Behavior of Hybrid Systems of Earth Retaining Structures

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Abstract: Hybrid earth retaining structures are the best solution for solving traffic crowded problems in side hill situations where the sides of the both upper and lower roadways can be widen at the same time. In hybrid systems, two different systems of earth retaining structures are used included cut wall system and fill wall system. Although the benefit of hybrid systems in solving traffic congestion problems, there aren't more studies at the recent time discussing the behavior and design of such hybrid systems. In addition to, the previous studies are only deal with one type of hybrid systems called hybrid MSE/soil nailing wall and no other hybrid configurations are used. The goal of this paper is to study the behavior of hybrid systems of earth retaining structures included various types of hybrid systems. It could be included from this study that there are other hybrid systems that produce more global factor of safety and less wall deformations than the most common hybrid system MSE/soil nailing wall such as cantilever/anchored sheet pile hybrid wall and MSE/anchored sheet pile hybrid wall.

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Keywords: Earth-retaining structures, Hybrid earth retaining systems, MSE/Soil Nailing hybrid wall, MSE/Anchored sheet pile hybrid wall, Cantilever/Soil Nailing hybrid wall, Cantilever/Anchored sheet pile hybrid wall, PlAXIS FE modeling.

1. Introduction

Today, many countries need to increase the width of the road to solve traffic crowded problems. This is achieved by using earth-retaining structures. The best solution to wide both upper and lower roadways at the same time is using hybrid earth retaining structures. This means using two different earth-retaining systems included cut wall system, and fill wall system. Fig. 1 represents a schematic diagram of a hybrid wall system [1]. In the lower portion of the wall a soil-nailing wall is used represented the cut wall type. In the upper portion of the wall a MSE wall is used represented the fill wall type. This system is called MSE/soil nailing hybrid wall and it's considered the most common hybrid system and no other hybrid wall configurations are used till the recent time. In spite of the benefit of hybrid systems, there is a lack of design procedures for such hybrid systems. The main rule on designing hybrid systems is taking into account the surcharge load from the upper wall in designing the lower wall. In addition to taking into account the movement of the lower wall in designing the upper load. So the lower wall was designed as a full height wall containing the portion of the upper wall to sustain the surcharge load.

There are some attempts to study the behavior and design of hybrid MSE/soil nailing system. The way to estimate nails tensile forces and length is presented in design charts produced by Alhabshi.

[1].The equivalent vertical and horizontal distributed loads of the MSE portion acting on the soil-nailing wall are calculated by two simplified equations presented in Wei [2]. Rabie [3] concluded that finite element analysis must be used with limit equilibrium solutions to study the behavior of hybrid earth retaining systems.

This paper illustrates the behavior of different hybrid earth retaining structures. The analysis was done by using 2d finite element analysis program PLAXIS V.8 [4]. The results were discussed to study the behavior of hybrid systems in terms of the global factor of safety, total deformation of the wall, lateral wall displacement, reinforcement tensile forces, and anchor forces. The hybrid earth retaining structures used in this study are:

MSE/Soil nailing hybrid wall,
MSE/Anchored sheet pile hybrid wall,
Cantilever/Soil nailing hybrid wall, and
Cantilever/Anchored sheet pile hybrid wall.

2. Plaxis Finite Element Models

For a present study, four hybrid earth-retaining models have been used separately to retain 18.00 m height of dense sand soil as indicated in Fig. 2. The ratio of cut wall height to fill wall height is taken equal to 1.00. Mohr coulomb model was used to simulate the soil with 15-node triangle element. The dimension of the model has been chosen so that any boundary effects on the response of the wall are eliminated [5]. Table 1 represents the properties of the soil used in the analysis according to Zhu [6].

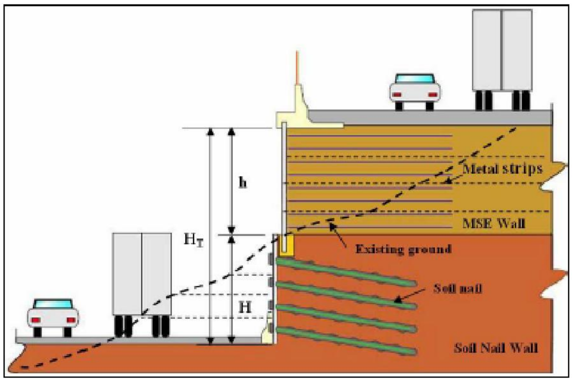


Fig. 1: Schematic diagram of a cross section in a hybrid wall system [1]

For Soil Nail Wall

From manual solution considering the full wall height, the length of the soil nailing was taken equal to 13.00 m with 100 mm grouting hole's diameter and 25 mm rebar's diameter. The inclination of nails was 15° below horizontal. The vertical and horizontal spacing were taken equal to 1.00 m x 1.00 m. A shotcrete facing was used with thickness equal to 200 mm. The soil-nailing wall and the shotcrete facing were modeled by using plate structure elements as in Babu & singh [7]. The interface reduction factor, R_{int}, was taken equal to 0.8.

For MSE wall

From manual solution considering wall's height equal to H/2, the reinforcement of MSE wall consists of W11 steel bar mats with 150 mm center-to-center longitudinal bars spacing and 600 mm transverse bars spacing. The length of the reinforcements was taken equal to 7.00 m. Segmental precast concrete facing panels were used with dimension equal to (.75 x.75 x.3 m). The reinforcements were modeled by using geogrid elements whereas the precast concrete panels were modeled by using plate elements as in Morrison et al [8]. The interface reduction factor, R_{int}, was taken equal to 0.8.

For anchored sheet pile wall

From manual solution considering the full wall height, a steel box pile with 6.00 m penetration depth was used in the analysis. The anchor was installed at level equal to 25 % of the sheet pile height [9] and 2.00 m center-to-center spacing. The anchor length was taken equal to 13.50 m. The length of the anchor was chosen so that the anchor plate is located completely outside the active zone of the sheet pile wall [10]. The sheet pile was simulated by using plate structural element whereas the anchor was simulated by using fixed end spring element as in Kumar & Dey [11]. The interface reduction factor, R_{int}, was taken equal to 0.65.

For cantilever wall

From manual solution considering wall's height equal to H/2, an L-shaped cantilever wall with width equal to 6.00 m was used in the analysis. The thickness of the wall was taken equal to 50 cm. The wall was modeled by using plate structural element as in Petersson [12]. The interface reduction factor, R_{int}, was taken equal to 0.8.

The properties of the plate elements, geogrid, and anchor used in the analysis were listed in Table 2 to Table 4.

Table 1: Soil parameters used in PLAXIS analysis

Identification	**Type**	$\gamma_{unsat.}$ [KN/m^3]	$\gamma_{sat.}$ [KN/m^3]	**Eref.** [KN/m^2]	ν [-]	**Cref** [kN/m²]	φ [°]
Dense Sand	Drained	18.00	18.00	40.000	0.35	5	38
Medium Dense Sand {MSE wall backfill}	Drained	16.00	16.00	30.000	0.30	0.25	34

Table 2: Plate data sets parameters

Identification	**EA** [KN/m]	**EI** [KN/m^2/m]	**D** [m]	**W** [KN/m/m]	**V** [-]	M_p [kN.m/m]	**Np** [KN/m]
Panels	6.00E6	4.50E4	.30	5.1	.15	1E15	1E15
Sheet Pile	6.544E6	7.692E5	1.188	2.518	.15	1E15	1E15
Soil Nailing	2.602E5	162.60	.087	—	.2	1E15	1E15
Shotcrete Wall	4.2E6	1.4E4	.2	3.20	.15	1E15	1E15
Cantilever Wall	1.25E7	2.6E5	.5	5.75	.3	1E15	1E15

Table 3: Geogrid data sets parameters

Identification	**EA** [KN/m]	N_p [KN/m]
Reinforcement	3.776E4	1E10

Table 4: Anchor data sets parameters

Identification	**EA** [KN/m]	**Lspacing**:m]
Anchor	1.126E6	2.00

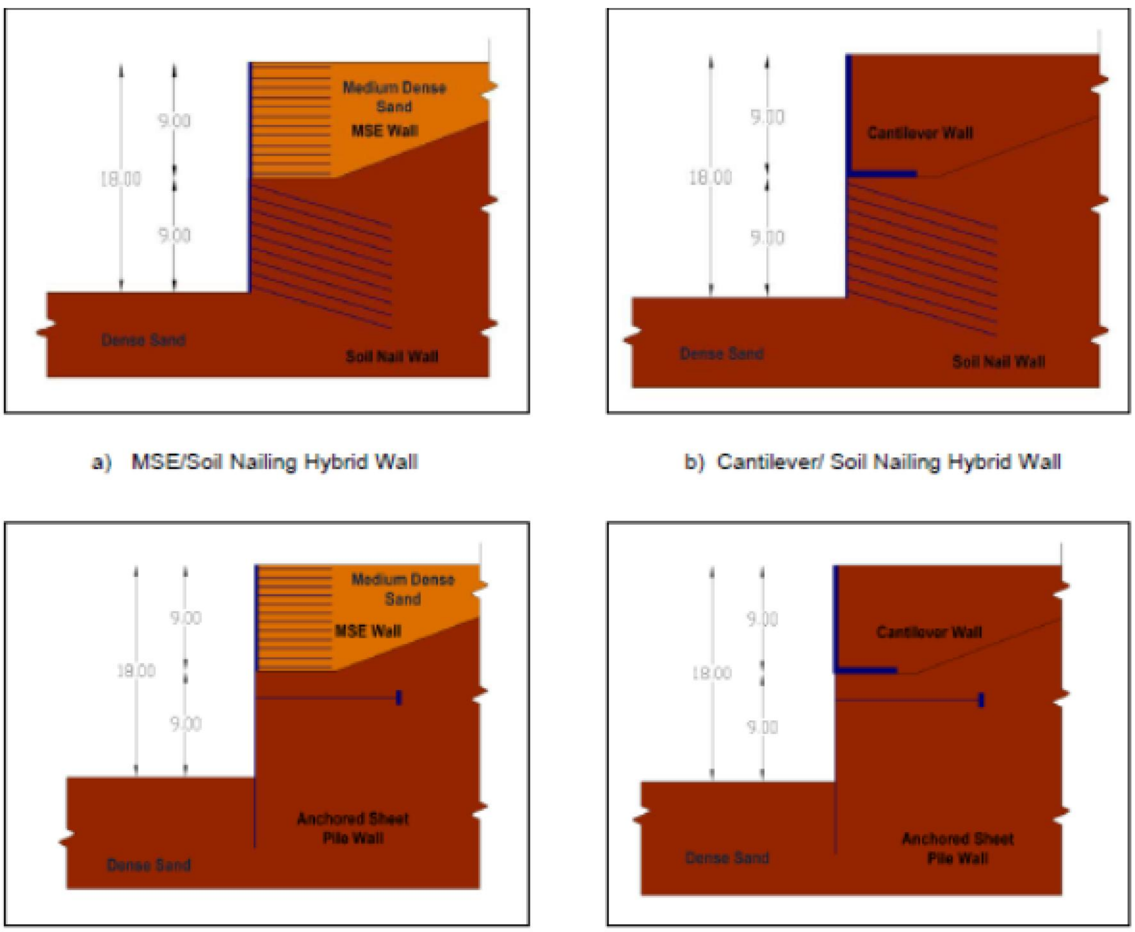
3. Results and Discussions

Four models were analyzed separately to study the behavior of hybrid earth retaining structures. The results were obtained in terms of global factor of safety, total deformation, lateral wall displacement, reinforcement tensile forces, and anchor forces as discussed below.

Total Displacement

Fig. 3 indicates a plot of deformed mesh for different hybrid earth retaining structures. The analysis results obtain that:-

- The most common hybrid system, MSE/soil nailing hybrid wall, produces the maximum value of the deformations compared to other hybrid systems.
- Cantilever/anchored sheet pile hybrid wall produces the lowest wall deformations compared to other hybrid systems.
- Hybrid cantilever/anchored sheet pile wall and MSE/ hybrid anchored sheet pile wall almost produce the same.



a) MSE/Soil Nailing Hybrid Wall
b) Cantilever/ Soil Nailing Hybrid Wall
c) MSE/Sheet Pile Hybrid Wall
d) Cantilever/Sheet Pile Hybrid Wall

Fig. 2: Schematic diagram of hybrid earth retaining systems used in the analysis

Lateral Wall Displacement

Fig. 4 indicates a comparison between different hybrid earth retaining systems in terms of lateral wall displacement. The results obtain that the hybrid MSE/soil nailing wall produces the maximum lateral displacement whereas the hybrid cantilever/anchored sheet pile wall produces the lowest lateral displacement compared to other hybrid systems.

Global Factor of Safety

Table 5 emphases that the most common hybrid system, MSE/soil nailing hybrid wall, isn't considered the best hybrid system as it produces the lowest global factor of safety compared to other hybrid systems. In contrast the best hybrid system is the cantilever/anchored sheet pile wall as it produces the highest global factor of safety.

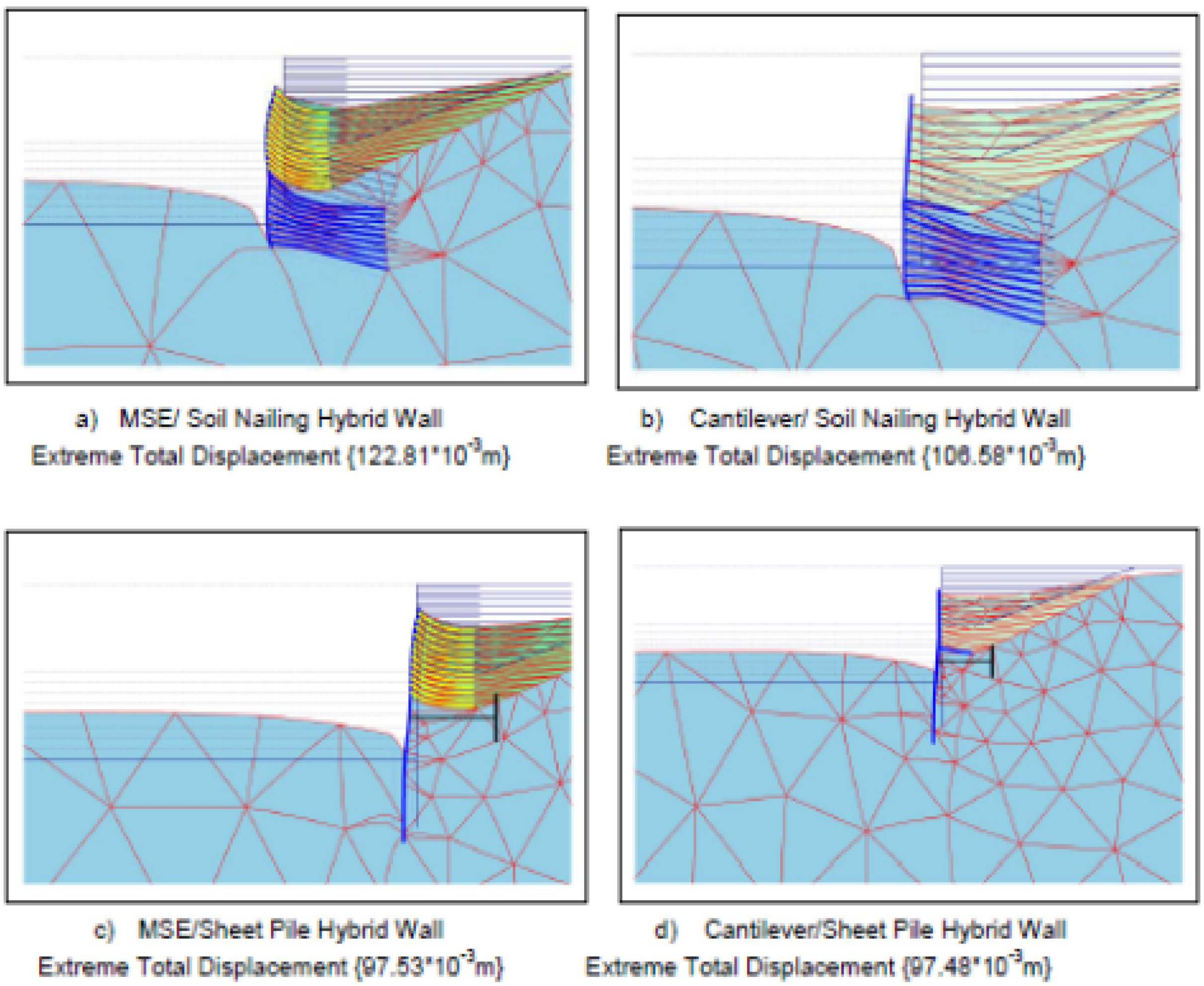


Fig. 3: Plot of deformed mesh for different hybrid earth retaining systems (Displacements scaled up 50.00 times)

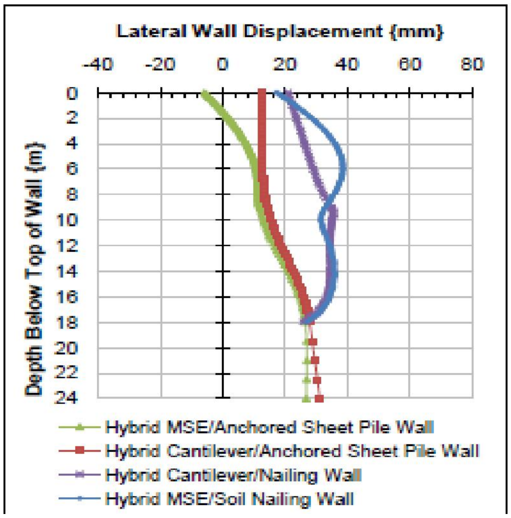


Fig. 4: Variation of lateral wall displacement with depth for different hybrid earth retaining systems

Reinforcement Tensile Forces

Fig. 5 indicates the variation of maximum reinforcement tensile force with depth for MSE portion and soil-nailing portion of different hybrid systems. The results indicate that:

For soil nailing wall portion, the nail bars almost produce the same maximum axial force in case of hybrid MSE/soil nailing wall and hybrid cantilever/soil nailing wall.

For MSE wall portion, the hybrid MSE/anchored sheet wall pile produces more reinforcement tensile forces than the hybrid MSE/anchored sheet pile wall.

Anchor Forces

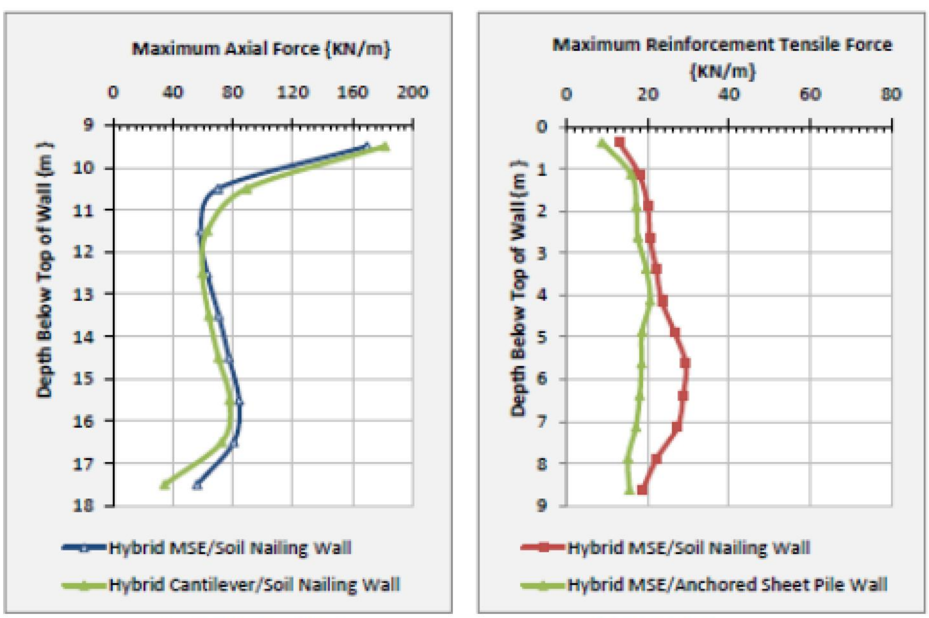
It could be obtained from Table 6 that, hybrid cantilever/anchored sheet pile wall produces higher anchor forces than hybrid MSE/anchored sheet pile wall.

Table 5: Global factor of safety for different hybrid earth retaining systems

Earth Retaining Wall System	**Global Factor of Safety**
Hybrid Cantilever/Soil Nailing Wall	2.16
Hybrid MSE/Soil Nailing Wall	2.32
Hybrid MSE/Anchored Sheet Pile Wall	3.38
Hybrid Cantilever/Anchored Sheet Pile Wall	3.50

Table 6: Comparison between hybrid systems in terms of anchor forces

Earth Retaining System	**Anchor Force** {KN/m}
Hybrid MSE/Anchored Sheet Pile Wall	514
Hybrid Cantilever/Anchored Sheet Pile Wall	586.5



a) Soil Nailing Wall b) MSE Wall

Fig. 5: Maximum reinforcement tensile force for different hybrid earth retaining systems

Summary and Conclusion

Based on the numerical analyses and the results obtained, various conclusions that have been drawn for the behavior of hybrid earth retaining systems in **dense sand soil** are as follows:

- The most common hybrid earth retaining wall, MSE/soil nailing hybrid wall, isn't considered the best hybrid system as it produces the maximum wall deformations and the lowest global factor of safety.
- Hybrid cantilever/anchored sheet pile wall and hybrid MSE/anchored sheet pile wall almost produce the same maximum wall deformation value. However, the cantilever/anchored sheet pile wall produces lower lateral displacement than the MSE/anchored sheet pile hybrid wall.
- The maximum soil nails axial forces is the same in case of hybrid MSE/soil nailing wall and hybrid cantilever/soil nailing wall.
- Hybrid MSE/soil nailing wall produces higher reinforcement tensile forces than hybrid MSE/sheet pile wall.
- Hybrid cantilever/anchored sheet pile wall produces higher anchor forces than hybrid MSE/anchored sheet pile wall.

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