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An experimental study on the behavior of the helical tiebacks in the flexible retaining walls

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Abstract. In the implementation of most civil structures, especially underground, deep excavations with a vertical slope are required. Using flexible retaining walls is applied as one of the ways to stabilize vertical holes. Therefore, it is necessary to know the parameters affecting the performance of such walls in reducing their horizontal movement. In this research, by building a suitable laboratory model, the parameters of the amount of flexibility, the embedment depth of the wall, the type and number of tieback in the wall were investigated for 42 static laboratory models. The purpose of this research is to study the flexible retaining wall with helical tieback compared to simple tieback at different heights, which shows the best performance in terms of reducing horizontal displacement in proportion to increasing or decreasing flexibility. On the other hand, one of the parameters affecting the flexibility of the wall, which is its bending stiffness, was extracted by numerical software outputs and studied on the results such as relative flexibility, stiffness, safety and numerical stability of the wall.The results of this study show that among the parameters, in the first place, the effect of the type of tieback is inhibited and in the second place, the ratio of thickness to wall height is known as the most important parameter. the best performance for walls with the helical tiebacks in reducing their horizontal displacement can be economically, flexibly and stability assigned to a wall that tiebacks is in the range of $^{H2}/_{t}$ to $^{H4}/_{t}$ and its flexibility ratio is $^{2}/_{3}$.

Keywords: flexible; helical tieback; simple tieback

1. Introduction

Today, in areas where the excavation with a permissible slope is not possible, excavation with a vertical slope is required. For this purpose, to control such excavations as one of the solutions, using restrained flexible retaining walls (concrete diaphragm) which are considered a type of flexible retaining walls is recommended (FHWA 2015, Martínez *et al*. 2017). Although techniques to make the flexible retaining walls have rapidly developed, the complex behavior of structure, the bracing, and the soil interaction with these members is not fully understood (Hanna and Matallana 1970, James and Phillips 1971, Liu and Dugan 1972, Hanna and Kurdi 1974, Anderson *et al*. 1977, Plant *et al*. 1980, Ilieş *et al*. 2015). The stability of soil around the pit by the concrete diaphragm wall and the research on its behavior have long been studied. In the soil stability method, lateral braces were used to improve the performance of such walls. In addition to the effect of using tiebacks for the stability of wall, the height of wall is one of the significant factors affecting the lateral movement of wall (Ola 1989, Rajapakse 2015, Comodromos *et al*. 2015). Studying the internal behavior of restrained concrete retaining wall and the analysis of this behavior under the effect of superimposed load on the soil adjacent to the wall at different depths of the earth has always been part of the study of such walls. In the discussion of wall flexibility and rigidity, the flexibility of wall plays an important role to reduce the lateral pressure on the retaining wall (Yajnheswaran *et al*. 2015, Yu *et al*. 2015, Ertugrul *et al*. 2017). The effects of clay in the analysis of the behavior of concrete diaphragm retaining wall were studied in the past. However, adequate knowledge of the behavior of this type of soil and engineering properties of clay, such as compaction and its effects on structures adjacent to the pit is of crucial importance. To this end, the looser the clay, the more pressure on the wall, which also causes the wall to collapse. The helical tiebacks can be used in a wide range of soil conditions. Using this method in dense soils is one of the latest achievements due to the development of this method (Araujo *et al*. 2012, Stanier *et al*. 2014, Du *et al*. 2015, Truty 2016). By examining the displacement behavior of retaining walls for soil in normal and dry condition, more displacement has been observed than other soil conditions in the wall Ren *et al*. (2020). The static experimental study on the horizontal displacement of the flexible retaining walls is one of the parameters that many researchers have studied. For this purpose, the deformation of retaining wall was investigated by modeling the retaining wall on a small scale in the laboratory in the thin sheet box and using measuring gauges and strain gauges that focus on the soil by applying load (Araei and Towhata 2014, Ibrahim

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2015, Ghanbari and Ahmadabadi 2015). Investigating the deformation process of flexible retaining walls and finding out the degree of deformation of the structure under the loads is one of the priorities that previous researchers have addressed. These researchers have used sensors which are considered to move the flexible retaining wall at specific distances to determine the degree of deformation and displacement of structure (Huang and Luo 2009, Wang *et al*. 2015, Stramondo *et al*. 2016, Han *et al*. 2016, Ren *et al*. 2020, Korini *et al*. 2021). The use of reinforcements in flexible retaining walls has a significant effect on reducing the lateral pressure of the ground on such walls. On the other hand, the flexible behavior of flexible retaining walls is affected by the lateral pressure of the ground on such walls Ertugrul and Trandafir (2013).

One of the important applications of helical members is used in the helical piles, the helical foundations, and the helical tiebacks Duran, De (2012) and Donald, Deardorff (2018). The helical tieback has a high installation speed and reliability, which are their most significant advantages Stephenson (2003) and Young (2012). If the helical tieback is incorrectly installed, it is easy to move and relocate like temporary tieback cases. The helical members can be installed under climatic conditions and with commonly available equipment and less manpower Perko (1999). Study on the behavior of helical restraints in different soils is one of the parameters affecting their behavior. Clay is one of the types of soils that have a significant effect on the behavior of such inhibitions (Wang *et al*. 2013, Stanier *et al*. 2015, Tang and Phoon 2016). Today, the use of helical restraints as one of the influential members in the behavior of retaining walls has been studied Mahmoudi *et al*. (2020). One of the important and influential parameters on the strength of the Helical Tiebacks is the effect of the number, distance and diameter of the helix on such restraints on the stability of retaining walls. On the other hand, most use of Helical Tiebacks is for foundations and less is used in retaining walls, especially flexible retaining walls (Cerato and Victor 2009, Tsuha and Aoki 2010, Mittal and Mukherjee 2013, Wang *et al*. 2013, Lany and Deng 2018).

Considering the effect of the flexibility degree of wall on the lateral displacement of the wall, a study in this regard seems necessary. On the other hand, the lack of study on the effect of helical tiebacks on the flexibility of retaining walls, especially flexible retaining walls, shows the need for this research. Therefore, 42 small-scale wall models in different embedment depths and reinforcement conditions were studied. In addition to the flexibility effect of wall on its lateral displacement, the effect of embedment depth and using different lateral tiebacks on the wall performance were evaluated, and the results were discussed and compared.

2. Materials, tools and how to perform the test

2.1 The soil

The soil used in this paper is a type of clay-based on the Unified Soil Classification System (USCS) called CL. Fig.

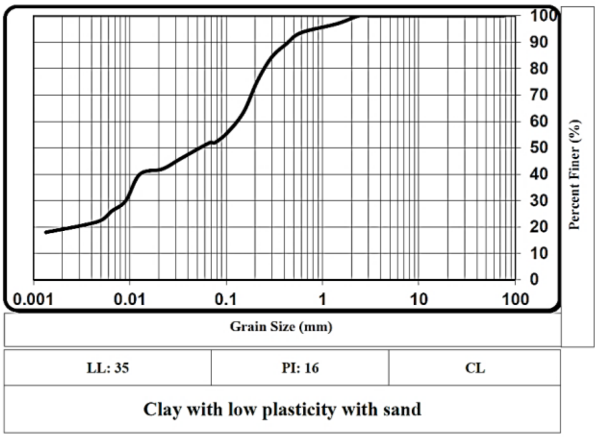


Fig. 1 The Grain Soil Distribution Curve

1 shows the grain size distribution curve of this soil. This soil has a specific weight in the loose state equal to 1178.57 kg/m^3 and the dense state equal to 1375 kg/m^3, and its specific density is equal to 2.8. A summary of soil geotechnical properties is given in Table 1.

2.2 The tieback

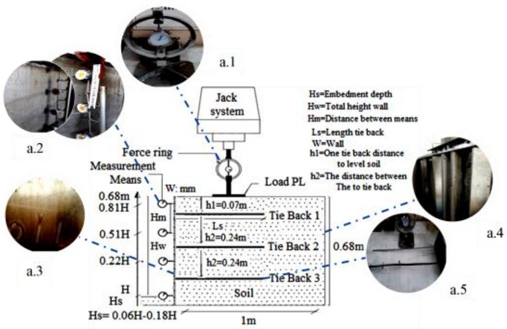
To restrain the retaining wall, 1, 2, and 3 simple and helical tiebacks were used. The choice of width and length of the tieback was made according to Stipho's study (1988). The tieback is made of a corrosion-resistant galvanized steel sheet with a maximum tensile strength of 120 MPa. This tieback has dimensions of 0.56 m in length, 0.007 m in width, and 0.001 m in thickness. This tieback is connected to the body of retaining wall with screws by a sheet measuring 0.15 × 0.15 m. In this study, the choice of diameter, number and distance between Helical in the Tieback axis is considered based on paper Rawat and Gupta (2017). Therefore, for Helical Tieback, diameter 0.031 m, number 3 and distance 0.093 m are considered (Fig. 2(a.5)). The number of Helical in the Tieback is selected based on its most effective state, which is 3 (Rawat and Gupta 2017). On the other hand, all 3 Helical are in the range after the Failure Surface.

2.3 The testing machine

In modeling the concrete diaphragm retaining wall, due to very small thickness compared to the height and length of wall, the possibility of using concrete materials is almost eliminated. In this regard, regarding the behaviors of steel sheet and restrained concrete diaphragms due to flexibility, to a large extent, are similar to each other, steel sheet was used for the experimental modeling Saba (2002). As shown in Fig. 2, the testing machine has dimensions of length, width, and height of 1, 0.70, and 0.68 meters which is made of galvanized steel sheet. Three vertical walls of the testing machine are fixed with a thickness of 0.7 mm and are connected by universal welding. Only one of walls which has different thicknesses equal to 1 and 3 mm, can be moved. Furthermore, the conditions are provided to

Table 1 Summary of the geotechnical properties for the soil

Clay	φ	υ	ψ	G_s	C (kN/m^2)	$\gamma_{min\ dense}$ (kN/m^3)	$\gamma_{max\ dense}$ (kN/m^3)
	31°	0.3	0°	2.8	103	11.79	13.75



(a) The Model of testing machine

(b) The Overview of testing machine

Fig. 2 The Testing Machine

investigate the effect of the embedment of retaining wall on the recommended ranges of 0.06H, 0.12H, and 0.18H which according to the height of the wall (0.68 m), is equal to 0.04, 0.08, and 0.12 m. The dimensions of wall, especially its height, are the important controlling factors compared to a real model. The higher the box, the closer the results are to reality. Selecting the dimensions of testing machine is based on the previous studies (Stipho 1988, Saba 2002, Shabani *et al*. 2016, Mahmoudi *et al*. 2020). In order to eliminate the friction between the joint surface of the wall and the soil, very lubricating oil with very low viscosity has been used (Fig. 2(a.3)). In order to prevent and eliminate the lateral pressure of the soil at the model boundaries and to prevent lateral deformation of the walls during its construction and loading (creating a plane strain condition), vertical elements along the wall have been used (Fig. 2(a.4)). To calculate the effect of scale in the recommended laboratory model, a relative density of 84% should be used (Sabermahani *et al*. 2008).

2.3.1 The Force application system

A 49 kN jack is used to apply the vertical force (Fig. 2). This jack transmits the force to the sheet measuring 0.15 × 0.69 meters and the thickness of 0.01 meters. The force is located at a distance of 0.125 m from the wall and in the vicinity of the Rankin failure surface (Shabani *et al*. 2016).

2.3.2 The Measuring system

In these experiments, a dynamometer with a capacity of 30 kN and an accuracy of 0.01 mm was used (Fig. 2(a.1)). Moreover, four displacement gauges with an accuracy of 0.01 mm and the displacement of 0.01 m, which are located at heights of 0.0, 0.15, 0.35, 0.55 m, respectively, from the bottom of wall, were used (Fig. 2(a.2)).

2.4 The test schedule

To conduct this research, 42 experiments were erformed according to Table 2. In these experiments, the amount of superimposed load (10 kN / m) and the specific weight of clay (1375 kg/m^3) are considered constant. The first main reason for choosing a load of 10 kN/m is taken from Stipho's 1988 paper. Due to the close agreement of the results of laboratory studies with Stipho's paper, this amount of load became the basis of validation of laboratory studies. The second reason is that if a load greater than this amount is applied to the wall with three rows of tiebacks, it will cause the wall to collapse. Also, the purpose of choosing this overhead is to evaluate the performance of the wall in the condition before rupture, which is selected based on the performance of the reference wall. On the other hand, this load was chosen as a strip load, because of the ratio of length to width greater than 10 (L/B>10), which this load imposes on the soil surface

3. Results and dscussions

In this section, the results of experiments and the effect of various factors on the displacement of wall are discussed. Among these various factors, wall thickness (t), wall embedment depth (G), number tiebacks of simple and helical can be expressed.

It is worth mentioning, In order to control the embedment depth for Horizontal displacement the wall, during the construction of the test device, a 5 cm sheath was designed at the bottom of the wall, which was obtained by trial and error testing. In all the figures of chapter 3.1, especially in Fig. 5, this value can be seen for the without tieback wall with a thickness of 1 cm and 0.15H embedment depth, which has a lower maximum displacement. Inside this sheath, the heel of the retaining wall along with the soil of the same material behind it is poured to a width of 5 cm and the depths of 0.06H, 0.12H and 0.18H in front of it (Saba 2002).

Table 2 The Schedule of tests

Number helical tie back				Number simple tie back				Embedment depth (Hs:mm)			Wall thickness (W:mm)		Number
0	1	2	3	0	1	2	3	40	80	120	1	3	
+				+				+			+		1
+				+					+		+		2
+				+						+	+		3
+				+				+				+	4
+				+					+			+	5
+				+						+		+	6
	+							+			+		7
	+								+		+		8
	+									+	+		9
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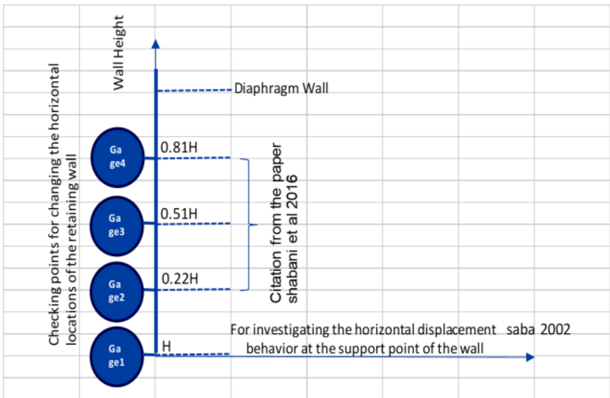
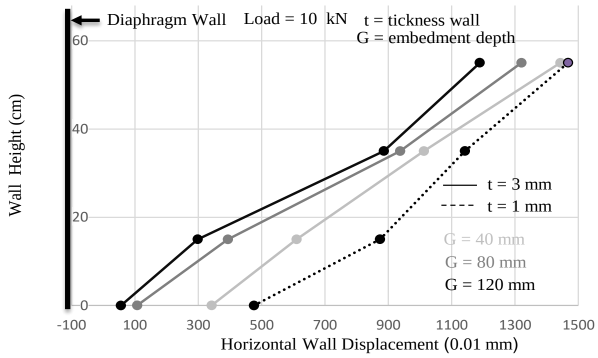
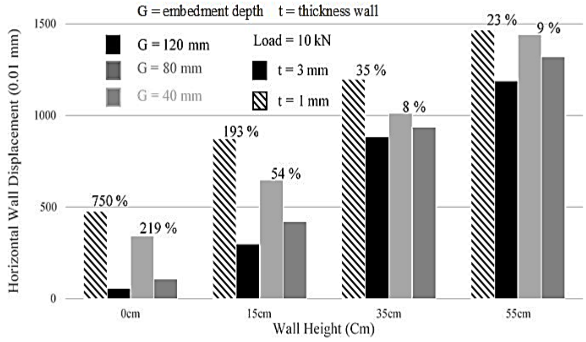


Fig. 3 The geometric location of the studied points in the horizontal movement of the wall



(a) The horizontal displacement diagram of wall



(b) The horizontal displacement of the wall at the different levels

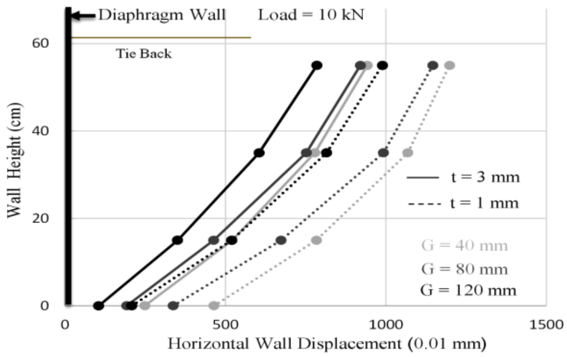
Fig. 4 The horizontal displacement of the wall without the lateral tieback

3.1 Investigation of the effect of the tieback on the wall displacement

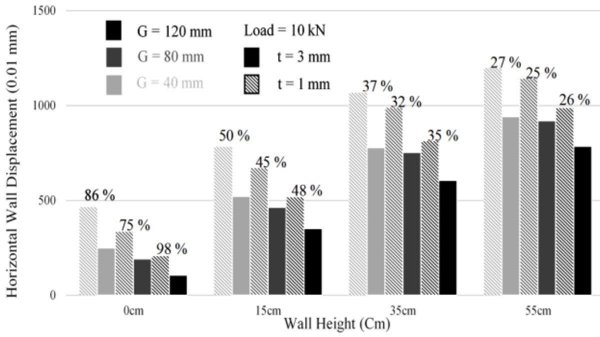
3.1.1 The investigation of the wall displacement without using the tieback

Fig. 4 shows the changes in the displacement of horizontal wall not using the tieback at the height levels H, 0.22H, 0.51H and 0.81H with two thicknesses of 1 and 3 mm and the embedment depths of 40, 80, and 120 (0.06H-0.12H-0.18H) millimeters. Due to the instability is shown by the wall for 1 mm thickness in the embedment depths of 40 and 80 mm, the diagram wasn't drawn. Fig. 4(a) shows that the changes in the horizontal displacement of wall are greater for all cases at the top of wall which is the largest contribution to the wall with the greatest thickness and embedment. The behavior of wall in these cases is flexural behavior. This flexural behavior in the wall with less thickness and more embedment has its greatest contribution.

On the other hand, the bottom of wall (H) is displaced as well as the top of wall which shows the least horizontal displacement for the wall with more embedment and thickness. By an increase of 0.81 times the height of the

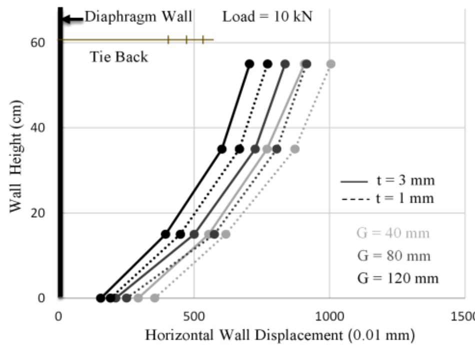


(a) The horizontal displacement diagram of wall

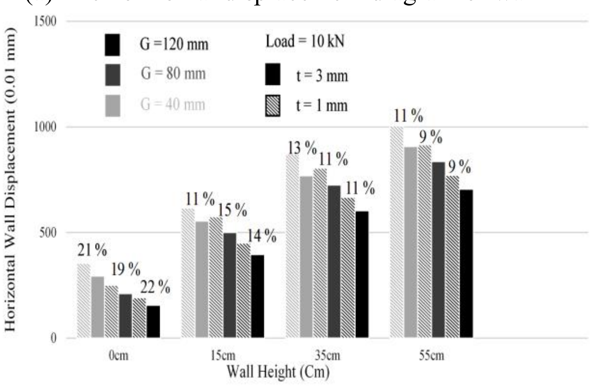


(b) The horizontal displacement of the wall at the different levels

Fig. 5 The horizontal displacement of the wall with the simple tieback



(a) The horizontal displacement diagram of wall



(b) The horizontal displacement of the wall at the different levels

Fig. 6 The horizontal displacement of wall with the helical lateral tieback

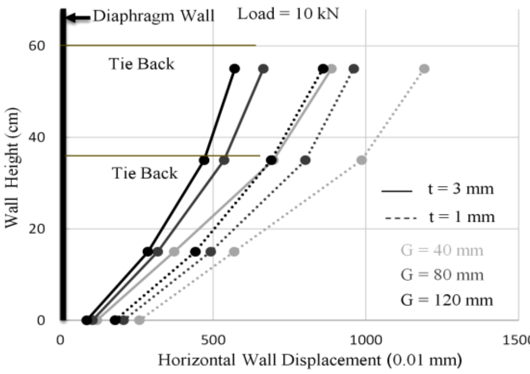
wall (H-0.81H), the lowest horizontal displacement for the wall with the highest thickness and the embedment and at the rate of 21.23 times is equal to (1189-56) and the highest horizontal displacement for the wall with the least thickness and maximum embedment at the rate of 3.08 times is equal to (476-1468). Fig. 4(b) shows the difference in the percentage of the horizontal displacement of wall at different levels and positions. By reducing the wall thickness threefold (1-3), the largest contribution in this difference is related to the bottom of the wall (H) with 750%. Furthermore, this value at the top of the wall at the level of 0.81H (68 cm) is decreased from 750% to 23%, in fact, a decrease of 727% is observed. The result of this percentage difference can be further considered to reduce the flexural behavior of the wall between two levels of 0.51H to 0.81H and increase the flexural behavior of the wall between two levels of H to 0.51H.

3.1.2 The effect of the simple tieback on the wall displacement

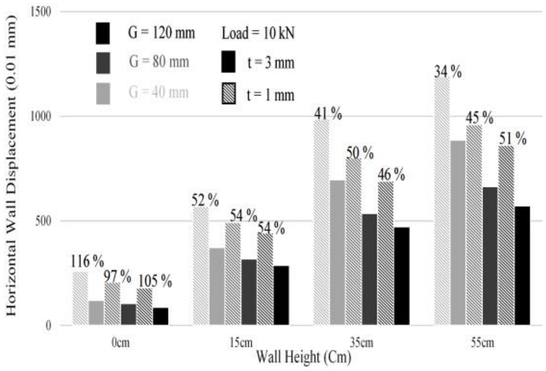
Fig. 5 shows the changes of the horizontal displacement of wall for the simple tieback at the different height levels with two thicknesses of 1 and 3 mm and the embedment depths of 0.06H, 0.12H, and 0.18H. Fig. 5(a) shows that using the tieback, the wall shows the shear behavior. By increasing wall height, the horizontal displacement of the wall at the top of wall compared to the bottom of the wall has increased. The behavior of wall for 1 and 3 mm thicknesses for the embedment of 40 and 80 mm is close to each other, but is more different in the embedment of 120 mm. Hence, this difference among the walls with the embedment of 40 and 80 mm on the top of wall (0.81H) is 1.02 times (920-942) and at the foot of the wall (H) is 1.30 times (192-249). The presence of tieback caused the highest reduction in the horizontal displacement of wall at the bottom of wall (H), which is by 1.98 times, and the lowest reduction in the horizontal displacement at the top of wall l (0.81H) is by 1.24 times. Therefore, the presence of tieback has increased the stability 0.74 times in the horizontal displacement of wall at the top of wall relative to the bottom of wall. Fig. 5(b) shows the highest difference at the bottom of wall (H) and the lowest difference at the top of wall (0.81H). The effect of the tieback on the top of wall indicates that there is a smaller percentage difference among all cases. For this reason, by a decrease of 60.33% on average (86.33-26), the horizontal displacement of the wall has been from H level to 0.81H. In all three height levels 0.22H, 0.51H, and 0.81H, the percentage difference in the horizontal displacement of wall is close to each other, but not at the bottom of wall (H).

3.1.3 The effect of the helical tieback on the wall displacement

Fig. 6 shows the changes in the horizontal displacement of wall for the helical tieback at different height levels for two thicknesses (1 and 3 mm) and three embedment depths of 0.06H, 0.12H, and 0.18H. The presence of helical tieback makes the shear behavior of wall closer to each other in all cases. The presence of the helical tieback and a threefold increase in the wall thickness has the greatest effect on

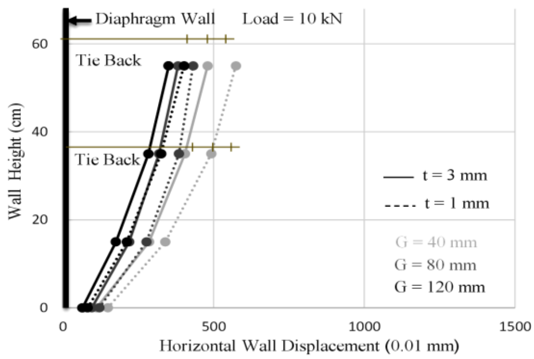


(a) The horizontal displacement diagram of wall

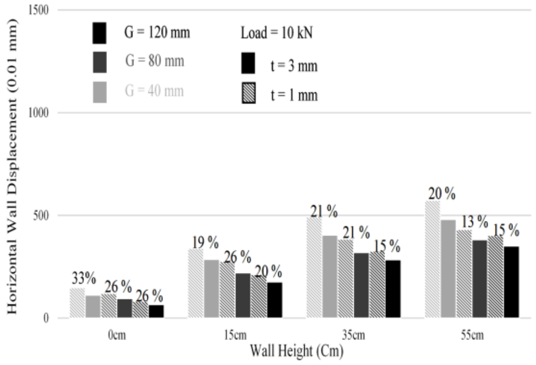


(b) The horizontal displacement of the wall at the different levels

Fig. 7 The horizontal displacement of the wall with two simple lateral tiebacks



(a) The horizontal displacement diagram of wall



(b) The horizontal displacement of the wall at the different levels

Fig. 8 The horizontal displacement of the wall with two helical lateral tiebacks

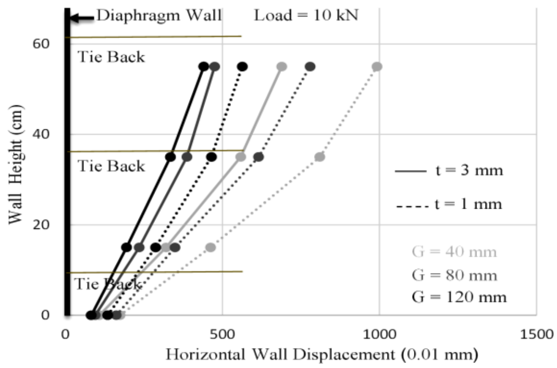
reducing the horizontal displacement on the wall with less thickness and embedment (1 and 40 mm), by 1.10 times and at the bottom of the wall by 1.20 times. Therefore, the difference of 0.10 times in the horizontal displacement of the wall for this case is observed in the total height of the wall. In Fig. 6(b), the range of percentage differences in the various levels for the horizontal wall displacement is between 9% and 22%. This difference in three height levels of 0.22H, 0.51H, and 0.81H is very close to each other, compared to the height level of the bottom of wall (H). By a threefold reduction in flexibility, a reduction of 10%, 10%, and 13% is observed for the embedment of 0.06H, 0.12H, and 0.18H at two height levels of 0.81H and H, respectively.

3.1.4 The effect of two simple tiebacks on the wall displacement

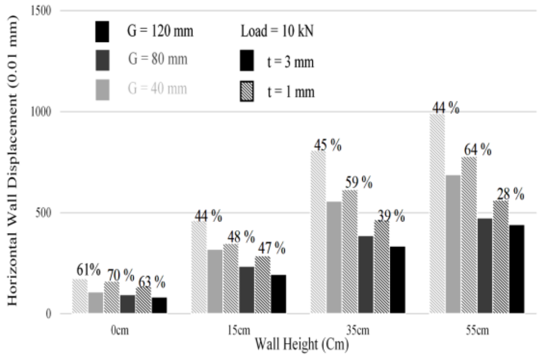
Fig. 7 shows that the changes of the horizontal displacement of wall for two simple tiebacks at the different height levels with two thicknesses and three embedment depths of 0.06H, 0.12H, and 0.18H. Fig. 7(a) shows that by a threefold increase in the wall thickness, the shear behavior in the walls with the embedment of 0.12H and 0.18H, is closer to each other at the bottom of the wall (H) in comparison with the embedment of 0.06H. Thus, a 1.31-fold (191-251) decrease in the horizontal displacement at the bottom of wall (H) for the thickness of 1 mm and a 1.35-fold decrease (156-211) for the thickness of 3 mm have occurred from 0.12H to 0.18H. Using more tiebacks, the behavior of wall tends to approach its original state, and as a result, the shear behavior of wall decreases, and the stability of the wall increases. Fig. 7(b) shows the highest shear behavior at the bottom of wall. Therefore, the highest percentage of difference is observed at this level. By examining the percentage difference among the horizontal displacements at the different levels, the lowest value in the height level is at 0.22H. Therefore, by doubling the number of tiebacks, the greatest effect is to reduce the percentage difference in the middle of the wall. The smallest difference among the obtained percentages is related to the height level of 0.22H (54-52%), and the highest difference is related to the height level H (97-116%).

3.1.5 The effect of two helical tiebacks on the wall displacement

Fig. 8 shows the changes in the horizontal displacement of wall at the different height levels for two thicknesses (1 and 3 mm), two helical tiebacks, and the embedment depths of 0.06H, 0.12H, and 0.18H. As seen in Fig. 8(a) the horizontal displacement of wall at the top and the bottom of the wall is very close to each other. The effect of two helical tiebacks is to make the horizontal displacement of the wall closer in all cases except in the wall with less thickness and embedment (1 and 40 mm). By a ratio increase of 3 to 0.81 times the thickness to the height for the wall with the embedment of 0.18H, the maximum decrease in horizontal wall displacement is in the range from 4.90-5.40 times (65-351, 82-402). By a threefold reduction in

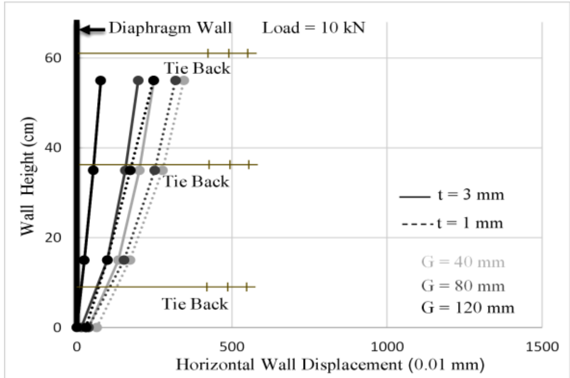


(a) The horizontal displacement diagram of wall

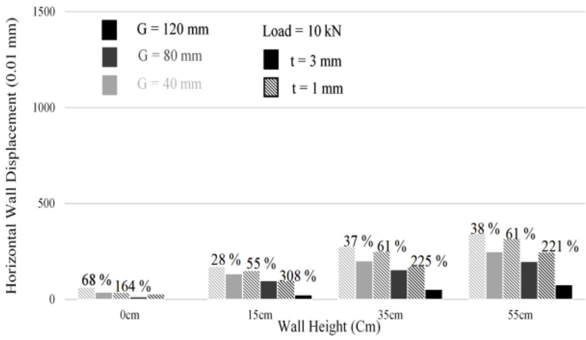


(b) The horizontal displacement of the wall at the different levels

Fig. 9 The horizontal displacement of the wall with three simple lateral tiebacks



(a) The horizontal displacement diagram of wall



(b) The horizontal displacement of the wall at the different levels

Fig. 10 The horizontal displacement of the wall with three helical lateral tiebacks

flexibility to 0.81-fold in the height at the bottom of the wall (H) with the embedment of 0.06H, the greatest reduction in the displacement occurred from 1.33-fold (112-149) to 1.19-fold (480-574). In Fig. 7(b), obtained difference in the percentages is very close to each other Thus, the existence of two helical tiebacks has caused the shear behavior of the wall to be closer to each other at all height level and to be closer to the initial behavior and more stability of the wall. By a threefold increase in the wall thickness, the highest percentage difference is in the height levels of 0.51H and 0.81H for the wall with the embedment of 0.06H and at the height levels of H and 0.22H for the wall with the embedment of 0.12H. Comparing the difference in the percentage of the horizontal displacement of the wall at the total height levels, the lowest of these values are for the wall with the embedment of 0.12H and at the height level of 0.81H by 13%, and the highest value is related to the wall with the embedment of 0.06H at the height level (H) by 33%.

3.1.6 The effect of three simple tiebacks on the wall displacement

Fig. 9 shows the changes in the horizontal displacement of wall at different height levels for cases with two thicknesses (1 and 3 mm), three simple tiebacks, and the embedment depths of 0.06H, 0.12H, and 0.18H. In Fig. 8(a), by a threefold increase in the number of tiebacks, the horizontal displacement of the wall for two levels (H) and (0.22H) are closer to each other than two levels of 0.51H and 0.81H. By an increase of 0.81 times, the wall height for the wall with the thickness of 3 mm, the greatest decrease in the horizontal displacement is observed in the wall with the embedment of 0.06H by 6.37 times (108-689). By an increase of 0.81 times, the wall height for the wall with a thickness of 1 mm, the maximum decrease in the horizontal displacement for the wall with the embedment of 0.06H is 5.7 times (174-992). By a threefold reduction in the flexibility (1-3) at the bottom of the wall (H), the greatest reduction in the horizontal displacement is 1.7 times in the embedment of 0.12H (95-162) and at the level of 0.81H for the embedment of 0.12H is 1.64 times (475-779). In Fig. 9(b), with a threefold increase in the wall thickness, the highest percentage difference in the horizontal displacement is 70% for the wall with the embedment of 0.12H, and the lowest is 28% for the wall with the embedment of 0.18H.

3.1.7 The effect of three helical tiebacks on the wall displacement

Fig. 10 shows the changes in the horizontal displacement of wall at different levels for cases with two thicknesses (1 and 3 mm), three helical tiebacks, and the embedment depths of 0.06H, 0.12H, and 0.18H. Based on Fig. 9(a), by increasing the number of helical embedment in the wall threefold, the behavior of wall changes from shear to linear mode with the constant slope and approaches the initial shape of wall which indicates the stability of the wall. On the other hand, as the behavior of the wall changes from less thickness to greater thickness, it indicates that applying the helical tieback not only does not make the wall rigid, but also shows the flexible behavior with more stability. By increasing the wall height by 0.81 times for the thickness of 3 mm, the maximum decrease in the horizontal displacement is 0.12H and is 14.14 times (14-198). Compared to the 0.81-fold increase in the wall height for a thickness of 1 mm, the maximum decrease in the horizontal displacement of the embedment of 0.12H is 8.59 times (37-318). The wall reaches its initial state at the height level H and its stability, the criterion to compare is the level of 0.22H. By a threefold reduction in the wall flexibility (1-3), at the level of 0.22H, the greatest decrease in the horizontal displacement of the embedment is 4.08-fold (24-98) and at the level of 0.81H for the embedment of 0.18H is 3.2 times (77-247). A threefold reduction in the flexibility and a threefold increase in the thickness and the number of helical tiebacks have changed the type of the support of the bottom of wall from the rolled to the embedment. In Fig. 10(b), with a threefold increase in the wall thickness, the minimum and maximum percentages obtained for the wall for the embedment are 0.06H and 0.18H at the level of 0.22H, respectively. The difference in the percentage of the horizontal displacement of the wall with the embedment of 0.06H compared to 0.12H is about two times, but the embedment ratio of 0.12H to 0.18H varies between 3.5 to 5.5 times.

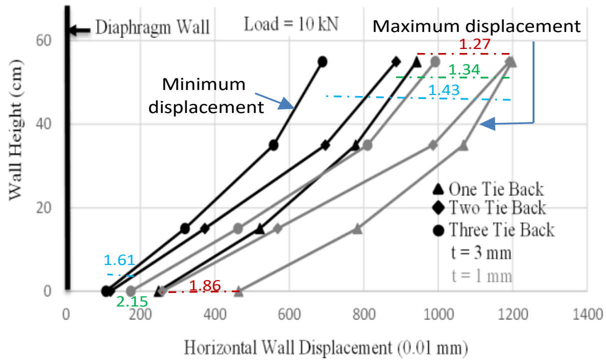
3.2 The investigation of the embedment depth on the horizontal displacement of the wall

3.2.1 The embedment depth of 40 mm (0.06H)

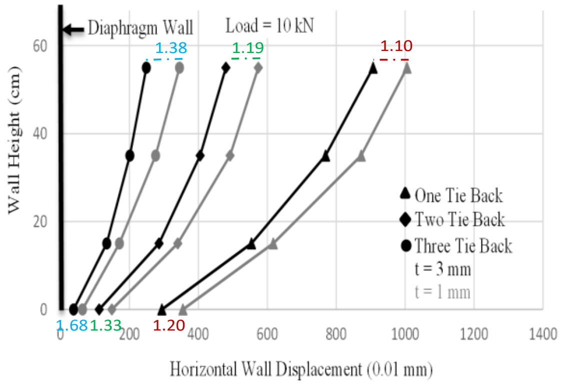
Fig. 11 shows the amount of the horizontal displacement of wall in the different positions for simple and helical tiebacks with the embedment of 0.06H. Fig. 11(a) shows the minimum displacement for the wall with more tiebacks and more thickness and the maximum displacement is for the wall with fewer tiebacks, and less thickness. These changes in the height level of 0.81H are relatively greater than the height level of H. In Fig. 11(b), with a threefold increase in the wall thickness, its behavior is close to each other in all tiebacks states. The difference is that three helical tiebacks show more stable behavior. By a threefold increase in flexibility in the wall with the embedment of 0.06H, for the wall with the simple tieback, the minimum and maximum horizontal displacement of the wall at the height level of 0.81H and H is 1.27 times (942-1198) and 1.86 times (249-464) and for the helical tieback is 1.10 times (907-1005) and 1.20 times (294-355). For the wall with two simple tiebacks, they are 1.34 times (887-1191) and 2.15 times (120-259), and in two helical tiebacks, they are 1.19 times (480-574) and 1.33 times (112-149). For the walls with three simple tiebacks, they are 1.43 times (689-992) and 1.61 times (108-174), and for three helical tiebacks, they are 1.38 times (249-345) and 1.68 times (38-64).

3.2.2 The embedment depth of 80 mm (0.12H)

Fig. 12 shows the horizontal displacement of wall in different positions for the simple and the helical tiebacks with the embedment of 0.12H. By a threefold increase in the amount of the flexibility for the wall with the simple tieback, the minimum and maximum horizontal displacement of wall at the height level of 0.81H and H are

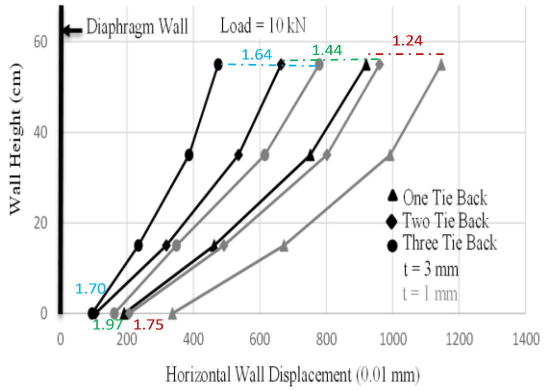


(a) The simple tieback

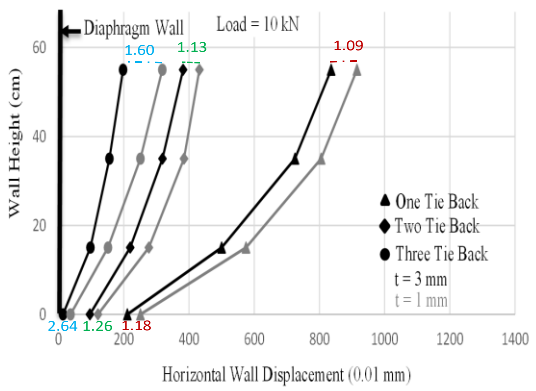


(b) The helical tieback

Fig. 11 The horizontal displacement of the retaining wall for the embedment of 40 mm (0.06H)



(a) The simple tieback



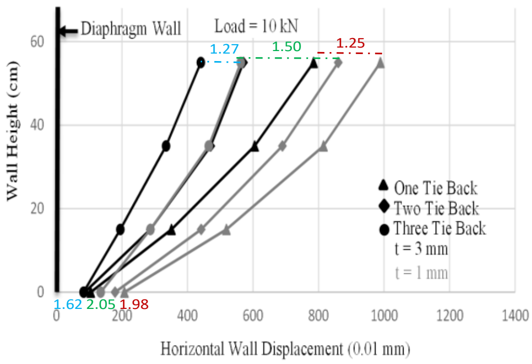
(b) The helical tieback

Fig. 12 The horizontal displacement of the retaining wall of the embedment of 80 mm (0.12H)

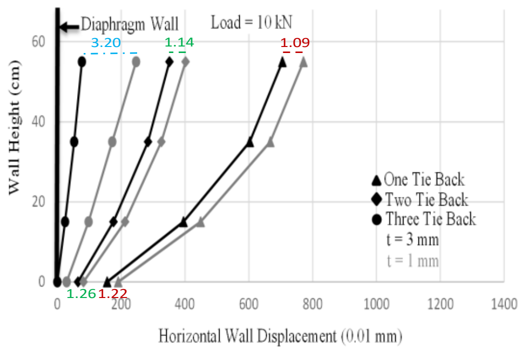
Table 3 The ratio of effective parameters in the amount of flexibility to the wall thickness

					$E1/t$	40		$Nh1/t$	1000		$H1/t$	0
Code 1	t= 0.001	q/t	10000	E/t	$E2/t$	80	Nh/t	$Nh2/t$	2000	H/t	$H2/t$	150
											$H3/t$	350
					$E3/t$	120		$Nh3/t$	3000		$H4/t$	550
					$E1/t$	13		$Nh1/t$	333		$H1/t$	0
Code 2	t= 0.003	q/t	3333	E/t	$E2/t$	27	Nh/t	$Nh2/t$	667	H/t	$H2/t$	50
											$H3/t$	117
					$E3/t$	40		$Nh3/t$	1000		$H4/t$	183

E: Embedment depth, t: thickness Wall, N h: Number helical, H: Height Wall, q: Load



(a) The simple tieback



(b) The helical tieback

Fig. 13 The horizontal displacement of the retaining wall of the embedment of 120 mm (0.18H)

1.24 times (920-1146) and 1.75 times (192-337), and for the helical tieback are 1.09 times (836-915) and 1.18 times (211-251). For the wall with two simple tiebacks, they are 1.44 times (664-960) and 1.97 times (105-207), and for two helical tiebacks, they are 1.13 times (382-432) and 1.26 times (96-121). For the wall with three simple tiebacks, they are 1.64 times (475-779) and 1.70 times (95-162), and for three helical tiebacks, they are 1.60 times (198-318) and 2.64 times (14-37). As a result, applying the helical tieback has caused more stability of wall, especially in the cases with two and three tiebacks.

3.2.3 The embedment depth of 120 mm (0.18H)

Fig. 13 shows the horizontal displacement of wall in different states for the simple and the helical tiebacks with the embedment of 0.12H. By a threefold increase in the flexibility for the wall with the simple tieback, the minimum and maximum horizontal displacement of the wall at the height level of 0.81H and H are 1.25 times (785-989) and 1.98 times (105-208) and for the helical tieback are 1.09 times(705-771) and 1.22 times (156-191). For the wall with two simple tiebacks, they are 1.50 times (571-860) and 2.05 times (87-179), and for two helical tiebacks, they are 1.14 times (351-402) and 1.26 times (65-82). For the walls with three simple tiebacks, they are 1.27 times (441-563) and 1.62 times (83-135), and for three helical tiebacks, they are 3.20 times (77-247) and a very high amount (0-29).

3.3 The helical tieback on the wall flexibility

By studying the effect of simple tieback and helical on the horizontal displacement of the wall, the most effective state of the wall is the helical tieback. Accordingly, the study on the effect of such tiebacks in the discussion of wall flexibility, which is one of the parameters of research innovation, is examined in the following cases. Since the basis of the studies is based on the discussion of wall flexibility, all parameters are dimensionless in proportion to wall thickness and are measured (Table 3).

3.3.1 The displacement top of the wall (0.81H)

The study of the displacement top of the wall is due to the fact that the most horizontal wall displacement occurs in this part and is considered as one of the critical points in the retaining wall (Saba 2002). Consequently, the amount of horizontal displacement above the wall in different cases is studied according to Table 4.

From the study of the data in Table 4 and their analysis in Fig. 14 it can be found that by increasing the rigidity of the wall by 3 times, the amount of reduction in the horizontal displacement of the wall in the cases where the wall has one and two rows of helical tieback is a closer match than the wall with 3 rows of helical tieback. The slope of the graph is uniform and gentle from state 1 to 2 tieback and from state 2 to 3 tieback for embedment depth 0.05H and 0.10H, relatively mild but for 0.15H, it is associated with a large upward trend. The reason for this can be related to the better performance of the wall for the depth of 0.15H compared to other depths. The maximum amount of horizontal displacement reduction for the wall with the highest number of tieback and 0.18H embedment depth is defined as 3.20 times.

Table 4 The horizontal displacement above the wall ($^{H4}/_{t}$)

	Serial exp.1	Serial exp.2	Serial exp.3	Serial exp.4	Serial exp.5	Serial exp.6
		Code 1			Code 2	
	$^{Nh1}/_{t}$	$^{Nh2}/_{t}$	$^{Nh3}/_{t}$	$^{Nh1}/_{t}$	$^{Nh2}/_{t}$	$^{Nh3}/_{t}$
$^{E1}/_{t}$	1005	574	345	907	480	249
$^{E2}/_{t}$	915	432	318	836	382	198
$^{E3}/_{t}$	771	402	247	705	351	77

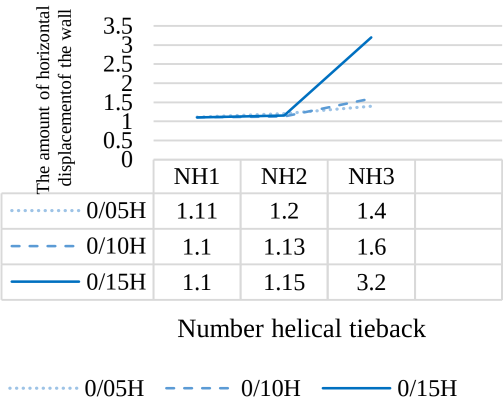


Fig. 14 Investigating the amount of horizontal displacement of the wall based on the number of helical tieback

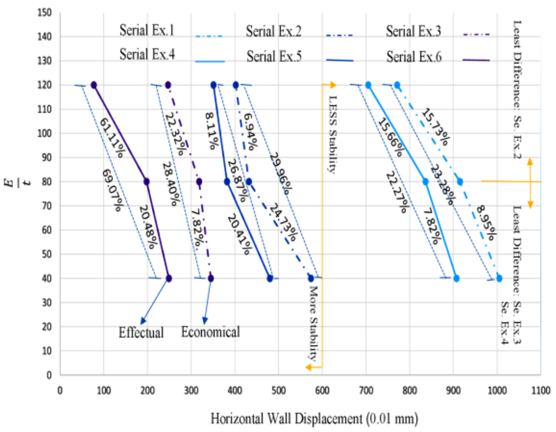


Fig. 15 Investigation of the horizontal wall displacement at 0.81H level for Code 1 and Code 2 modes

Fig. 15, which is plotted according to the results of Table 4, shows that with a 3-fold increase in wall flexibility, a 40.67% (69.07-28.40) decrease in the horizontal wall displacement is observed for S EX.3 and S EX.6 modes. While in other wall modes, this behavior will increase. In S EX.2 and S EX.5 modes, due to the close horizontal wall displacement for $^{E2}/_{t}$ and $^{E3}/_{t}$ embedments, different behavior occurs in their diagrams compared to other modes. With a 3-fold increase in the flexibility and the wall embedment from $^{E1}/_{t}$ to $^{E2}/_{t}$ modes the following results are observed: A reduction of 12.66% in the horizontal wall displacement for S EX.6 to S EX.3 compared to other modes; in addition, for $^{E2}/_{t}$ to $^{E3}/_{t}$ modes, a decrease of 38.79% and 1.17% is observed in the horizontal wall displacement for S EX.6 to S EX.3 and S EX.5 to S EX.2. If the number of helical restraints for the retaining wall is increased by 2 and 3 times, the stability performance in the horizontal wall displacement is increased by 2 and 3 times compared to the case with a number of helical restraints. Because the greatest reduction in the horizontal wall displacement occurs for S EX.6 mode, this mode has been selected as the most effective mode in reducing the horizontal wall displacement. On the other hand, due to the close behavior of S EX.3 to S EX.6 and a 3-fold reduction in the wall thickness, S EX.3 mode has been selected as the most economical mode.

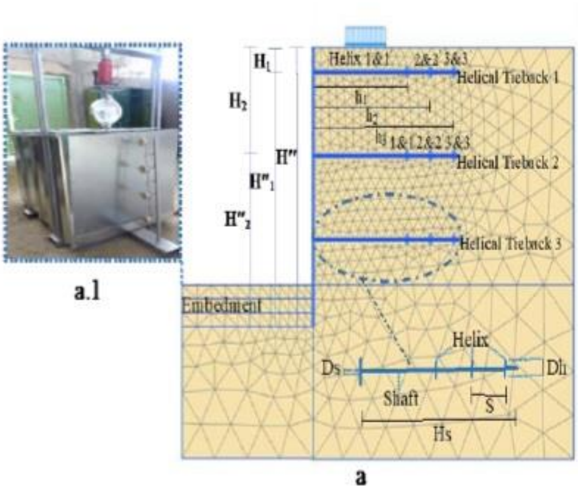
3.3.2 The behavioral mechanism of stress on the horizontal wall displacement

Plaxis software was used to study and extract the results of numerical studies to determine the bending stiffness parameters of the wall. Therefore, in order to model the model and assign the soil material, the Bore Hole menu is used, and the Load menu is used to assign the load, and the tiebacks, wall and helix plates are used from the Plate menu. Also, Mohr-Coulomb soil failure criteria and clay geomechanical parameters ϕ, C and E are considered to be 31º, 103 kN/m2 and 250 kN/m2, respectively. In order to connect the helix plates with the tieback, the Rotation fixity program is used. 15-node triangular elements are also used for meshing the model. The modeling done in the software along with its boundary conditions are shown in the Figs. 16 and 17.

For both numerical and laboratory calculations, a wall with a depth of 0.18H and a thickness of 0.003 m was selected, which is a wall with the best performance in horizontal displacement. The 7 modes studied in chapter 3.1 were investigated for this wall. In Fig. 18, a 10% agreement between the numerical and experimental results can be seen.

So, after performing the necessary verification by PLAXIS finite element software and the acceptable agreement between the numerical and experimental results obtained in Fig. 18, the behavioral mechanism of the amount of stress on the horizontal displacement of the wall is investigated.

In Fig. 19, with a 3-fold increase in the wall thickness, the highest concentration of stress occurs in walls with greater thickness and embedment. While such behavior is symmetrical for walls with two or three helical tiebacks, the highest stress concentrations are observed in thinner walls. Thereupon, the presence of more helical tieback reduces the tension around the retaining wall. In Fig. 20, the lowest



(a) General modeling of helical tiebacks in numerical research
(a.1) Experimental model
Fig. 16 Modeling done in numerical research

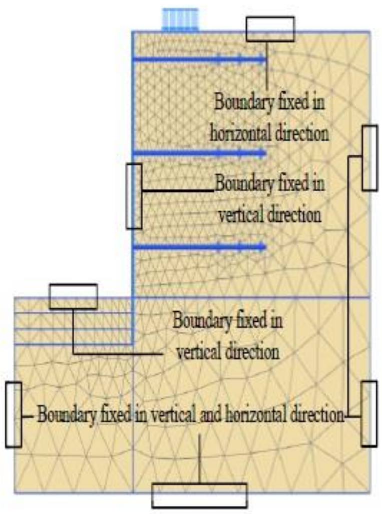


Fig. 17 Boundary conditions of the numerical model

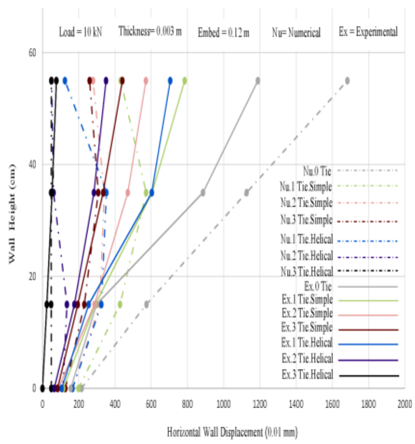


Fig. 18 The validation diagram

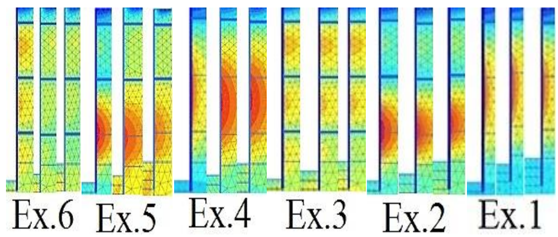


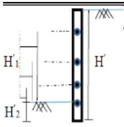
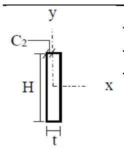
Fig. 19 Contour of the horizontal displacement stress wall

amount of stress bubble relative to the center of the wall at the beginning of the red stress contour and the highest amount related to the orange stress contour is the basis of the study. Range of stress bubbles at wall height for embedment $E1/_t$ for both wall thicknesses 0.001 and 0.003

Table 5 The Summary of the theoretical bending moment (M) and the maximum theoretical bending moment (M_{max}) results

		$E3/t$							
		Item exp. A	Item exp. B	Item exp. C	Item exp. D	Item exp. E	Item exp. F		
		Code 1			Code 2				
		$Nh1/t$	$Nh2/t$	$Nh3/t$	$Nh1/t$	$Nh2/t$	$Nh3/t$		
M	$H1/t$	-1.055	0.761	2.893	-16.986	-4.550	-6.041	1	Row
	$H2/t$	2.191	2.924	-4.358	27.493	26.120	-6.328	2	
	$H3/t$	3.308	-5.370	-3.170	34.561	-22.683	-6.550	3	
	$H4/t$	1.096	4.182	4.010	17.428	7.458	11.644	4	
M_{max}		0.002	0.004	0.004	0.017	0.007	0.012	5	

Table 6 The Summary of results of relative flexibility, the stability number, the maximum bending moment and the wall design moment

	Table of relative wall flexibility studies for different modes														
	Different study modes														
	POS.1				*1	POS.2				*2	POS.3				*3
	S_{yG} (I_{yG}/C_2): 11.34E-08 EI: 11.33 $\sigma_{all} = Cte = 172.5$														
	Item exp. A					Item exp. B					Item exp. C				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
H′ H'_1	0	0.150.350.550.55				0	0.150.350.550.55				0	0.150.350.550.55			
H′ H'_2		0.12					0.12					0.12			
ρ	0.000002	0.0053	0.05	0.20	0.20	0.000002	0.0053	0.05	0.20	0.20	0.000002	0.0053	0.05	0.20	0.20
Log_ρ	-5.69	-2.27-1.31		-0.7	-0.7	-5.69	-2.27-1.31		-0.7	-0.7	-5.69	-2.27-1.31		-0.7	-0.7
S_n	-	0.620.270.170.17				-	0.620.270.170.17				-	0.620.270.170.17			
M_d		0.00002					0.00002					0.00002			
M	-8.620	2.041	3.328	1.515	1.515	-6.591	3.584	-5.070	4.354	4.354	-2.364	-3.485	-3.181	4.145	4.145
M_{max}	-	-	-	-	0.002	-	-	-	-	0.004	-	-	-	-	0.004
$\times 10^{-5} Md/M$	-0.2	0.9	0.6	1.3	1.3	-0.3	0.6	-0.4	0.5	0.5	-0.8	-0.6	-0.6	0.5	0.5
$\times 10^{-1} Md/Mmax$	-	-	-	-	0.1	-	-	-	-	0.05	-	-	-	-	0.05

	POS.4				*4	POS.5				*5	POS.6				*6
	S_{yG} (I_{yG}/C_2):10.2E-07 EI: 306 $\sigma_{all} = Cte = 172.5$														
	Item exp. D					Item exp. E					Item exp. F				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
H′ H'_1	0	0.150.350.550.55				0	0.150.350.550.55				0	0.150.350.550.55			
H′ H'_2		0.12					0.12					0.12			
ρ	0.0000007	0.000002	0.00016	0.00066	0.00066	0.0000007	0.000002	0.00016	0.00066	0.00066	0.0000007	0.000002	0.00016	0.00066	0.00066
Log_ρ	-6.15	-5.69-3.79-3.18-3.18				-6.15	-5.69-3.79-3.18-3.18				-6.15	-5.69-3.79-3.18-3.18			
S_n	-	0.620.270.170.17				-	0.620.270.170.17				-	0.620.270.170.17			
M_d		0.0002					0.0002					0.0002			
M	-16.986	27.493	34.561	17.428	17.428	-4.550	26.120	-22.683	7.458	7.458	-6.041	-6.328	-6.550	11.644	11.644
M_{max}	-	-	-	-	0.017	-	-	-	-	0.007	-	-	-	-	0.012
$\times 10^{-5} Md/M$	-1.2	0.7	0.6	1.1	1.1	-4.3	0.8	-0.9	2.7	2.7	-3.3	-3.2	-3.0	1.7	1.7
$\times 10^{-1} Md/Mmax$	-	-	-	-	0.12	-	-	-	-	0.29	-	-	-	-	0.17

mm between $H2/t$ and $H4/t$, This range is for embedment $E2/t$ between $H2/t$ and $H3/t$, To embedment $E3/t$ occurs between the three ranges $H1/t$ and $H2/t$, $H2/t$ and $H3/t$, $H3/t$ and $H4/t$. By increasing the number of helical tieback, the disappearance of the critical stress bubble range at the bottom of the wall for EX .3 is observed and in all cases (A, B, C) for EX.6 occurs, and the wall tends to stabilize. For EX .1, 2, 3 modes, the maximum stress bubble range, the maximum value is related to the wall with $E1/t$ embedment except for EX 3-B mode and in EX .4 mode, this range is for $E3/t$ and for EX .5, this range is $E2/t$ and in EX .6 mode Is in three modes (A, B, C), $E1/t$.

3.3.3 The Relative flexibility of the retaining wall

In this study, the relative flexibility of the retaining wall in relation to different wall heights for cases, the safe wall, the wall stability number, the range of flexibility changes and the wall rigidity are investigated. The relative flexibility number of the retaining wall is based on Eq. (1) (Das 2014) where the values of EI and H′ are calculated according to Table 6. In addition to determining the relative flexibility of the retaining wall that is the basis of the study, other values such as the stability number (Sn) and the design moment (Md) are determined according to Eqs. (2) and (3) and in which the allowable bending stress of the wall Is (σ_{all}) which is considered fixed and equal to 172.5 (Das 2014). Furthermore, the basis of the design section (SyG) is calculated according to Eq. (4) (Johnston 2007). In all calculations, the value of theoretical moment (M) and maximum theoretical moment (M_{max}) are extracted from numerical results and its summary is given in Table 5.

$$\rho = \frac{H'4}{EI} = \frac{(H'1 + H'2)4}{EI} \quad (1)$$

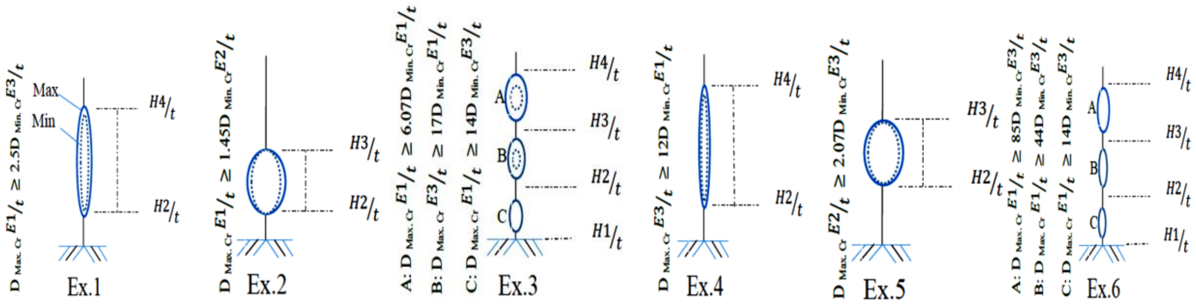


Fig. 20 The Behavioral mechanism of the horizontal wall displacement stress contours

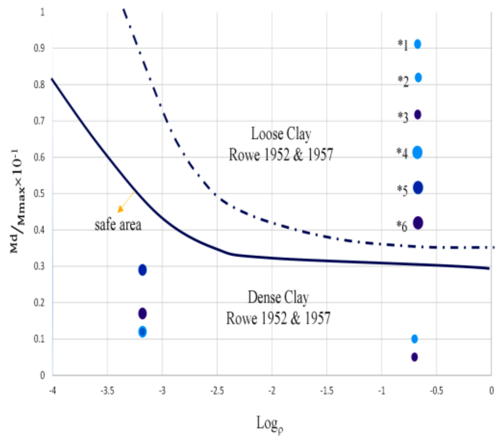


Fig. 21 Logρ versus $^{Md}/_{Mmax}$ diagram

$$Sn = \frac{Md}{\sigma_{all}} \tag{2}$$

$$Sn = 1.25\frac{C}{\gamma.H} \tag{3}$$

$$SyG = \frac{IyG}{C2} \tag{4}$$

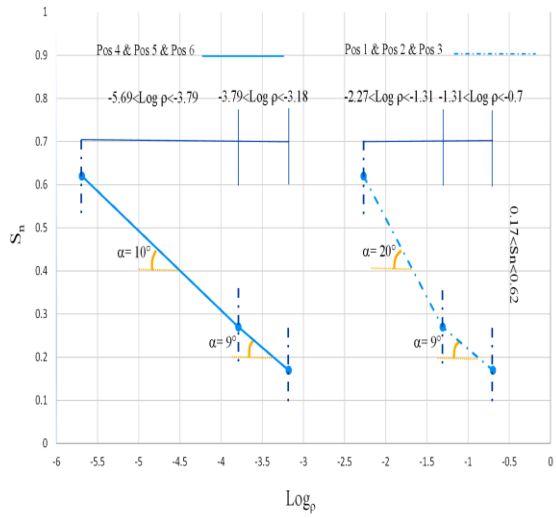


Fig. 22 Logρ versus Sn diagram

Safe wall

Fig. 21 shows that the wall safety will not be directly related to an increase in the number of helical restraints. Therefore, a wall with a greater thickness (0.003 mm) and 2 helical tiebacks shows a much better performance in the wall safety than 3 tiebacks. On the other hand, the best performance in terms of safety is for a wall that helical tiebacks are installed in the range of $^{H2}/_{t}$ to $^{H4}/_{t}$ relative to the height of the wall. The lower the M_{max} value in the wall, the more safety the wall, which is given for the different wall modes in Eq. (5).

$$\overrightarrow{\text{Safty}} \quad *1<*2\leq*3<*5<*6<*4 \tag{5}$$

The choice of wall in terms of safety is defined based on its proximity to the safe range for dense clay (CL_{Dense}), which is given in Eq. (6), respectively.

$$\overrightarrow{M_{max}} \quad *3\leq*2<*1<*4<*6<* \tag{6}$$

The reason for the equal sign for the modes * 2 and * 3 in Eqs. (5) and (6) is because of their overlap.

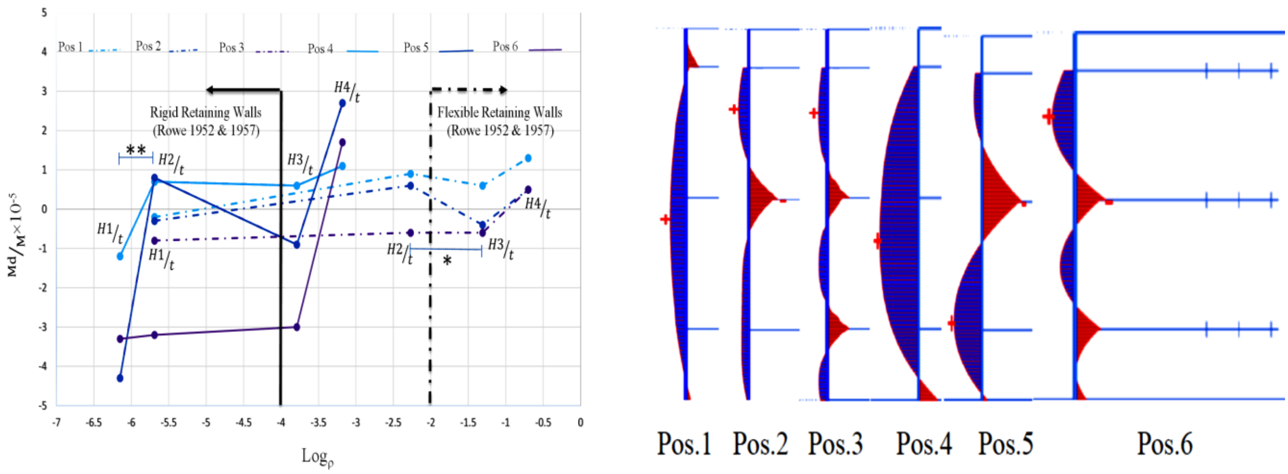
The important point to be made in this section is that from Braja M. Dass's point of view, it is considered a light wall for which Eq. (7) is established (Dos 2014). However, based on the results obtained from this section, this relationship will not be correct for walls with a helical tiebacks.

$$M_d<M_{max} \tag{7}$$

Numerical wall stability (Sn)

In this part, because the stability number Sn is related to the three parameters C, ϒ and H according to Eq. (3) (Dos 2014), and all three parameters are constant in all modes, so the value of Sn will be constant for all modes.

In Fig. 22, a 3-fold reduction in the wall thickness results in a 2-fold reduction in the wall flexibility. Accordingly, to determine the ratio of flexibility to wall thickness, the number $^{2}/_{3}$ is obtained. On the other hand, in the discussion of flexibility for the wall, the wall thickness item is more effective than the number of helical tiebacks in this area. This is because by changing the thickness of the wall, its flexibility changes, but by changing the number of the helical tiebacks, the amount of the wall flexibility will not change. Although the presence of a helical tieback drives the wall behavior toward stiffness by reducing its



(a) Logρ versus $^{Md}/_{M}$ diagram

(b) The Minimum and the maximum amount of M bending moment for different modes

Fig. 23 The study of flexibility and rigidity of the wall in different modes

horizontal displacement, it does not directly affect the flexibility of the wall.

Range of changes in flexibility and rigidity of the wall

In Fig. 23(a) for Pos 1,2,3 (Flexible wall) modes the range of changes $^{Md}/_{M}$ is in the range $-1<{}^{Md}/_{M}<2$ and for Pos modes 4,5,6 (Rigid Wall) in the range $-5<{}^{Md}/_{M}<3$. Correspondingly, the range of changes of $^{Md}/_{M}$ for rigid wall compared to flexible wall will be about twice. The behavior of the wall is similar in Pos 1,2 and Pos 4,5 and Pos 3,6 modes. The greatest change in the wall flexibility behavior for Walls with less thickness is related to the height range $^{H2}/_{t}$ to $^{H3}/_{t}$ (*) and for Walls with more thickness is related to the height range $^{H1}/_{t}$ to $^{H2}/_{t}$ (**).

$^{2}/_{3}$ The behavior of rigid walls in the height range $^{H2}/_{t}$ to $^{H4}/_{t}$ is close to $^{1}/_{3}$ the behavior of flexible walls is in the height range $^{H1}/_{t}$ to $^{H2}/_{t}$.

Fig. 23(b) shows the minimum and maximum amount of the bending moment M. In this case, the wall behavior for Pos 1,4 and Pos 2,5 and Pos 3,6 modes is close to the each other. While in the wall flexibility discussion discussed in Fig. 19(a), the behavioral trends of the modes are generally different, except for Pos 3,6, which will behave closely in both modes.

The study in Fig. 23(b) shows that the presence of the helical tieback in the discussion of reducing lateral buckling of the wall (bending moment M) in walls with a lower thickness, has a much better performance than walls with a larger thickness.

Overall conclusion, the best performance for walls with the helical tiebacks in reducing their horizontal displacement can be economically, flexibly and stability assigned to a wall that tiebacks is in the range of $^{H2}/_{t}$ to $^{H4}/_{t}$ and its flexibility ratio is $^{2}/_{3}$.

4. Conclusions

To investigate the different parameters on the performance of wall, 42 experimental models are evaluated under the superimposed load equivalent to 10 kN/m. These parameters are the thickness, the embedment, and the number of lateral wall tiebacks. The following are the most important results of this study.

• By examining the effect of the changes in the horizontal displacement of wall without the tieback, the behavior of the wall in this state is the flexural behavior. This flexural behavior in the wall with less thickness and more embedment has its greatest contribution. By reducing the wall thickness threefold, the greatest difference in the percentage of the horizontal displacement of wall is related to the bottom of wall (H) with 750%. While, this value at the top of the wall at the level of 0.81H (68 cm) has increased from 750% to 23%, which indicates a decrease of 727%. The result of this percentage difference can be further considered to reduce the flexural behavior of the wall between two levels of 0.51H to 0.81H and increase the flexural behavior of wall between two levels from H to 0.51H.

• By installing the simple tieback in the wall, the behavior of the wall in its horizontal displacement is the shear behavior. Thus, the presence of the tieback tends to cause the highest reduction in the horizontal displacement of the wall at the bottom of the wall (H) by 1.98 times and the least reduction in the horizontal displacement of the wall at the top of the wall (0.81H) by 1.24 times. Therefore, the presence of the tieback tends to cause 0.74 times more stability of the horizontal displacement of the wall at the top of the wall than at the bottom of the wall. Examining the behavior of the helical tieback in the horizontal displacement of wall shows that the difference in the percentage of displacement at three height levels of 0.22H, 0.51H, and 0.81H are very close to each other, relative to the height of the bottom of the wall (H). By a threefold reduction in the flexibility of the wall, a reduction of 10%, 10%, and 13% was observed for the embedment of 0.06H, 0.12H, and 0.18H at two height levels of 0.81H and H, respectively.

• By a threefold increase in the wall thickness with two simple tiebacks, the behavior of wall in its horizontal displacement is the shear behavior which is closer to each other in the walls with the embedment of 0.12H and 0.18H compared to the embedment of 0.06H in the height level H. Moreover, there was a 1.31-fold (251-191) horizontal displacement in the height level (H) for the thickness of 1 mm and a 1.35-fold decrease (211-156) for a 3 mm thickness from the embedment of 0.12H to 0.18H.

• By a threefold reduction in the flexibility of wall with two helical tiebacks, the greatest reduction in the horizontal displacement of the wall by 1.33 and 1.19 times at the height level of 0.81H and H is related to the wall with the embedment of 0.06H. The presence of two helical tiebacks has caused the shear behavior of the wall in all height levels to be closer to each other and to be closer to the initial behavior and to cause more stability of the wall. With a threefold increase in the wall thickness with the embedment of 0.06H, the highest percentage difference is observed at the height levels of 0.51H and 0.81H and the wall with the embedment of 0.12H at the height levels of H and 0.22H. By a threefold reduction in the flexibility for the wall with the most helical tiebacks for the embedment of 0.18H, the maximum horizontal displacement reduction at the height level of 0.22H is 4.08 times (24-98) and at 0.81H is 3.2 times (77-247). By a threefold increase in the wall flexibility, the lowest and highest percentage differences for the walls with the embedment of 0.06H and 0.18H is at the level of 0.22H. The difference between the percentage of the horizontal displacement of wall for the embedment from 0.06H to 0.12H is about two times, and the embedment from 0.12H to 0.18H varies from 3.5 to 5.5 times.

• By a 0.81-fold increase in the height of the wall with three simple tiebacks and the embedment of 0.06H, there are a 6.37- and 5.70-fold decrease in the horizontal displacement for the walls with the thicknesses of 3 and 1 mm, respectively. On the other hand, by reducing the thickness threefold by 0.81 times compared to the height of the wall with the embedment of 0.12H, there is a 0.06-fold reduction in the horizontal displacement of the wall.

• Using the maximum number of helical tiebacks to the wall (three tiebacks), the wall behavior changes from the shear to the linear mode with the constant slope and approaches its initial state, which indicates the stability of wall. On the other hand, as the behavior of the wall with less thickness approaches the behavior of the wall with more thickness, it indicates that applying the helical tieback not only does not make the wall rigid but also shows the flexible behavior with more stability. One of the effects of helical tieback on the wall is that the rolled earth support at the bottom of the wall becomes free earth support. By examining the behavioral states of wall, the horizontal behavior of the wall is in a more orderly way by applying the helical tieback. Hence, the range of these deformations for the walls with the same number of tiebacks but variable in thickness is close to each other.

• For the wall with the embedment of 0.06H, with a 3 and 0.81-fold increase in the flexibility and the height of the wall, respectively, the differences in the horizontal displacement of wall with the simple tieback and the helical tieback are 0.59 and 0.10 times, respectively. These differences are 0.81 and 0.14 times for the wall with two simple and helical tiebacks and 0.81 and 0.30 times for the wall with three simple and helical tiebacks. For the wall with the embedment of 0.12H, with a 3 and 0.81-fold increase in the flexibility and the height of the wall, respectively, the differences in the horizontal displacement of wall with the simple tieback and the helical tiebacks are 0.50 and 0.09 times, respectively. These differences are 0.53 and 0.13 times for the wall with two simple and helical tiebacks and 0.06 and 1.04 times for the wall with three simple and helical tiebacks. For the wall with the embedment of 0.18H, with an increase of 3 and 0.81 times in the amount of the flexibility and the height of wall, respectively, the differences in the horizontal displacement of the wall with the simple tieback and the helical tieback are 0.73 and 0.13 times. This difference is equal to 0.55 and 0.12 times for the wall with two simple and helical tiebacks and 0.35 and ∞ times for the wall with three simple and helical tiebacks.

• The most effective mode (S Ex.6) in reducing the horizontal displacement of the wall is related to the wall with the greatest thickness and the number of helical tiebacks. Moreover, the most economical mode (S Ex.3) is related to the wall, which by reducing the thickness of the wall by 3 times, shows a behavior close to the most effective mode in reducing the horizontal displacement of the wall. On the other hand, the largest decrease in the horizontal wall displacement for both S Ex.3 and S Ex.6 modes is 40.68%.

• The wall safety will not be directly related to increasing the number of the helical tiebacks. Consequently, the best performance in terms of safety is for a wall that the helical tiebacks are mounted in the range $H2/t$ to $H4/t$ relative to the height of the wall.

• According to studies by Braja M. Das (2014), a light wall with a M_{max} greater than Md is considered. According to the studies conducted in this study, this relationship has not been established for the desire for helical tiebacks and will not be true.

• By reducing the thickness of the wall by 3 times, the flexibility of the wall reduces by 2 times. Thereupon, to determine the ratio of flexibility to wall thickness, the number $2/3$ is obtained.

• The greatest change in the wall flexibility behavior for thinner walls is related to the height range $H2/t$ to $H3/t$ and for the thicker walls in the height Is in the range of $H1/t$ to $H2/t$.

•The greatest effect of helical tiebacks tendency in controlling and reducing the amount of lateral buckling of the wall is related to walls with less thickness than walls with greater thickness.

One of the limitations of this research is the use of helical tiebacks in environments with sulfated soil, high organic matter and soil pH less than 5.5 according to AC358 standard. On the other hand, the value of the stability capacity of the helical tiebacks depends on the surface of the helix plates, so damage to the plates can cause a significant decrease in their resistance.

Among the suggestions that can be mentioned for future studies: 1- The effect of gender of simple and helical tiebacks, Diameter and geometric shape, the angle of the helix plates with the brace shaft. 2- Dynamic study to investigate the behavior of tiebacks and retaining wall. 3- Study on the type of soil, including its density and layered structure behind the wall and the slope of the embankment behind the wall.

Data availability statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request including: (1) specimens geometry data; (2) soil properties data; (3) Horizontal wall displacement data for all modes of Tiebacks, wall thickness and embedment depth; (4) model geometry; (5) The Grain Soil Distribution Curve. (6) Validation diagram and its data. (7) All results and outputs of numerical studies.

Conflict of interest

There is no conflict of interest in this manuscript.

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