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Finite Element Analysis of Segmental Precast Concrete Panel Reinforced Earth Retaining Wall

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ABSTRACT

Reinforced earth retaining walls are being utilized more frequently in civil infrastructure projects as an alternate design structure to typical reinforced concrete walls and other structures for supporting backfill. The objective of the present study is to model and analyze a 2-dimensional Segmental Precast Concrete Panel (SPCP) wall using the 2-dimensional finite-element tool PLAXIS and analyze the behaviour of the wall concerning the effect of reinforcement type and surcharge loads. The present work also includes the investigations of the effects of reinforcement type and surcharge loads, as well as the influence of different supporting systems on the deformations and ground-surface settlements of the SPCP wall. Ribbed steel reinforcements, Polyethylene Terephthalate (PET) geogrids and Density Polyethylene (HDPE) geogrids are used to evaluate the wall deformations for reinforcement types. For ribbed-steel reinforcement, ground settlements and wall deformations are 14% and 25% less compared to those of PET and HDPE geogrid reinforcements, respectively. With the increase in surcharge on the backfill soil, wall deformations and surface-ground settlements are increased significantly by 150%. To decrease the deformations of walls resting on soft soil, pile foundations and aggregate piers are considered as supporting solutions. In the case of reinforced blocks with pile foundation as supporting systems, the wall deformations and settlement are 60% lesser than for aggregate pier supporting systems.

KEYWORDS: Segmental precast concrete panel, PLAXIS, Reinforcement type, Aggregate pier, Pile Foundation, Wall deformation.

INTRODUCTION

For supporting earth fills in civil infrastructure projects throughout the past three decades, MSE retaining walls have been used more and more as a structural substitute to traditional reinforced-concrete (RC) retaining walls. Geotechnical and environmental engineering streams are increasingly using geosynthetics. Over time, these items have aided engineers and builders in solving a variety of engineering issues when the usage of traditional building materials would be constrained or significantly more expensive (Souliman *et al.*, 2011). The two main components of reinforced soil are soil and reinforcement consisting of various materials and qualities (Hulagabali et al., 2018a). Reinforced earth retaining walls are also called MSE walls. Different types of reinforced earth retaining walls are Modular Block Walls (MBWs), Segmental Precast Concrete Panel (SPCP) walls, geosynthetics-wrapped walls and gabion walls. The most significant advantages of MSE walls are their flexibility and capacity to absorb deformation caused by poor subsoil conditions in foundations. These walls can

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retain earth fills of substantial and adaptable height and sustain applied loads on the surface at a lower cost than RC walls. Due to the backfill's interaction with the inclusion materials, the MSE wall functions as a cohesive, flexible block that can withstand a variety of loading types and deformations. In addition, based on measurements made in seismically active regions, these structures have exhibited a greater resilience to seismic loading than rigid concrete structures. Numerous scholars have performed comprehensive numerical and case-based investigations emphasizing the behaviour of MSE walls.

To explore the behaviour of linked and unconnected back-to-back walls under operating loads, a numerical model was developed by Sravanam *et al.* (2020). In-depth discussions were held regarding the impact of reinforcement stiffness on tensile force profiles, the maximum tensile force that can be developed within the reinforcement, as well as lateral pressures and lateral deformations for both linked and unconnected walls. The tensile forces developed in the reinforcement for the connected case were found to be consistent over the length of the reinforcement, while the lateral pressures at the facing in both cases were found to be nearly equal. Hulagabali *et al.* (2018b) examined the behavior of reinforced earth retaining wall of 6-m height with different types of support systems. The authors took into account drilled shafts, pile foundations and rammed aggregate piers. The analysis was carried out using the finite-element software PLAXIS 2D. Deflection of the walls, ground settlement behind them and the displacement of the facing panels were compared across the three different foundations. Wall deformations, ground settlements and facing panel deflections were found to be less compared for the drilled shaft. Koerner and Koerner (2018) reported 320 failures of MSE walls. The database included 99 extreme deformation cases and 221 collapse cases. 71% of the walls were between 4m and 12m tall, 94% walls were reinforced with geogrids and the remaining 6% were reinforced with geotextile. In less than four years after the completion of construction, 246 (77%) failed (12 of which failed during construction). 232 (73%) used reinforced soil with silt and clayey soils. 245 (76%) walls were improperly compacted. 317 (99%) were due to inadequate design or construction (incidentally, none were due to defects in the geosynthetic manufacturing material). Rollins, Price and Bischoff (2012) conducted full-scale tests on three 400-mm pipe piles spaced behind a 10.5-m high MSE wall at 1.6, 2.9 and 5.2 pile diameters. The piles were double-coated with a low-density polyethylene (LDPE) sheets of 0.25-mm thickness to reduce drag. Calculated tensile forces in the reinforcements adjacent to the pile nearest to the wall were higher, suggesting that the reinforcing grid provided additional resistance to pile movement.

The aim of the present study is to analyze a two-dimensional SPCP wall using the FEM tool PLAXIS and validate the numerical model with field wall instrumented data available in the literature. It also aims to perform the parametric analysis using the FEM tool, considering the influence of reinforcement type and surcharge loads. Furthermore, it aims to analyse the influence of different supporting systems, such as aggregate pier and pile foundation on the wall deformations and ground-surface settlements of the SPCP wall resting on soft clay. The flowchart of the research design used for the numerical study is shown in Fig. 1.

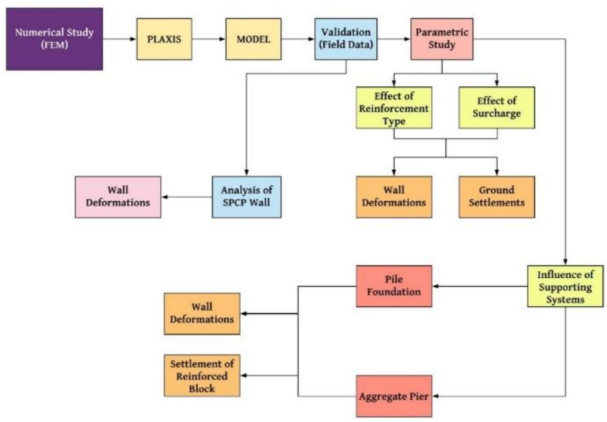


Figure (1): Flowchart of the numerical study

Validation Study of the PLAXIS Model

The SPCP wall is modeled as per the field wall instrumented and analyzed by Runser *et al.* (2001) to validate PLAXIS model of the present study. Parametric analysis using the 2-dimensional finite-element method involves investigating the effects of backfill soil stiffness, foundation soil stiffness and panel-soil interface shear on the MSE wall performance. The height of the wall (H = 16.9 m) and the embedment depth (D=1.5m) are chosen. The numerical model's width is chosen to simultaneously reduce the impact of problem boundaries and optimize computation time. The reinforcement length is considered as 70% of the height for the top 17 layers and 90% of the height for the bottom 5 layers, as per design code (AASHTO, 2010; Berg *et al*., 2009). The facing is modeled as a segmental precast panel with 1.5-m height with a joint thickness of 20 mm. Linear elastic plate elements are used to model the panels and joints (also known as bearing pads). Through hinge contacts that have no rotational stiffness, the elements are joined. As a result, the bending moment, but neither vertical nor horizontal loads, can be transmitted at the contact between each bearing pad and the adjacent concrete panels. The Mohr-Coulomb elastic-plastic materials are used to represent the soil zones. Each panel unit has two horizontal rows of reinforcement components attached to it (with uniform vertical spacing between reinforcements being 0.75m, except for the top and bottom layers). The filling soil in front of the wall is used as the foundation soil for the sake of simplicity. The numerical wall is constructed gradually from the bottom up to mimic field construction.

Geometry of the Wall

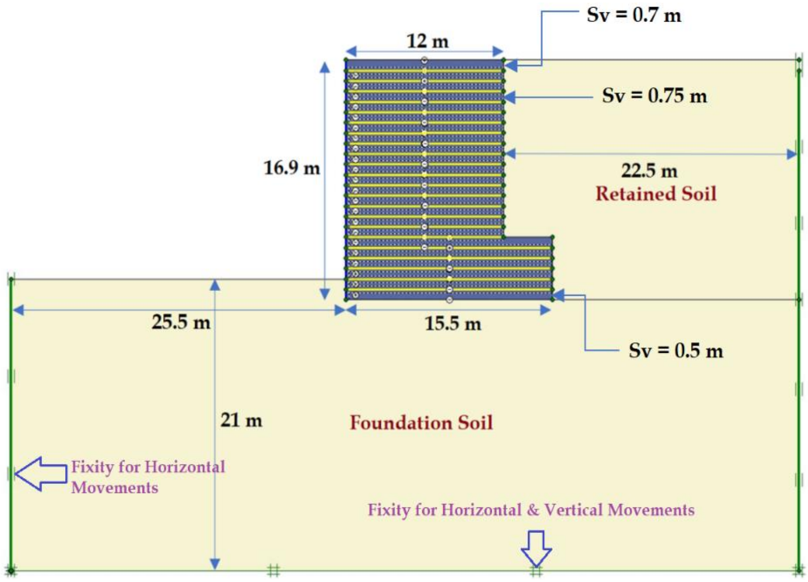
The wall geometry is selected to match the 17-m height field wall studied by Runser *et al.* (2001). In the study conducted by Runser *et al*., 2001, a 17-m height wall reinforced with steel strip is modelled to compare with the field measurements. The field wall was constructed as part of the US 24 bypass near Logansport, Indiana, USA. This wall was designed by Reinforced Earth Company. MSE wall was constructed as an abutment wall consisting of segmental precast concrete panels, ribbed steel strips and freely draining backfill material. The instrumented section of the wall is 16.9m tall. Details of wall geometry used for analysis are given in Table 1. Bearing pads are modelled in between precast concrete panels. The depth of embedment is 1.5m. Geometry details of MSE wall geometry used for analysis to match with the field wall by Runser *et al.* (2001) are given in Fig. 2(a). The deformed mesh of the wall is shown in Fig. 2(b).

Material Properties

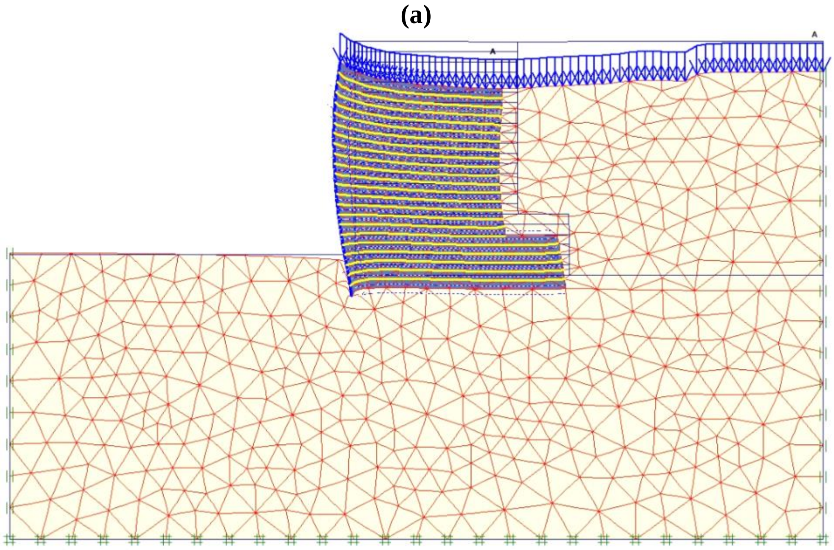
The wall consists of 22 reinforcements with a constant vertical spacing of 0.75m throughout the height of the wall, except for the top and bottom of the wall. Reinforcements have a length of 12m (0.7H). The lower five reinforcements have lengths up to 15.5m to reduce the applied bearing pressure. Reinforced soil is poorly graded sand (SP) with a unit weight of 20.8 kN/m^3. Reinforced soil has an angle of internal friction of 38^0 and cohesion is zero. Retained soil has a unit weight of 19.73 kN/m^3 and an angle of internal friction of 35.3^0. The material types and dimensions vary between projects. The concrete panels in PLAXIS are made of plate elements. The Mohr-Colomb failure criterion is used to model the soil zones as linear-elastic material. Steel strips are used with varied stiffness and used at different wall heights, as shown in Table 2.

Table 1. Details of wall geometry used for the validation study

S. No.	Property	Value	Unit
1	Height of the wall	16.9	meter
2	Type of facing panels	Segmental precast concrete panels	-
3	Thickness of facing panels	0.15	meter
4	Segmental panel, EA	11 x 10^6	kN/m
5	Segmental panel, EI	11 x 10^3	kN/m^2/m
6	Weight, W	10	kN/m/m
7	Poison's ratio, μ	0.15	-
8	Type of reinforcement	Ribbed steel strips	
9	Length of reinforcement	12m (for top 17 layers) 15.5m (for bottom 5 layers)	m
10	Spacing of reinforcements	0.75 m (for middle reinforcements) 0.7 m (for top reinforcement) 0.5 m (for bottom reinforcement)	m



(a)



(b)

Figure (2): (a) Details of wall geometry to match field wall by Runser *et al.* (2001) and (b) Deformed mesh of MSE wall used for the validation study

Table 2. Reinforcement properties

Height above toe of wall (m)	Linear-elastic stiffness $(EA)_{rein}$	Stiffness
0 – 2.3	88 MN/m	very high stiffness
2.3 – 6.1	73 MN/m	stiff
6.1 – 9.9	59 MN/m	medium stiffness
9.9 – 16	44 MN/m	low stiffness
>16	73 MN/m	stiff

No attempt is made to replicate compaction effects by introducing a transient surcharge pressure at each soil layer during construction, in order to keep the numerical modeling as straightforward as feasible (Huang *et al.*, 2013). The steel strip reinforcement components are modelled as continuous sheets with just axial stiffness with the ability to transfer load to the surrounding soil through interface shear using the PLAXIS geogrid element. Soil properties used in PLAXIS modeling for the validation study are shown in Table 3.

Table 3. Soil properties used in PLAXIS modeling for the validation study

Material	Parameter	Value
Reinforced soil	Unit weight (kN/m^3)	20.8
	Friction angle (degrees)	38
	Cohesion (kPa)	Zero
	Elastic modulus (E_b) (MPa)	50
	Poisson's ratio	0.3
Retained and foundation soil	Unit weight (kN/m^3)	19.73
	Friction angle (degrees)	35.3
	Cohesion (kPa)	Zero
	Elastic modulus (E_b) (MPa)	50
	Poisson's ratio	0.3

Meshing and Boundary Conditions

The 2-dimensional FEM model has 1346 elements, 12,900 nodes, 16,152 stress points and 15-noded triangular elements. The average size of the elements is 1.28m. Very fine elements are used for meshing. Denser mesh has been generated for the reinforced block, as there is an interaction between reinforcements and soil and between facing panels and soil. The interfaces are introduced in the structural elements to get accurate deformations. The number of elements used in the corners and junctions suffice to obtain accurate results. The size of the elements depends upon their location in the geometry. Behind the facing panels, the denser mesh is generated to get precise behaviour of facing panels. The sides of the wall geometry are fixed for horizontal movements. The bottom of the geometry is fixed for both horizontal and vertical movements, as shown in Fig. 2(b). Boundary conditions are selected to suit the field conditions.

Comparison of Wall Deformations

The recorded lateral deformations throughout the instrumented height studied by Runser *et al*. (2001) are compared with the horizontal deformations obtained from the present numerical study. As seen from Fig. 3, the difference between the present FEM analysis and field instrument data is less than 5mm. PLAXIS results are in good agreement with field data. Hence, further parametric analysis can be carried out to study the wall behaviour.

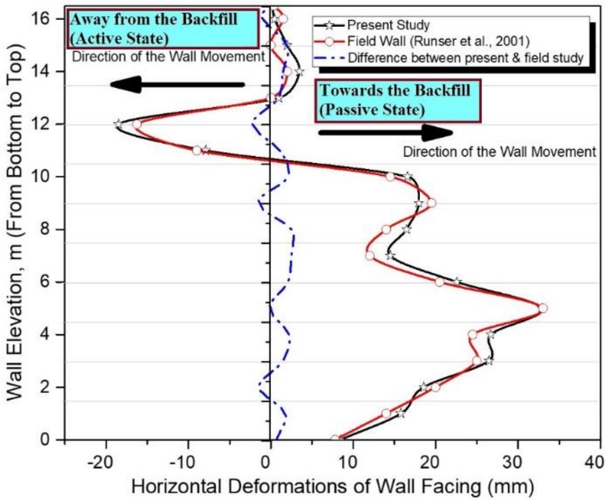


Figure (3): Comparison of PLAXIS wall deformations with field wall results

Parametric Study to Analyze the Wall Behaviour

After the successful validation of the present numerical model, a parametric research was carried out to investigate the effects of fill type and foundation soil stiffness on the wall displacements for different reinforcement types on the wall deformations and the effect of surcharge magnitudes has been studied. Wall dimensions adopted for the parametric analysis are shown in Fig. 4(a).

Geometry of Wall

The details of wall geometry used for analysis are shown in Table 4. The height of the wall is considered 16.5m. The length of the reinforcements is considered 0.7H. Bearing pads are modelled in between precast concrete panels. The depth of embedment is 1.5m. The two-dimensional MSE wall model used in the PLAXIS is shown in Fig. 4(b). Height is reduced by 0.4m, compared to the validation study. The properties of facing panels are kept the same as in the validation study.

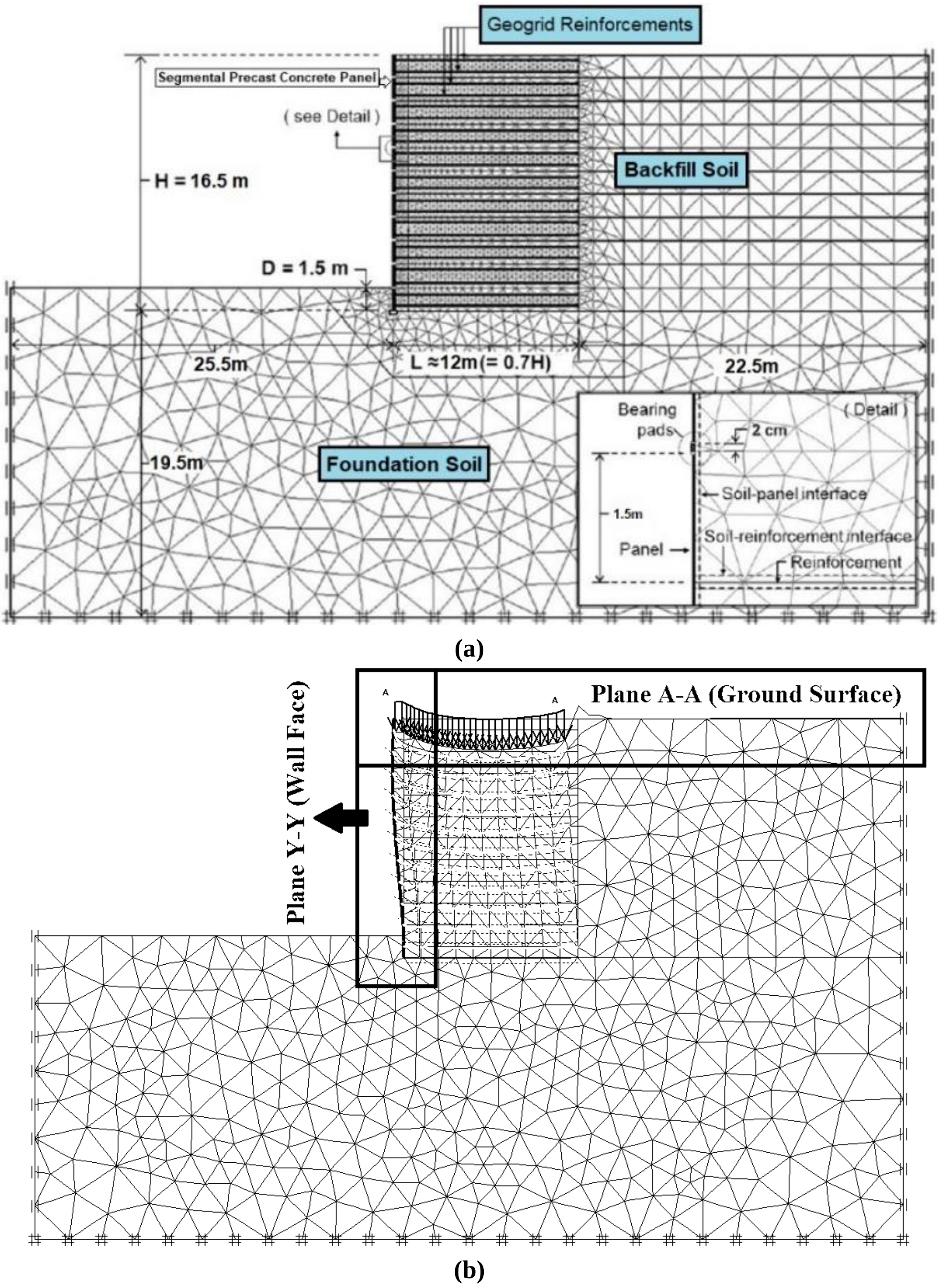


Figure (4): (a) Details of wall geometry used for the parametric study and (b) Two-dimensional wall with A-A and Y-Y planes

Effect of Reinforcement Type on Ground Settlements and Wall Deformations

Because of its flexibility and ability to withstand loads and deformations brought on by interactions between the material and the reinforcing material, the MSE wall is regarded as a cohesive block. According to the experimental histories, even the inclusion material's type significantly affects the wall movements. This study compares the behaviour of several geosynthetic straps to that of metallic strips. Soil and geometry details are given in Table 4. HDPE and PET geogrids are considered along with ribbed steel strips. The different types of reinforcements and their characteristics are listed in Table 5.

Table 4. Details of wall geometry used for the parametric study

S. No.	Property	Value	Unit
1	Height of the wall	16.5	meter
2	Type of facing panels	Segmental Precast Concrete Panels	-
3	Thickness of facing panels	0.15	meter
4	Segmental panel, EA	11×10^6	kN/m
5	Segmental panel, EI	11×10^3	$kN/m^2/m$
6	Weight, W	10	kN/m/m
7	Poison's ratio, μ	0.15	-
8	Type of reinforcement	Ribbed Steel Strips	
9	Length of reinforcement	12m	m
10	Spacing of reinforcements	1.5 (middle reinforcements) 0.75 (top and bottom reinforcements)	m
11	Stiffness of reinforcement, EA	88	MN/m

Table 5. Types of reinforcement and their properties

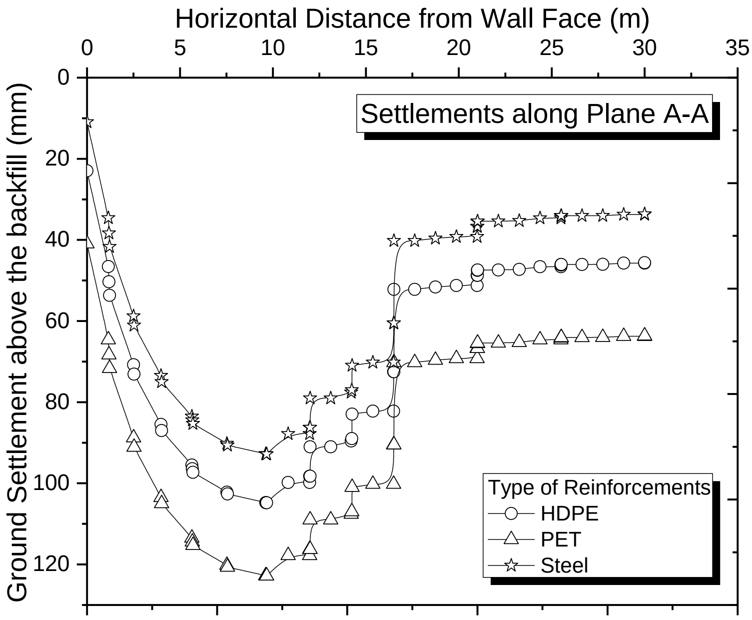
S. No.	Material and Properties	Value	Unit
1	HDPE geogrid		UX-1400 SB
	Thickness of geogrid	0.001	m
	Modulus of elasticity (E)	6.0×10^7	kPa
	Area (A= Thickness * Unit length)	0.001	m^2
	EA (HDPE geogrid)	60	MN/m
2	PET geogrid		Miragrid 3XT
	Thickness of geogrid	0.001	m
	Modulus of elasticity (E)	4.0×10^7	kPa
	Area (A= Thickness * Unit length)	0.001	m^2
	EA (PET geogrid)	40	MN/m
3	Ribbed steel strip (galvanized)		Grade 65 steel
	Thickness of strip	0.004	m
	Modulus of elasticity (E)	2.0×10^7	kPa
	Area (A= Thickness * Unit length)	0.004	m^2
	EA (ribbed-steel strip)	80	MN/m

The deformations are recorded until reinforcement fails at plastic condition. The ground settlement behind the face of the wall and horizontal and vertical wall-facing deformations are recorded and compared for three different reinforcements used for the analysis, as shown in Fig. 5. Deformations of the wall facing differ for each reinforcement type used, as the stiffness varies between them. The relationship between ground settlements and horizontal distance from a wall is shown in Fig. 5(a). Up to 34.5m from the wall face, the settlement impact is visible. According to the findings, soil that has been strengthened with steel strips and HDPE geogrid exhibits reduced settlement.

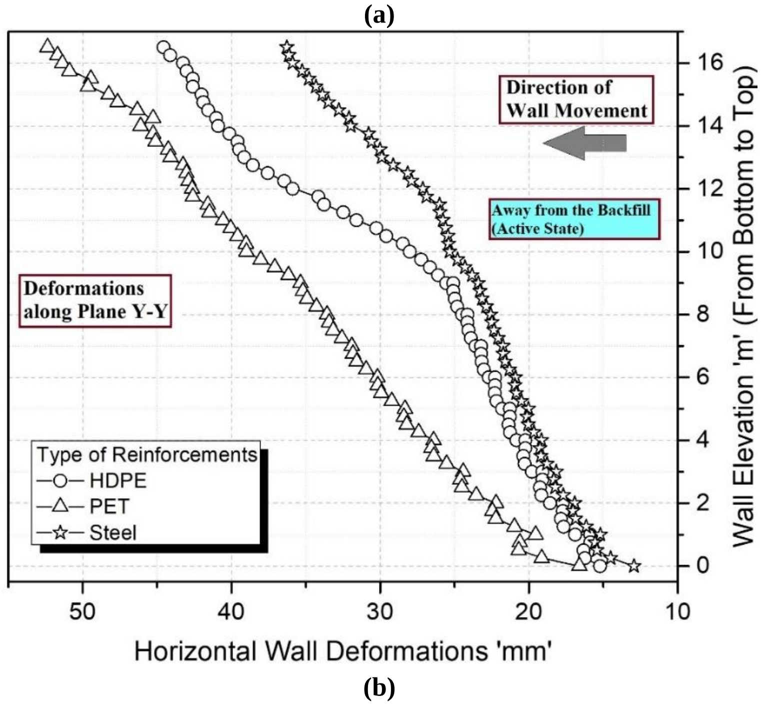
From the wall face to the right end of the model, ground-surface settlements are determined concerning different reinforcements. As seen from Fig. 5(a), maximum ground settlements are observed beneath the reinforced block. The percentage difference in ground settlements with HDPE reinforcements compared with PET is 15-20%. Further reduction in ground settlement occurred for steel reinforcement by 12%. For steel reinforcement, settlements are less compared with PET and HDPE reinforcements. As far as durability is concerned, HDPE straps can be considered, as there is the possibility of corrosion in galvanized steel strips.

Horizontal and vertical wall-facing deformations or deflections are evaluated along the wall elevation of 16.5-m height and the results are presented in Fig. 5(b) and Fig. 5(c). Both horizontal and vertical wall deformations are maximum near the top face of the wall and minimum near the bottom of the wall. The wall with PET geogrids shows more deflection compared with the walls with the other two reinforcements. Horizontal wall deformations show a difference of 17-20% near the top of the wall for the three different reinforcements. On the other hand, from the bottom of the wall to the middle portion (up to 10-m height), HDPE and steel reinforcements show almost similar horizontal wall deformations.

Similar to the horizontal deformation profile, vertical wall deformations are maximum in the upper half of the wall. The percentage difference in vertical wall deformations with steel strips and HDPE reinforcements is around 25-30%. Vertical deformations obtained with steel strips and HDPE geogrids show a difference of 10-18% from the height of 10m to 16.5m. Below this height, vertical wall deformations for wall with PET and steel reinforcements shows almost similar behaviour, as shown in Fig. 5(c).



(a)



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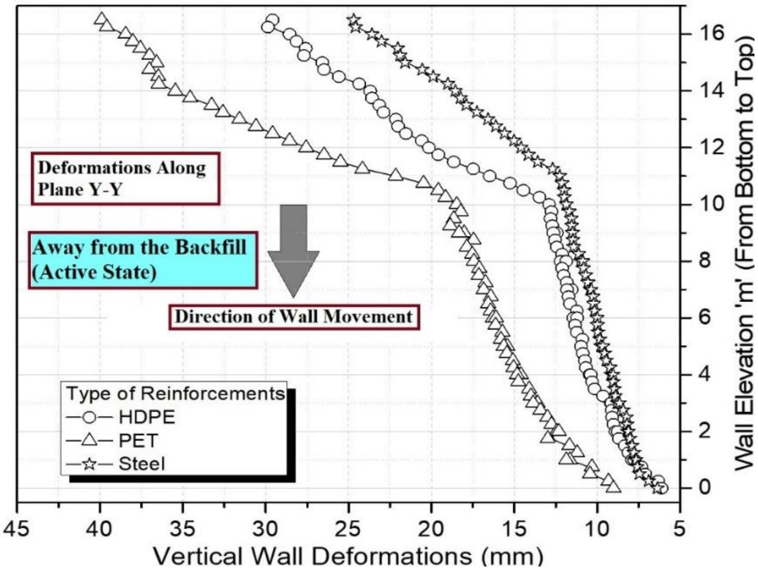


(c)

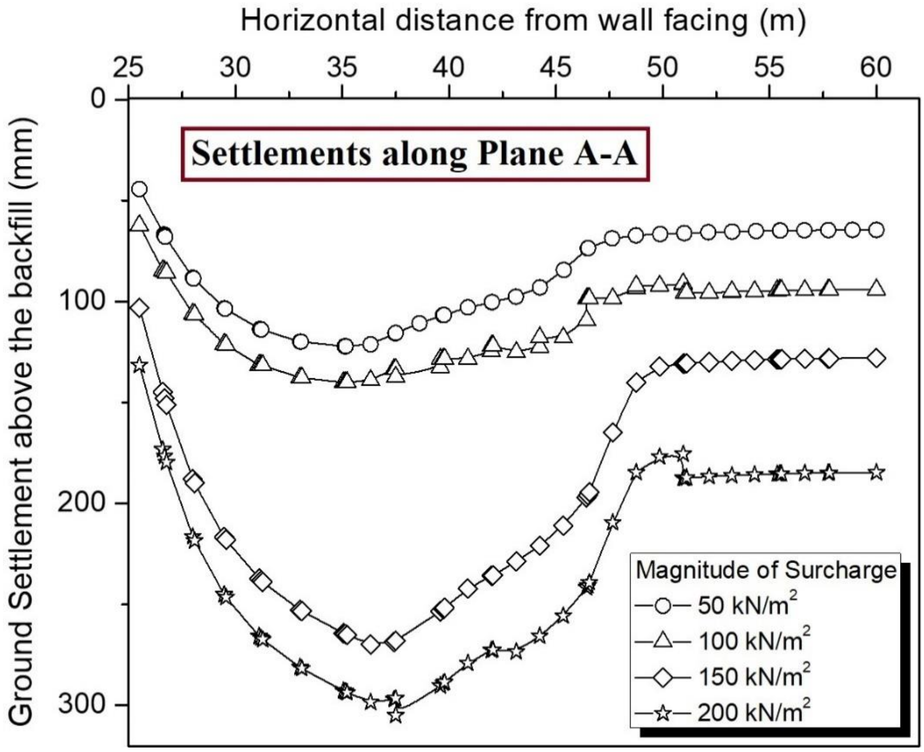
Figure (5): (a) Ground-surface settlement behind the wall facing, (b) Horizontal wall deformations and (c) Vertical wall deformations

Effect of Surcharge on Ground Settlements and Wall Deformations

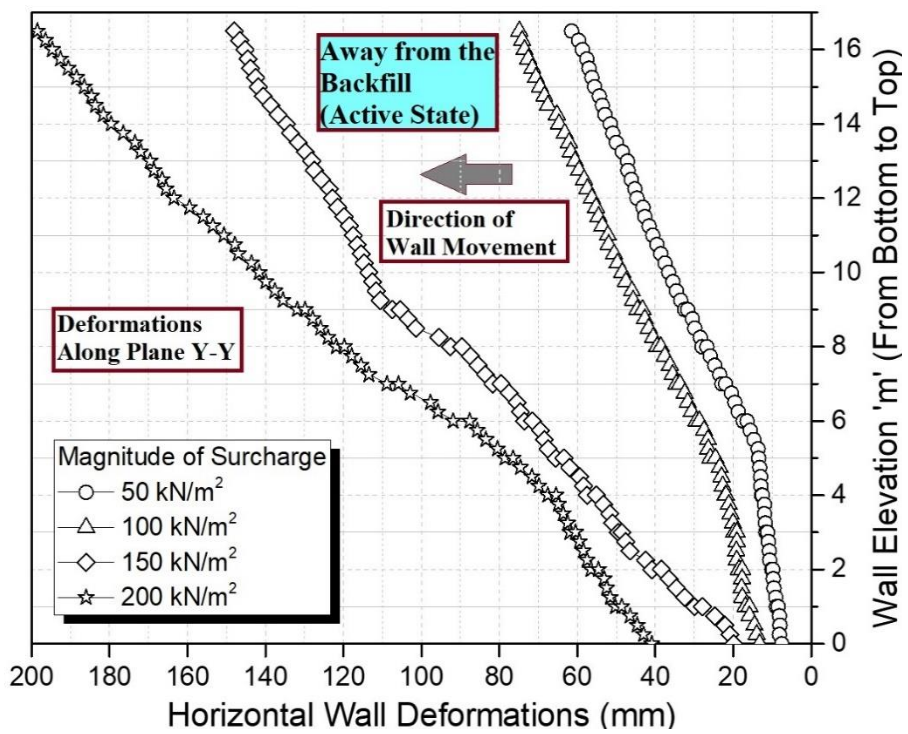
The wall is subjected to surcharge loads above the backfill from the wall face to the end of the geometry (From 25.5m to 60.0m, as shown in Fig. 4(a)). The surcharge is assumed as a uniformly distributed load with a vertically downward direction. The magnitudes used for the comparison of wall behaviour are 50, 100, 150 and 200 kN/m^2.

Ground-surface settlements are determined concerning four surcharge loads from the wall face to the model end (25.5m to 60m). As seen from Fig. 6(a), maximum ground settlements are observed below the reinforced block for a length of about 12m. The percentage difference in ground settlements with a surcharge of 200 kN/m^2 compared with 50 kN/m^2 is 80-85%. When the magnitude of the surcharge was increased from 100 to 150 kN/m^2, there was a sudden increase in the ground settlements. Beyond the reinforced block, ground settlements are less and become constant after 50m from the wall face. Higher magnitudes of the surcharge are selected for the analysis to incorporate live loads, accidental loads, crash barrier loads and dead loads from the pavements constructed above the wall. To minimize the settlements of the reinforced blocks due to higher surcharge loads, reinforcements of higher tensile strength can be used and the spacing between the reinforcements can be reduced. Horizontal and vertical wall deformations are also computed for different surcharge loads to compare the effects of the magnitudes on the wall deflections.

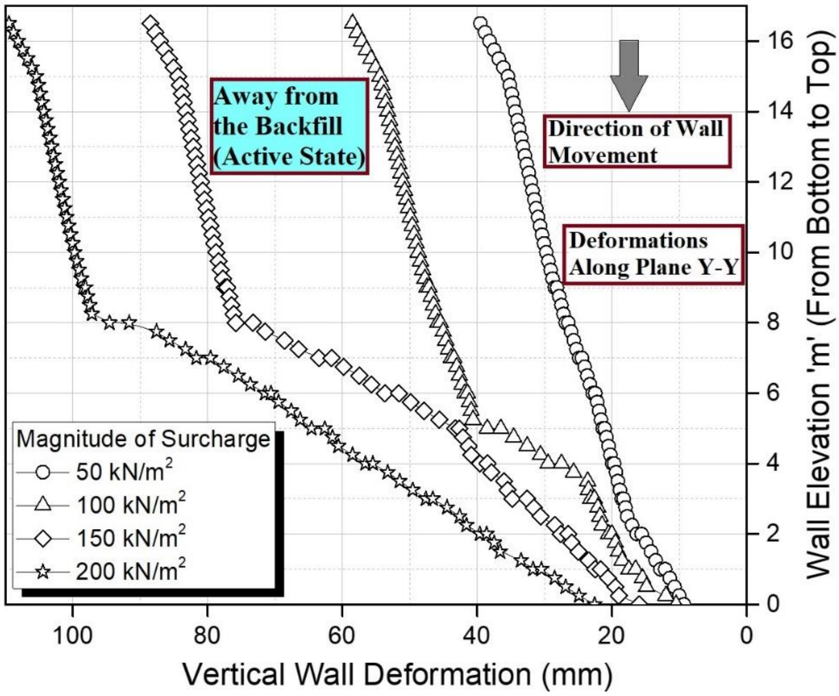
Maximum horizontal wall deformation observed from Fig. 6(b) is 200 mm for a surcharge magnitude of 200 kN/m^2. Horizontal wall deformations show a difference of 20-30% with 200 kN/m^2 and 150 kN/m^2 magnitudes. Walls with surcharge magnitudes of 50 and 100 kN/m^2 presented almost similar deformations with minor deviations. The difference in horizontal deformations obtained for surcharge magnitudes of 50 and 200 kN/m^2 is greater than 100%. At the bottom 4-m height of the wall, horizontal and vertical deformations of the wall are very close for all the four magnitudes of the surcharge, as seen in Fig. 6(b) and Fig. 6(c). Vertical wall deformations also show similar behaviour as horizontal deformations with lesser deformations.


Horizontal distance from wall facing (m)
Ground Settlement above the backfill (mm)
Settlements along Plane A-A
Magnitude of Surcharge
50 kN/m2
100 kN/m2
150 kN/m2
200 kN/m2

(a)


Away from the Backfill (Active State)
Direction of Wall Movement
Deformations Along Plane Y-Y
Magnitude of Surcharge
50 kN/m2
100 kN/m2
150 kN/m2
200 kN/m2
Horizontal Wall Deformations (mm)
Wall Elevation 'm' (From Bottom to Top)

(b)



(c)

Figure (6): (a) Ground-surface settlement behind the wall facing, (b) Horizontal wall deformations and (c) Vertical wall deformations

Influence of Supporting Systems on the Behaviour of MSE (SPCP) Wall

MSE walls built on soft compressible soils encounter issues with differential settlements. Settlements force facing panels to deflect more, which causes the MSE wall to partially fail or collapse. Different approaches can be used in the field to improve the performance of MSE walls on soft compressible soil layers. The provision of various sorts of supporting systems for the MSE wall is one such important option. Including laterally loaded shafts inside the reinforced block behind the facing panels is another way to improve the stability of the MSE wall. Huang *et al.* (2013) worked on laterally loaded drilled shafts in an MSE wall.

Supporting Systems Considered in the Wall Analysis

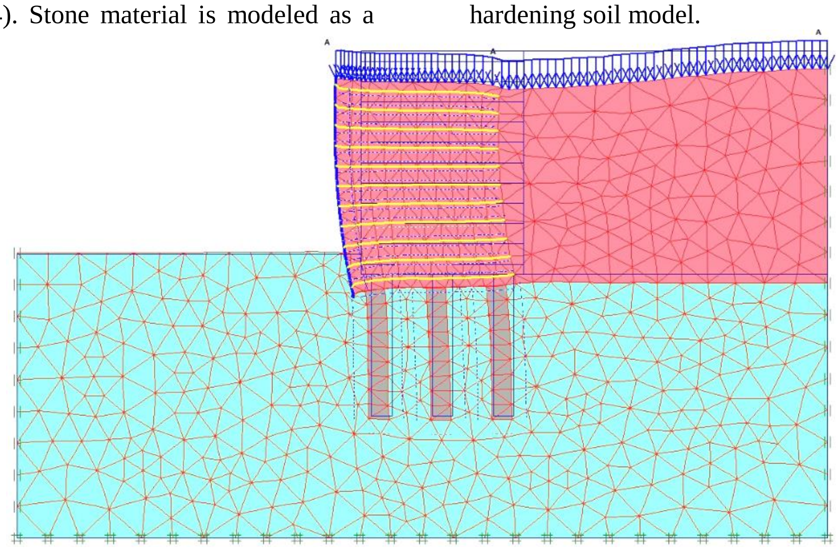
In the current study, foundation soil is considered soft clay with properties mentioned in Table 6. Settlements and wall deformations are studied for soft-clay foundation and an attempt is made to compare the performance of MSE wall with different supporting systems. Aggregate pier and pile foundations are used for the study.

Table 6. Foundation soil properties

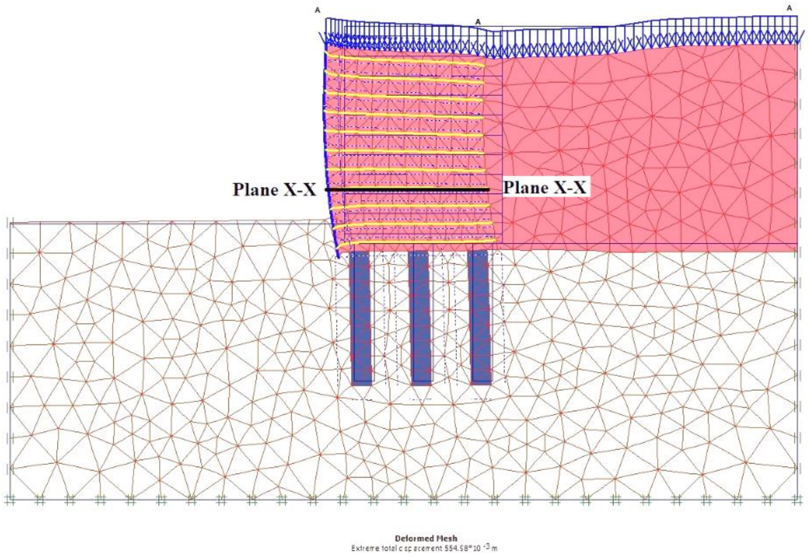
S. No.	Parameter	Value
1	Unit weight (saturated)	17 kN/m^3
2	Young's modulus (E)	2.4 x 10^4 kN/m^2
4	Cohesion (C)	45 kN/m^2
5	Angle of internal friction (φ)	20^0
6	Poisson's ratio (μ)	0.430

Aggregate Pier

Numerous case studies on the aggregate piers used to stabilize the compressible soil layers, increase bearing capacity and reduce settlements have been published recently. The piers are built by drilling holes between 610 mm and 915 mm in diameter, inserting stones inside the cavities and compacting aggregates with an impact tamper. Aggregates are added in successive 0.3-m lifts over the bottom bulbs to complete the piers. For the convenience of modeling in PLAXIS, the bottom bulb is not modeled. The deformed mesh of the MSE wall with the aggregate pier is shown in Fig. 7(a). Details of properties used for the aggregate pier are given in Table 7. The diameter and length of the pier are the same as those of the pile foundation, as given in Table 8. Properties of aggregates are used as per the guidelines of Ng & Tan (2014). Stone material is modeled as a hardening soil model.



(a)



(b)

Figure (7): (a) Deformed FE mesh of MSE wall with aggregate pier and (b) MSE wall model with pile foundation

Table 7. Hardening soil model for aggregate pier

S. No.	Parameter	Value
1	Unit weight (γ)	20 kN/m^3
2	E_{50}^{ref}	8000 kN/m^2
3	E_{oed}^{ref}	8,000 kN/m^2
4	E_{ur}^{ref}	24,000 kN/m^2
5	Cohesion (C’)	1 kN/m^2
6	Angle of internal friction (φ’)	45^0
7	Poisson’s ratio (μ)	0.20
8	p^{ref}	100 kN/m^2
9	m	0.5
10	k_x and k_y	1 m/day

Table 8. Mohr-Coulomb properties for pile foundation and its dimensions

S. No.	Parameter		Value
1	Diameter of the pile foundation		1 m
2	Length of the pile foundation		10.5m
3	Distance of 1st pile from wall facing		0.75m
4	Pile foundation material properties	Mohr-Coulomb model	
		Cohesion (C)	387 kN/m^2
		Angle of internal friction (φ)	35^0
		Young's modulus (E)	24,173 kN/m^2
		Poisson's ratio (μ)	0.20
		Unit weight (γ)	25 kN/m^3
5	Surcharge magnitude		100 kN/m^2
6	Steel-strip stiffness (EA)		59 MN/m

Pile Foundation

To transfer the structural loads to soils at a substantial depth below the base of the structure, a pile is a thin, placed structural part in the ground. When differential settlement caused by soil variability or non-uniform structural loads is too significant, pile foundations are utilized. Structural loads are made up of lateral loads, moments and uplift forces, either separately or in combination. Pile foundations are particularly helpful in boosting the soil's bearing capacity by giving it additional rigidity. Pile foundations will be quite helpful in the situation of soft soil beneath the MSE wall, as they provide higher strength and stability. Reinforced block and backfill in the MSE wall add additional weight, which must be transferred to the foundation. Further, the MSE wall is modeled with a pile foundation as a supporting system at the bottom of the reinforced block. Mohr-Coulomb properties of concrete material used for the pile foundation are calculated as per Euro Code-2 guidelines. Bored cast-*in-situ* piles are preferred in the case of MSE walls. These piles have better pile load-carrying capacity than aggregate piers. These piles can be constructed in groups along the length of the wall with a spacing of 2 to 3 times of diameter. Piles can be economical only in the case of smaller lengths of MSE walls. The properties of pile foundation material used in the analysis of the wall are given in Table 8. As seen in Fig. 7(b), three piles are used. Since it is a plain strain two-dimensional problem, the results obtained are restricted per meter length.

RESULTS AND DISCUSSIONS

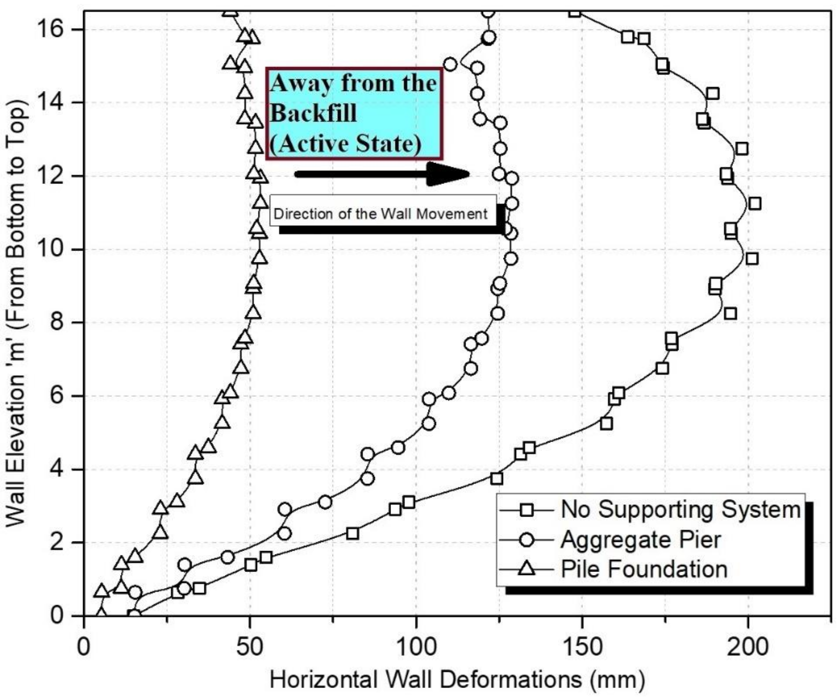
Wall with soft clay as foundation soil is modeled without any supporting systems and with supporting systems, aggregate pier and pile foundation. Horizontal and vertical deformations of the wall are obtained for three cases, as shown in Fig. 8(a). Settlements of the reinforced block are obtained beneath the block for a length of 12m.

Wall Deformations

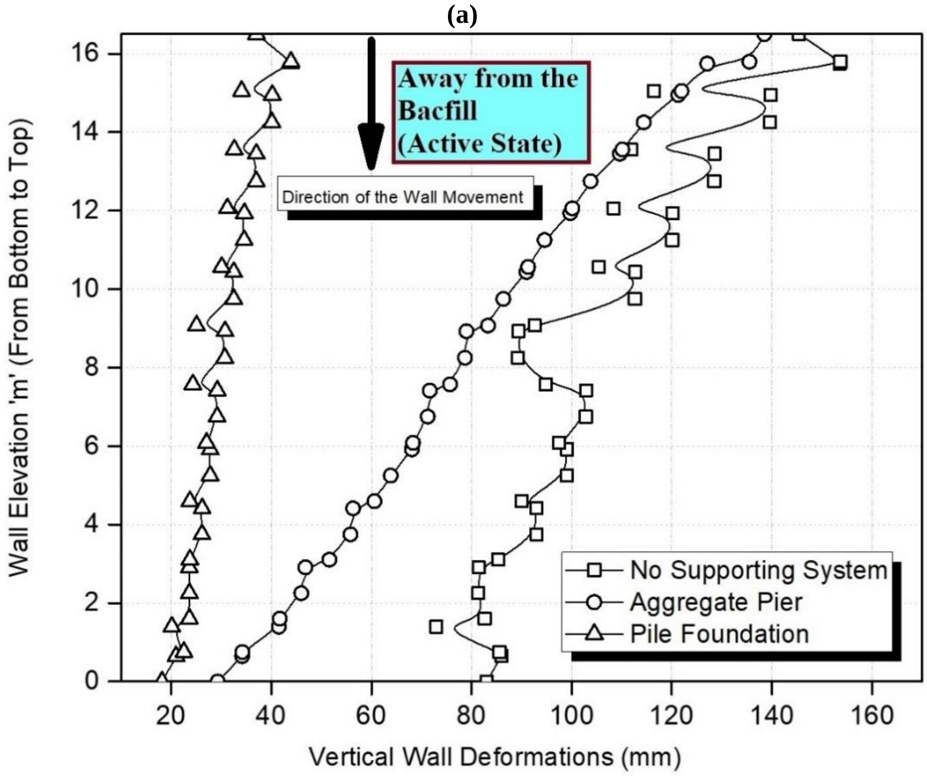
The horizontal wall deformations without any supporting systems are higher with a maximum value of 200 mm. Wall with aggregate pier shows horizontal deformation values ranging near 125 mm. Pile foundation as a supporting system shows horizontal wall deformations in the range of 25-50 mm. It is clear from the results that a wall with a pile foundation shows lesser wall deflections in the horizontal direction, as seen in Fig. 8(a). In the case of vertical wall deformations, pile foundation as a supporting system shows better performance compared with others, as deformations are much less. For a wall without supporting systems and with aggregate pier, vertical deformation values range from 40mm-150 mm. For a wall with pile foundation, vertical wall deformations are in the range of 20 mm-40mm, as shown in Fig. 8(b).

Settlement of the Reinforced Block

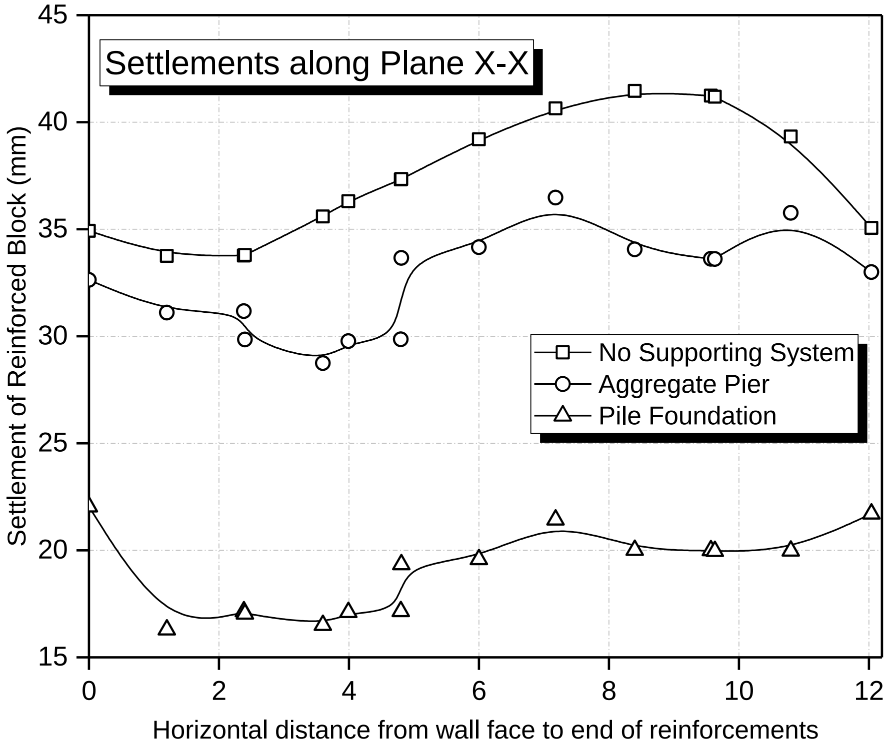
A reinforced block with a cross-sectional length of 12m (37.5m-25.5m=12m) is considered to evaluate the settlement below the reinforced block. A wall without any supporting systems shows higher settlements compared with a reinforced block with supporting systems. At a distance of 6m from the wall face, the settlement of the reinforced block along the horizontal profile becomes constant. The ranges of reinforced block settlements obtained from the analysis are given in Table 9, which is obtained from Fig. 8(c).



(a)



(b)



(c)

Figure (8): (a) Horizontal wall deformations, (b) Vertical wall deformations and (c) Reinforced block settlement

Table 9. Reinforced-block settlement range for different supporting systems

Supporting system	Within 6m from the wall face	Beyond 6m from the wall face
No support system	~ 35 - 40 mm	~ 40 mm
Aggregate pier	~ 30 mm	~ 35 mm
Pile foundation	~ 15 - 20 mm	~ 20 mm

CONCLUSIONS

From this analysis, it can be summarized that the wall with pile foundation is the most suitable supporting system for the MSE wall to have better performance. In most cases, the construction of the MSE wall does not require a foundation. It can be constructed with a leveling pad to support the facing panels. In the case of highly compressible clayey soil or soft clays, it is recommended to adopt pile foundation.

For ribbed steel reinforcement, ground settlements and wall deformations are less compared with PET and HDPE geogrid reinforcements. Ribbed steel reinforcements can be used in the case of tall reinforced soil walls to minimize large deformations. While considering steel reinforcements, corrosion should be considered in the design.

For PET geogrid, wall deformations are higher. For lesser surcharge loads, ground settlements and wall deformations are less. Wall deformations and settlements of reinforced block for pile foundation as a supporting system are less compared with those of other supporting systems.

For aggregate pier as a supporting system, deformations and settlements of reinforced blocks are higher. The aggregate pier can be more economical and easier to construct. When performance and durability are concerned, pile foundations can be a suitable option. The results show that even with aggregate piers, wall deformations and settlements are reduced in an acceptable range compared with the wall without a supporting system. The conclusions derived from the results of this study give a better idea of understanding the behaviour of the MSE wall associated with geotechnical materials and supporting systems.

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