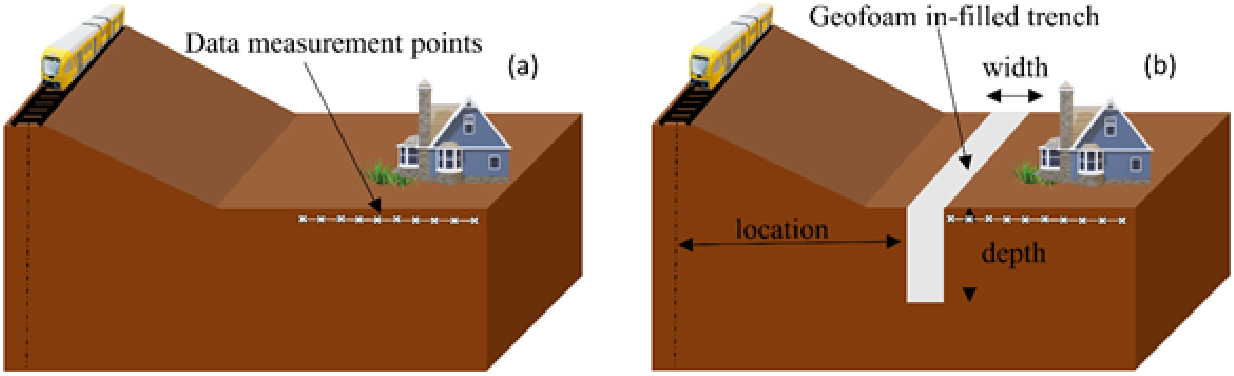

Figure-2: Railway embankment models (a) without trench (b) with EPS geofoam in-filled trench

Despite previous research works indicating that open trenches are more efficient than in-filled trenches, practical constraints in maintaining deep open trenches limit their field applications. These trenches are hence filled with construction materials like soil-bentonite mixtures, rubber-asphalt mixtures, etc., which possess excellent vibration mitigation characteristics.

The utilization of Expanded Polystyrene (EPS) geofoam as a wave barrier against ground vibrations has garnered significant attention recently. However, the survey of the literature reveals that limited research has been carried out on mitigating HST-induced ground vibrations using EPS geofoam. Research in this direction was hence carried out in the Railway Geotechnics Lab. at IITH, focusing on the mitigation of HST-induced ground vibration using EPS geofoam in-filled trenches. Finite element analyses were carried out using two-dimensional models of double-layer ballasted track segments for an axle load of 25 T using PLAXIS 2D, and the vibration attenuation efficiency of EPS geofoam trenches was evaluated in terms of reduction in the Peak Particle Velocities (PPV) of vibrations after installation of the trench beside railway embankment (**Figure 2**).

Studies were carried out on the influence of location, dimensions, and geofoam material in the trench for a wide range of train operating speeds. Results from the analyses revealed that vibration isolation trenches were most effective in mitigating vibrations when placed next to railway embankments. It was seen that deeper trenches exhibited a higher potential for attenuating vibrations and that the width of the trench was directly proportional to the efficiency of vibration attenuation.

About 44% reduction in the ground-borne railway vibrations could be achieved using optimized sections of EPS geofoam in-filled trenches. The research concluded that EPS geofoam in-filled trenches can serve as excellent passive vibration isolation barriers for attenuating ground-borne vibrations induced by high-speed trains.

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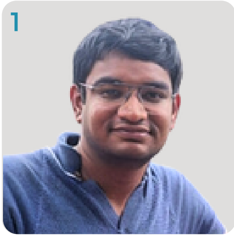
# Modeling and Analysis of Back-to-Back Mechanically Stabilized Earth Walls for Highway and Railway Bridge Approaches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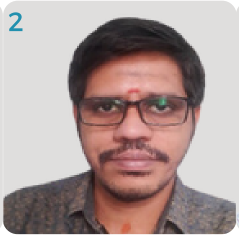
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Mechanically Stabilized Earth (MSE) Walls are flexible structures in which reinforcements are embedded into backfill to develop a frictional resistance between backfill soil and the reinforcements. This interaction through the mobilized frictional resistance provides stability of the MSE walls, as opposed to the conventional gravity retaining walls which achieves their stability by their self-weight.

Unlike a single MSE wall, when two MSE walls are placed in close proximity, they start to interact with each other, and a complex structure called back-to-back mechanically stabilized earth (BBMSE) walls is formed. MSE walls are designed based on the guidelines of the Federal Highway Administration (FHWA) [1]. FHWA guidelines for the design of BBMSE walls have given two extreme cases.

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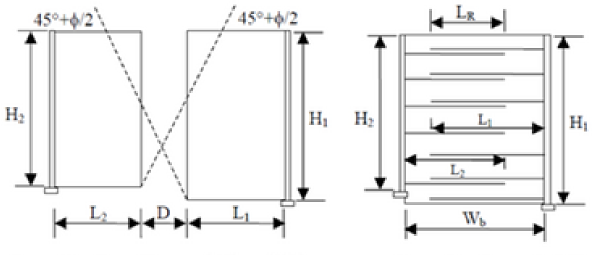
Case 1(a), in which the clear distance between the two walls is large enough ( such that they can be treated as two individual walls. In Case 1 (b), the overlap of reinforcements is more than 0.3 times the height of the short wall, and in this case, the active thrust can be ignored fully. **Figure 1** illustrates both cases of walls as per the FHWA. For the wall in between these two extreme conditions, FHWA recommends linear interpolation to obtain the active thrust at the end of the reinforcement.



Case (a): $D \geq H_1 \tan(45 - \emptyset/2)$ Case (b): $L_R \geq 0.3H_2$

Figure-1: Two cases for the design of BBMSE wall as per FHWA (f represents the friction angle of backfill)

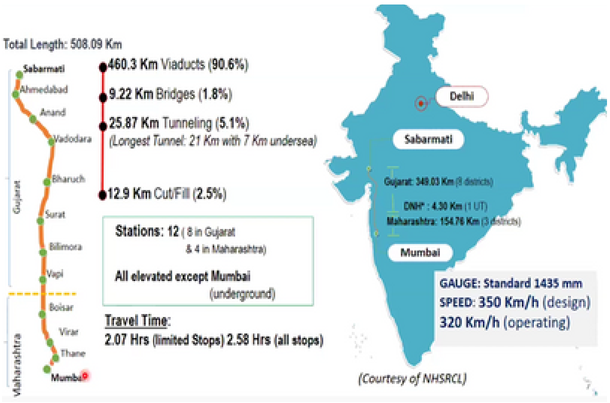


Figure-2: Railway line map of MAHSR project (courtesy: NHSRCL)

BBMSE walls are being used for highway bridge approaches worldwide, but in recent times they have also been used for railway bridge approaches. Japan made it a standard practice to use a BBMSE wall with a full-height rigid facing for the railway bridge approaches in high-speed trains. Even India's first bullet train project Mumbai to Ahmedabad high-speed rail (MAHSR), being implemented by India's National High Speed Rail Corporation Limited (NHSRCL) has proposed to adopt geosynthetic reinforced BBMSE wall for railway bridge approaches. MAHSR project consists of a railway line of 508.09 km comprising 475 km of elevated viaduct, 25.87 km of tunnels, 9.22 km of bridges, and 12.9 km of embankment section. **Figure 2** shows the railway line route for this project.

Furthermore, the proposed cross-section for the embankment, elevated viaduct, and BBMSE retaining wall for the bridge approach are illustrated in **Figure 3**.

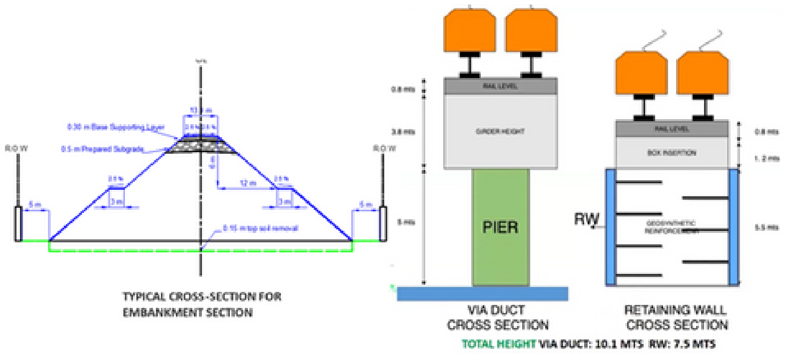


Figure-3: Proposed cross-section of the embankment, viaduct, and BBMSE wall for MAHSR project (courtesy: NHSRCL)

Accordingly, BBMSE walls for various conditions and loading scenarios are modeled and analyzed. Initially, a BBMSE wall with varying width-to-height (W/H) ratios subjected to compaction stress and surcharge loading was simulated by Sravanam et al., 2019 [2]. Walls with W/H ratios of 1.4, 1.7, 2.0, and 3.0 were considered. It may be noted that FHWA recommends the minimum length of reinforcement as 0.7H. **Figure 4** illustrates the models for the two extremes with W/H=1.4 (i.e., reinforcements right next to each other) and W/H=3.0 (i.e., reinforcements are far apart). In this modeling, the complex interaction between different interfaces, namely, the interface between wall facing and backfill, between backfill and reinforcements, and between two adjacent facing panels was modeled (as shown in **Figure 5**). Additionally, the maximum shear strain contours were also plotted for different conditions to identify the critical slip surfaces and their interaction within BBMSE walls (refer to **Figure 6**). It was observed that the lateral earth pressure at facing was independent of W/H ratio of the wall. Sravanam et al., 2020a [3] studied the behavior of connected (i.e., a single reinforcement running from one end to the other) and unconnected (having two reinforcements one for each wall) BBMSE walls with a W/H ratio of 1.4 for the highway bridge approaches and concluded that the lateral displacements were reduced by 50% in case of the connected wall as compared to the unconnected wall.

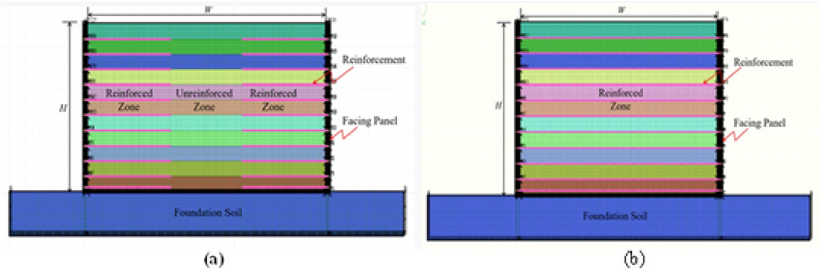


Figure-4: Models of BBMSE walls with (a) W/H > 1.4 (b) W/H =1.4

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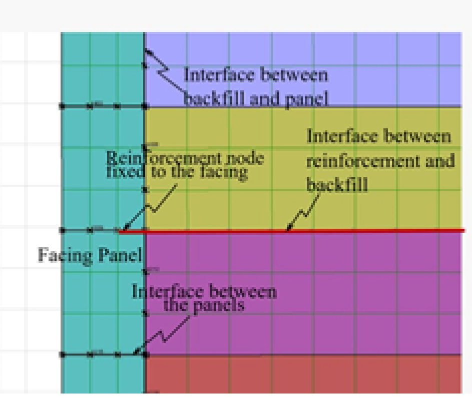

Figure-5: Interfaces between various components of BBMSE wall

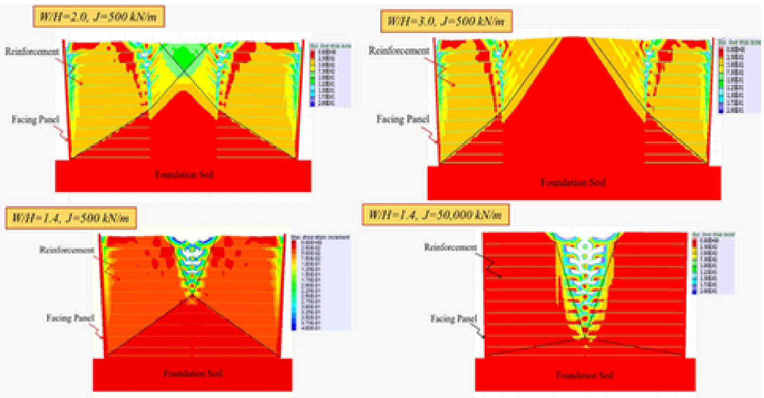

Figure-6: Critical slip surfaces for different BBMSE walls with varying W/H ratio

Furthermore, a BBMSE wall with full height rigid facing wall was studied by Sravanam et al., 2020b [4] in which an arching phenomenon was highlighted behind the wall facing because of the difference in stiffness of the wall and reinforced backfill which leads to mobilization of shear stresses along the interface between the unreinforced and reinforced zones.

Presently, a BBMSE wall with an 8.4 m wide backfill and a height of 6 m supporting a slab-track system with rails placed at a clear spacing of 1.435 m was simulated as shown in **Figure 7**. A finite element package, ABAQUS, was chosen to simulate the wall model, to analyze the interaction of connected reinforcements and backfill under the dynamic train loading. The E-5 series Shinkansen train has been proposed to be used for the MAHSR project having a wheel load of 67.5 kN, length of 253 m, and design speed of 350 km/h.

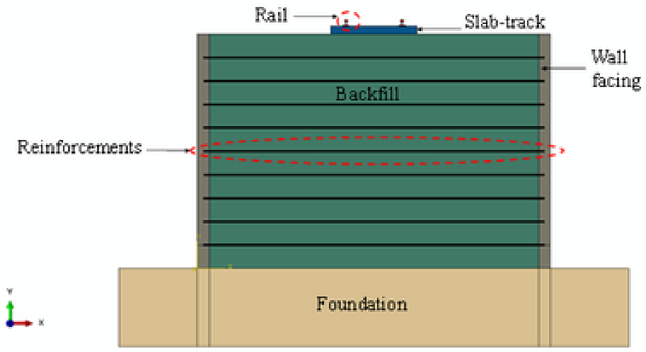

Figure-7: Developed model in the ABAQUS as a part of present study

Hence, the dynamic train load was applied in the form of a positive sinusoidal wave with a frequency of 38.8 Hz and an amplitude of 67.5 kN for a duration of 2.6 seconds. From the simulations, it was observed that the maximum vertical settlement occurring at the mid-length on top of the wall was about 17.8 mm and the maximum lateral displacement occurring on top of the wall facing was 12.5 mm.

Going forward, advanced numerical models considering the soil behaviour, the interaction between geosynthetics and backfill, and loading conditions will be developed for different width-to-height ratios. Furthermore, the research group at IIT Hyderabad, through a research project funded by the National Highway Authority of India through the Transportation Research and Innovation Hub (TRI HUB), is working extensively on developing ready-to-use design charts for lateral earth pressures and displacements for different scenarios to help the practising engineers involved with BBMSE walls.

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