Analysis of Mechanically Stabilized Earth walls

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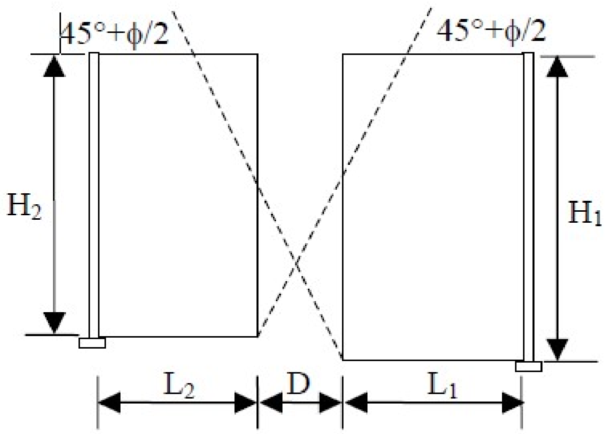
Abstract- **Back-to-back mechanically stabilized earth walls (BBMSEW) are used in highway applications like embankments, flyovers, bridge approaches, narrow ramps, turning lanes and earth dams. The design guidelines and literature available on BBMSEW are limited and in analytical method the BBMSEW has to be designed independently. Thus, it becomes necessary to understand the interaction of both the walls on either side in BBMSEW. Design guidelines of BBMSEW has been discussed in FHWA design manual (Berg et al. 2009). Berg et al. divided BBMSEW into two cases: Case 1 where in the width of the embankment between BBMSEW is more such that each wall acts independently and in Case 2 where there is an overlap in reinforcement in the middle resulting in interaction between the two walls. The BBMSEW is numerically analysed for the cases when distance D=0 to D≥Htan(45-ϕ/2) using Finite element analysis (FEA) to determine the effect by varying parameters such as width to height ratio of wall, backfill soil (friction and cohesion) and vertical spacing of reinforcement.**

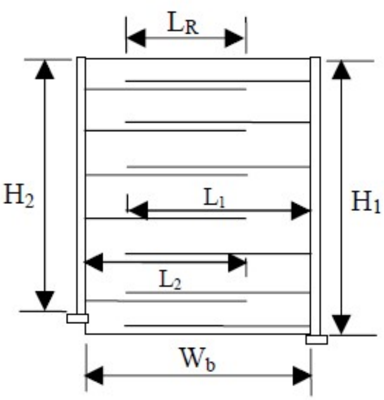
Keywords – Back-to-back mechanically stabilized earth walls, Geogrid, Finite element analysis, Reinforced backfill soil, Factor of Safety.

I. INTRODUCTION

MSE walls Since 1970s have gained widespread acceptance mostly for transportation applications because of their simple design, speedy construction, durability, aesthetics, reduced site preparation, durability and construction space requirement and also ability to bear large deformations without any structural distress [2]. They have found to be quite efficient, durable and highly resistance to static loads and dynamic loads. Many codes for design procedures and guidelines are available worldwide. Apart from their cost effectiveness and practical benefits, they have at least thirty percent lesser carbon footprint along with the great benefit in case of sustainability than conventional walls or other methods of stabilization, like RCC and concrete gravity retaining walls. Although the MSE wall has formal design requirements and guidelines, they are capable of adapting different local conditions like terrain geometry and different aesthetic choices, and prove to be cost effective as compared to other types of structures [3]. Figure 1 shows the two cases considered regarding the distance of two back-to-back walls, D, such as in the FHWA design guidelines. BBMSEW design has been discussed in design handbook of Berg et al. 2009. BBMSEW were classified into two types by Berg et al. as shown in Figure 1. In Case 1, as shown in Figure 1a the full width of base is large enough such that each wall on either side of BBMSEW behaves and can be designed independently. That is the active wedge behind each wall in BBMSEW can fully develop without intersecting with the reinforcement of both walls. In other words where the reinforcements coming either side of the facing panel, do not overlap. Theoretically, the active pressure is reduced if the distance, D, between the two walls of BBMSEW is less than $D = H_1\tan(45° - \phi/2)$ where H_1 is the height of taller of the parallel walls, since the active wedges at the back of each wall cannot fully spread out. However, it is considered for design purposes that when $D \geq H_1 \tan(45° - \phi/2) \approx 0.5H_1$ entire active pressure is mobilised. In Case 2, as shown in Figure 1b the reinforcements are overlapping making the two walls to interact. That is no active earth pressure from the backfill needs to be considered for external stability calculations when the overlap, L_R, is greater than $0.3H_2$, where H_2 is the shorter of the parallel walls. For intermediate geometries between Case 1 and Case 2 that is when distance D ranges from D=0 to D = H_1tan (45° - ϕ/2) the active earth pressure may be linearly interpolated from the full active case to zero [1].



(a)



(b)

Figure 1. Back-to-back Mechanically stabilized earth wall (a) Case 1 (b) Case 2.[1]

II. OBJECTIVE

The objective of this study is to analyse the stability of BBMSEW with geogrid reinforcement using finite element (FE) modeling to determine the effect of different parameters on the behaviour of BBMSEW. These parameters include such as width to height ratio of wall, backfill soil parameter (friction and cohesion), and vertical spacing in reinforcement.

III. NUMERICAL MODELING - FINITE ELEMENT ANALYSIS

The Midas GTS NX software was used in this study to perform the two-dimensional (2D) numerical analysis in the plane strain condition for foundation soil, backfill soil, facing panels and geogrid property for geogrid. The BBMSEW height is kept fixed, equal to 6 m, and foundation soil depth of 3m, the baseline model of BBMSEW with dimensions is shown in Figure 2. The distance between the walls varied from 1.267H to 3H. The two types of soils that are considered are backfill soil and base/foundation soil. The backfill soil used for MSE wall is considered to be granular fill as specified in FHWA. A stiff soil like rock is considered as the foundation soil to reduce its influence on the reinforced soil behavior. The constitutive model considered for both backfill soil and base/foundation soil is the Mohr Coulomb. In Table 1 properties of both the soils are tabulated. The reinforcement used to reinforce the BBMSEW was geogrid. The constitutive model used for geogrid was elastic. The vertical spacing of each layer of geogrid is 0.75 m and the reinforcement length was varied accordingly. The properties considered in modeling the geogrid are given in Table 2. For the current study the segmental precast concrete facing panels were modeled to simulate the wall. Each wall contains four segmental concrete facing panels of 1.5 m in width and height and 0.18 m in thickness. The facing panel properties used in modeling the segmental panel are given in Table 3. The walls are built in stages as per the construction sequence, simulating the real construction process of BBMSEW. The working strains, overall Factor of Safety (FoS) and displacement were evaluated using specified material parameters and dimensions.

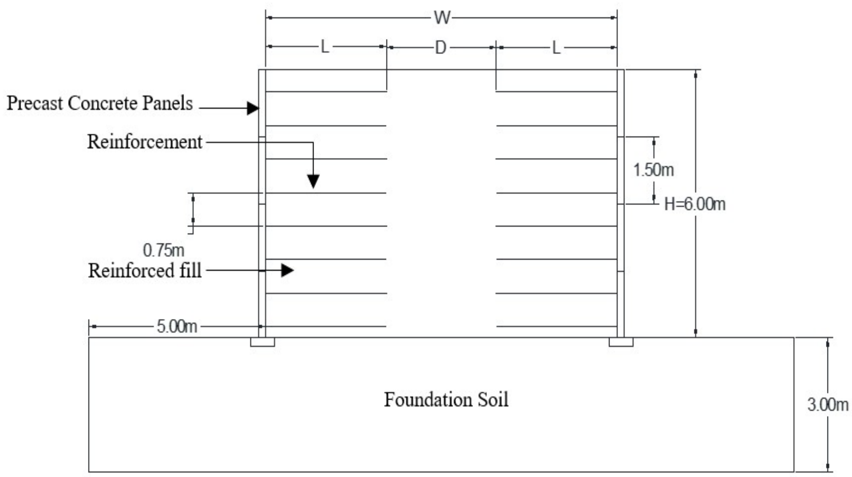


Figure 2. Baseline model of BBMSEW with dimension.

Table - 1 Material properties of backfill and base soil.

Model	Materials	Unit weight γ (kN/m³)	Friction angle ϕ (°)	Cohesion c (kPa)	Elastic Modulus E (kN/m²)	Poisson's Ratio, υ
Mohr Coulomb	Backfill soil	18	25, 30, 35 & 40	0	$3x10^4$	0.3
Mohr Coulomb	Base soil	22	30	15	$2x10^5$	0.25

Table - 2 Properties of Geogrid.

Model	Vertical spacing of reinforcement (m)	Unit weight γ (kN/m³)	Elastic Modulus E (kN/m²)	Poisson's Ratio υ
Elastic	0.75	0.5	$5x10^6$	0.4

Table - 3 Properties of Facing Panels.

Model	Size of facing panel (m)	Thickness of facing panel (m)	Unit weight γ (kN/m³)	Elastic Modulus E (kN/m²)	Poisson's Ratio υ
Elastic	1.5x1.5	0.18	24	$3x10^7$	0.2

IV. Critical Failure Surfaces

The location and shape of critical failure surfaces of the BBMSEW at different wall width to height ratios (W/H) determined based on the contours of plane strain in the FE analysis are indicated in Figure 3, 4, 5 and 6. In Figure 3 it is seen that the critical failure surfaces in two opposite walls do not intersect with each other, indicating that both the walls on either side behave independently. This conclusion is same with that in Case 1 as indicated by Berg et al. 2009. Since, by analytical method BBMSEW cannot be analysed to know its interaction mechanism, it becomes important to analyse the BBMSEW when the distance between the two walls decreases, the results shown below are based on the Finite element analysis. Figure 6 shows that critical failure surfaces are not developed within the BBMSEW when D=0 that is when reinforcement layers are not connected as they meet at the centre of the wall. As shown in Figure 6 that the critical failure surfaces are not developed at the end of each reinforcement which indicates that the two walls in BBMSEW do not behave independently. Figure 4 and Figure 5 shows critical failure surfaces when distance D is greater than 0 where the failure surface emerging from both walls intersect at each other hence they do not behave as independent walls.

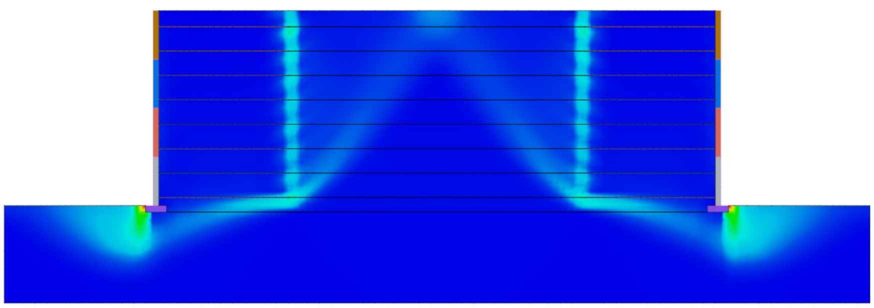


Figure 3. Critical failure surfaces within the wall at W/H = 3.0

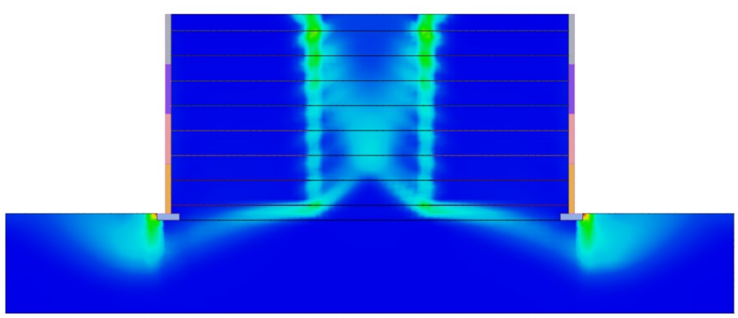


Figure 4. Critical failure surfaces within the walls at W/H = 2.0

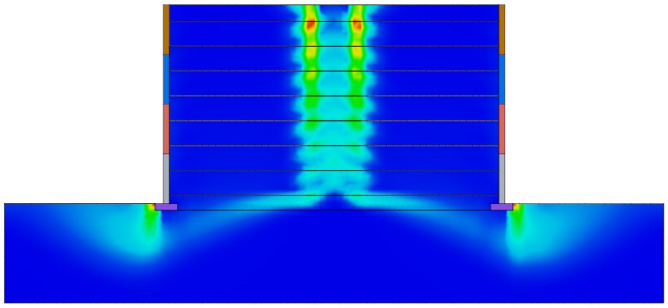


Figure 5. Critical failure surfaces within the wall at W/H =1.67

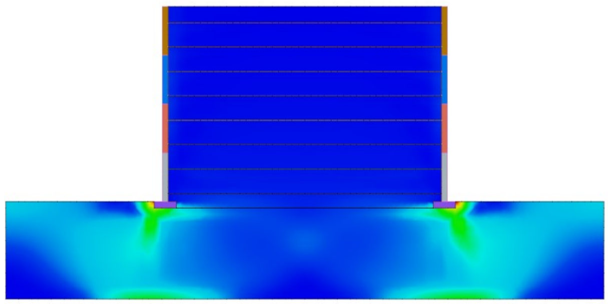


Figure 6. Critical failure surfaces within the wall at W/H = 1.4

V. Results from Analysis

5.1 Overall Factor of Safety –

Varying backfill friction angle - The FoS against shear failure was obtained using a strength reduction method (SRM) for same D i.e D=Htan(45-ϕ/2) and varying values of W/H ranging from 1.267 to 3H. The FoS for backfill soils with different friction angles 25°, 30°, 35° and 40° were obtained from analysis. As shown in Figure 7 the FoS of the BBMSEW increases with the increase in friction angle of backfill soil as well as the distance between the walls.

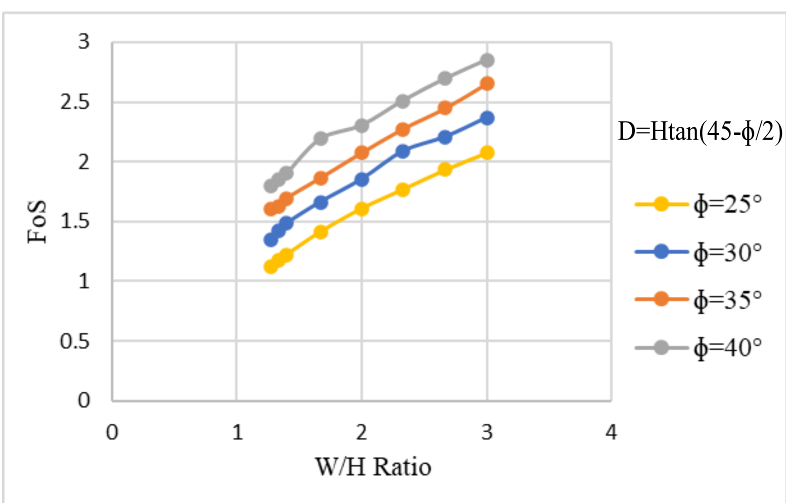


Figure 7. FoS for varying friction angle and W/H ratio.

Varying distance D for different W/H ratio - The FoS were obtained for D values ranging from 0 to 0.83H for four different W/H ratio. The results are given as the normalized distance between the BBMSEW (D/H) for backfill soil having friction angle of 35°as indicated in Figure 8. The FoS of the BBMSEW decreases with the increase in the distance D between the walls and increases with increase in W/H ratio for the same. Decreasing distance D leads to the increase in the FoS.

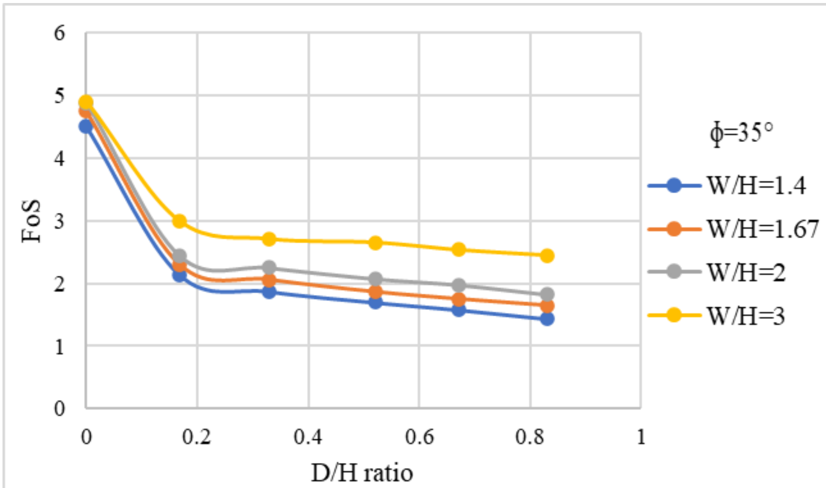


Figure 8. FoS for varying distance D for different W/H ratio.

Varying distance D and friction angle - The FoS for D values ranging from 0 to 0.83H for same W/H ratio of 1.67 and for varying reinforced soil friction angle of 30°, 35° and 40° were obtained from analysis. The results are shown as the normalized distance between the BBMSEW (D/H) for varying friction angle as shown in Figure 9. The FoS of the BBMSEW decreases with the increase in the distance between the two walls and then converges to a constant value. Decreasing distance D leads to the increase in the FoS for different friction angles.

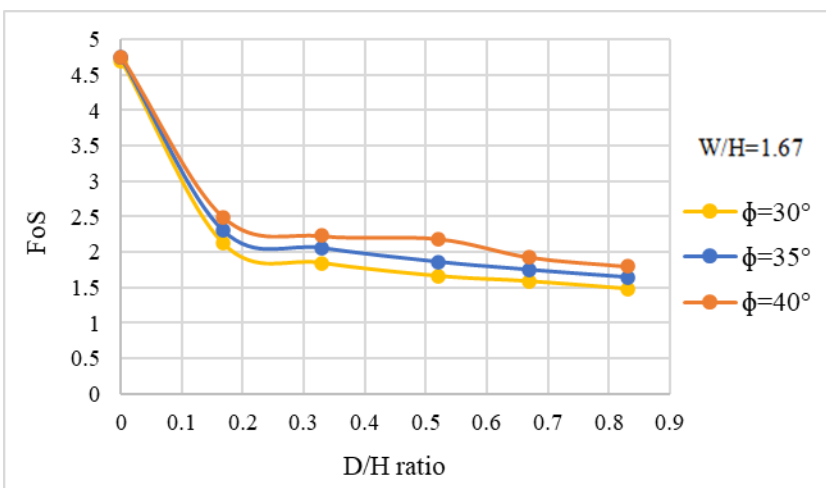


Figure 9. FoS for varying D distance and friction angle.

Varying vertical spacing between reinforcement - The FoS was determined for varying vertical spacing between reinforcement i.e 0.5m, 0.6m, 0.75m 0.9m and 1.2m for three different W/H ratio of 1.4, 1.67 and 2 having backfill soil friction angle of 35°. As seen in Figure 10 the FoS of the BBMSEW slights decreases by marginal value as vertical spacing between the reinforcement increases.

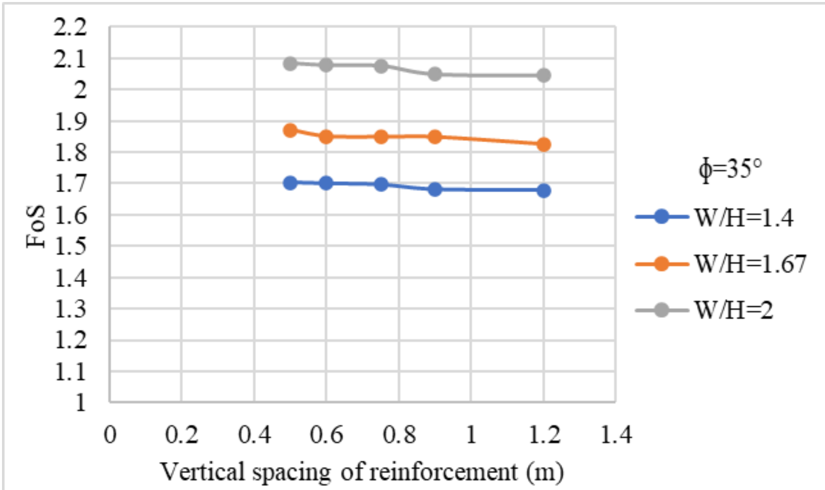


Figure 10. FoS for varying vertical spacing between reinforcement.

Varying cohesion value of reinforced soil - The BBMSEW was also analysed for varying cohesion value of backfill soil with W/H ratio of 1.67 and reinforced soil friction angle of 35°. From Figure 11 it is seen that FoS of the BBMSEW slightly increase with increase of cohesion value of reinforced soil.

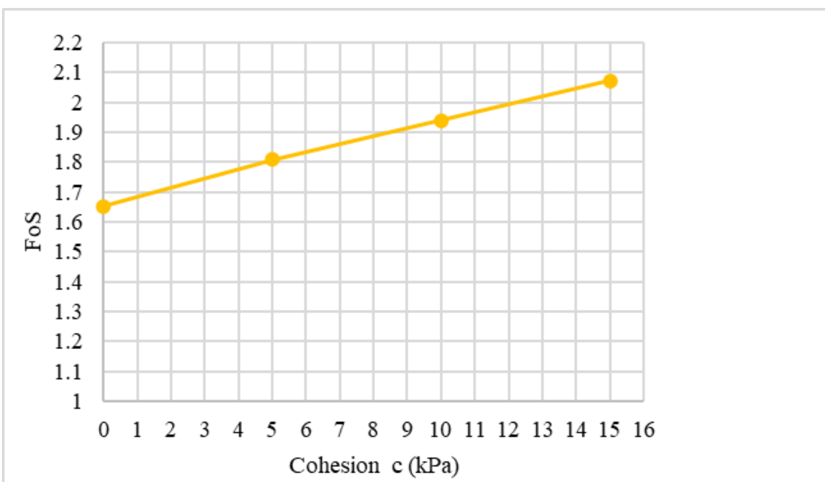


Figure 11. FoS for varying cohesion value of reinforced soil.

Same reinforcement length for varying W/H ratio - The BBMSEW was analysed for same length of reinforcement of L=0.7H which is minimum length of reinforcement recommended by FHWA for varying W/H ratio ranging 1.4 to 3 with backfill soil friction angle of 35° to determine FoS. Figure 12 shows that the FoS of the BBMSEW first increases and remains almost same as W/H ratio increases.

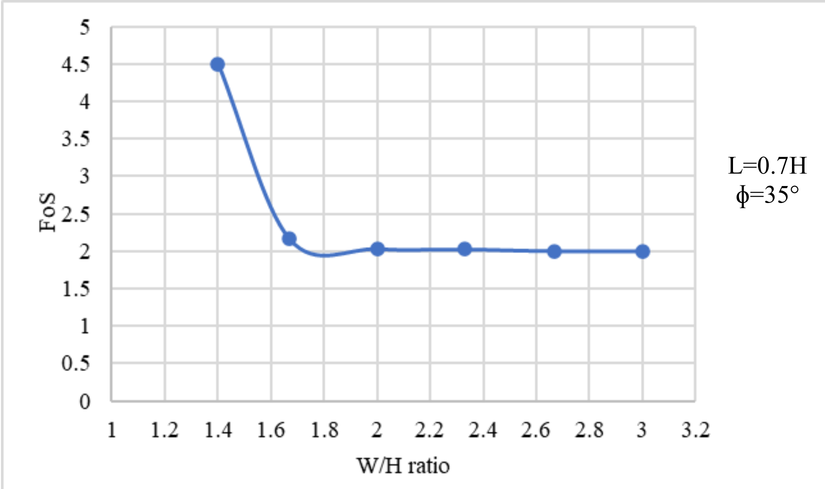


Figure 12. FoS for same reinforcement length for varying W/H ratio.

5.2. Soil/Reinforcement Shear Displacement at end of construction –

To determine the soil/reinforcement shear displacement at the end of construction stage analysis is done considering three different W/H ratio having same reinforcement length of 0.7H i.e 4.2m for backfill soil with friction angle of 35°. As seen in Figure 13 the displacement of soil/reinforcement increases from the bottom of the wall as height of wall increases till the fifth reinforcement layer i.e at 3.25m and then decreases as it reaches the full height of wall. As the W/H ratio and distance D increases, the values of the wall displacements slightly increase.

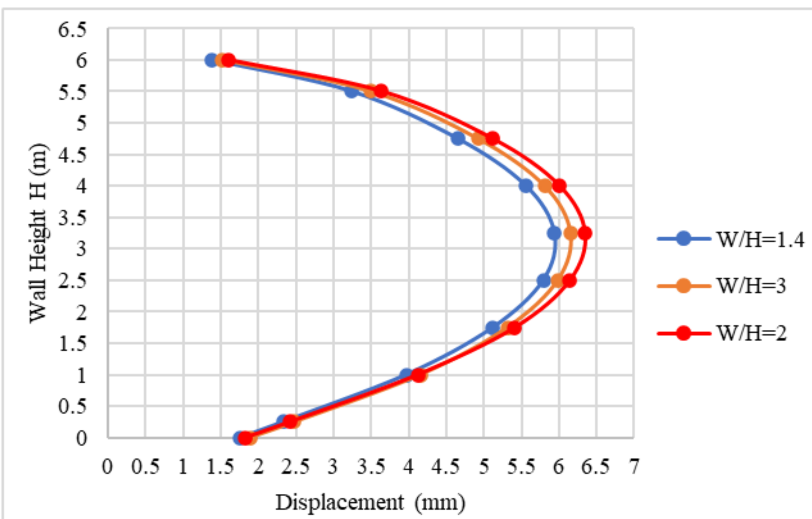


Figure 13. Soil/Reinforcement shear displacement at end of construction.

VI. CONCLUSION

The conclusions drawn from this study are:

1. The results obtained using Midas GTS NX are consistent with those of FHWA design guideline that considers there is significant interaction between the BBMSEW when D<Htan(45-ϕ/2) and the walls acts independently when the distance D≥Htan(45-ϕ/2).

2. The results obtained using FEA show that the FoS increases that is stability of BBMSEW increases as friction angle of backfill soil increases hence proves that backfill soil friction angle greater than or equal to 34° as recommended by FHWA is suitable since it gives a FoS greater than 1.5 for all W/H ratio.
3. For D = Htan (45-ϕ/2) the FoS increases with increasing the W/H ratio since length of the reinforcement increases as width of BBMSEW increases.
4. When D is close to zero the FoS increases that is as the distance D between the BBMSEW increases the FoS gets reduced.
5. The FoS decreases when distance D between the BBMSEW increases, but increases with increase in the backfill friction angle indicating that lesser the distance D better is the stability of BBMSEW.
6. As the vertical spacing between the reinforcement increases there is slight reduction in FoS by marginal value.

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