Journal of Civil Engineering and Materials Application
Journal home page: https://jcema.com

Received: 26 January 2018 • Accepted: 27 March 2018

Research

doi: 10.22034/JCEMA.2018.91986

Seismic Analysis in Stabilized Trench with Pile

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ABSTRACT

Due to the loss of life and damage to surface and underground structures, stabilization of trenches in order to control and stabilize landslides is very important. In the current study, the effect of the implementation of the pile has been analyzed to increase the stability of the trench under the impact of the earthquake. Therefore, a trench with 45° angle which reinforced by the pile, was analyzed with variable parameters, including the diameter of the pile (D) that was with a 0.9m diameter and other pile with 1.5m diameter, the buried length of the pile (L) was 10m and 15m. The space between the piles (S) to each other was implemented by three sizes; 0.3m, 4.5m and 0.6m, and the implementation of the pile with five forms on the span of the trench was analyzed to study its different behavior under seismic conditions. The results showed that with increasing the diameter of the pile and the implementation of the pile, the horizontal displacement of the span of the trench reduces 25% to the normal state. In addition, with an increase in the length of the pile, the level of the subsidence is 24 to 30 percent lower than the normal state.

Key words: Trench stability, Pile, Landslide, Soil rupture.

Journal of Civil Engineering and Materials Application is published by *Lexis Publisher*; Journal p-ISSN xxxx-xxxx; Journal e-ISSN 2588-2880.

1. INTRODUCTION

One of the preventing and controlling methods for stabilizing the trench that is placed on the philosophy of risk reduction is the use of piles that are utilized to reduce the subsidence and becoming sure of the stability. Although in most cases, the piles are designed to withstand vertical forces, but they can also withstand the lateral forces of the soil. Among these cases, there are slope stabilizing piles which bear the lateral force of the soil or piles which are implemented adjacent to the sloping embankment (1, 2). A comprehensive analysis of various experimental and numerical study has been performed on the slopes with the numerical and experimental study of pile-stabilized slopes under surface load conditions. In this research, by making a physical model of a variety of unstable sandy slopes, under extra loading on a small scale, as well as three-dimensional numerical modeling, it was concluded that the 3D shape of the rupture surface in front of the pile is triangular for the stabilized slopes. It was also observed that the distance of the soft soil from the land surface and its angle along the horizon is strongly influenced by the optimal locating of the piles (3). In another study, retaining structures, including piles and restraint (tensile restraint) was investigated. The study attempts to obtain the un-braced length of the restraints and depth of their locating to optimize the behavior and function of the restrained walls by tensile restraints (4, 5). In this study, the proper horizontal distance was obtained 1.5m for the length of the tensile restraints, the horizontal length needed to exit from the rapture wedge. The second tensile restraint distance is also recommended 3m below the first tensile restraint for better restraint of the proper displacement and operation of the protective system. In this research, another study was carried out in which the depth of the pile burial was evaluated and it was determined that increasing the depth of the burial lead to reduce the horizontal displacement of the excavation wall. The results of the investigation of different retaining structures showed that the use of them, including nailing and piling had the least displacement. Composite structures also have the best performance against uniform stresses that are applied near the slopes (6). During the performed researches on 300 deep excavations, which had been restrained by different methods, the maximum subsidence of the land in the vicinity of the excavation is about 0.42% of the excavation height. Also, the ratio of the most subsidence in the vicinity of the protected excavation to the most horizontal displacement of the wall is about 0.9 (7). By analyzing the reduction of strength in the slopes reinforced to one row of piles, it was concluded that the critical slip surface on a pile-reinforced slope has usually more surface than the corresponding slope without the pile. The favorable location for a pile on a slope reinforced with one row of piles is between the middle of the slope and the middle of the critical slip surface. Also, by optimizing the placement of the pile, the time required for the 3D analysis of the pile-reinforced slope is reduced (8). The researchers also proposed a new method for stabilization of the slopes by considering the analysis of pile stabilized slopes based on soil–pile interaction. The developed method allows the study of soil pressure and its distribution along the pile above the slip surface based on soil-pile interaction. The ability of the proposed method to predict the behavior of the piles during lateral movement from the slope instability has been confirmed through a number of real-scale loading tests (9). The obtained results of a simple evaluation of the level of stability of the pile-reinforced slop showed that the arrangement of the pile significantly affected the safety and the slipping surface factor of the pile-reinforced slope. There was also a piling area on the slopes where the pile has a small contribution to increasing the safety factor, and this area is an important reference for designing pile reinforcement (10). In examining the response of the pile during lateral motion of the slope, the results indicate the effect of the relative hardness between the pile and the soil on the rupture states, and also the relative depth of soil and stable soil displacement is not the only deciding factor for failure in the passive piles (11). Using 3D numerical modeling to study the effect of the pile parameters on the reliability of a pile-slope reinforced showed that using a 3D analysis give more insight than the complex problems of slope stability, these studies also showed that after a certain length of the pile, the increase in the length of the pile is unnecessary, and the diameter of the pile has a relatively small effect on the reliability of the pile-slope reinforced (12). The effect of the slope angle on the distribution of soil-pile pressure acting on the stabilizing piles in slopes showed that the angle of friction had a greater effect on the amount of pile-soil pressure on the pile than the slope angle (13, 14).

2. MATERIALS

In order to investigate the seismic behavior of the pile-reinforced trench, the favorable soil properties for modeling were considered in accordance with Table 1.

Table 1. Properties of the soil of the trench

Drained properties for soils 1	
soil 1	
Dry density(Kg/m³)	1715
Youngs modulus(Mpa)	163.7
Poissons ratio	0.3
Bulk modulus (MPa)	136.4
Shear modulus(Mpa)	63
Cohesion (Pa)	10000
Friction angle (degrees)	40
Dilation angle (degrees)	0

In this research, to illustrate the effect of the pile diameter on the results, piles with a diameter of 0.9 and 1.5 meters was used to restrain the trench, another pile properties have been shown in Table 2.

Table 2. Geometric properties and pile materials

Structural properties					
	Elastic modulus (Gpa)	Moment of Inertia (m4)	Cross Sect. Area (m2)	Mass Density (Kg/m2)	Pile Diameter (m)
Piles 1	20	0.0322	0.6362	2000	0.9
Piles 2	20	0.2485	1.767	2000	1.5

It is necessary to introduce the interaction between the pile structure and the soil mass in order to modeling correctly the pile-reinforced trench under seismic conditions, as well as the accurate assessment of changing the various parameters of the pile in the trench behavior under seismic conditions. For this purpose, the interaction parameters between the soil and the pile are taken into account in the modeling according to Table 3 (15).

Table 3. Soil and Structure Interaction Parameters

Coupling spring properties for pile-soil interface						
	Normal Stiffness (GN/m/m)	Shear Stiffness (GN/m/m)	Normal Cohesion (N/m)	Shear Cohesion (N/m)	Normal Friction (degrees)	shear Friction (degrees)
Soil 1	0.01	0.01	10000	10000	40	40

3. PROPERTIES OF MODEL SEISMIC CONDITIONS

In order to model the earthquake, a sinusoidal wave was applied to the bottom of the model's geometry in the two horizontal directions of the coordinate plane (x and y), which has an HZ1 frequency with the two characteristic respectively: in the x axis, the coordinate plane has g0. 2 acceleration and in the y axis has g0. 1acceleration and they are moving forward in two axes. An actuator was applied to reduce and increase (to create the frequency) of the HZ1frequency input range. Figure 1 shows the accelerated mapping of the seismic wave of the present study, which transmits in x direction of the coordinate plane.

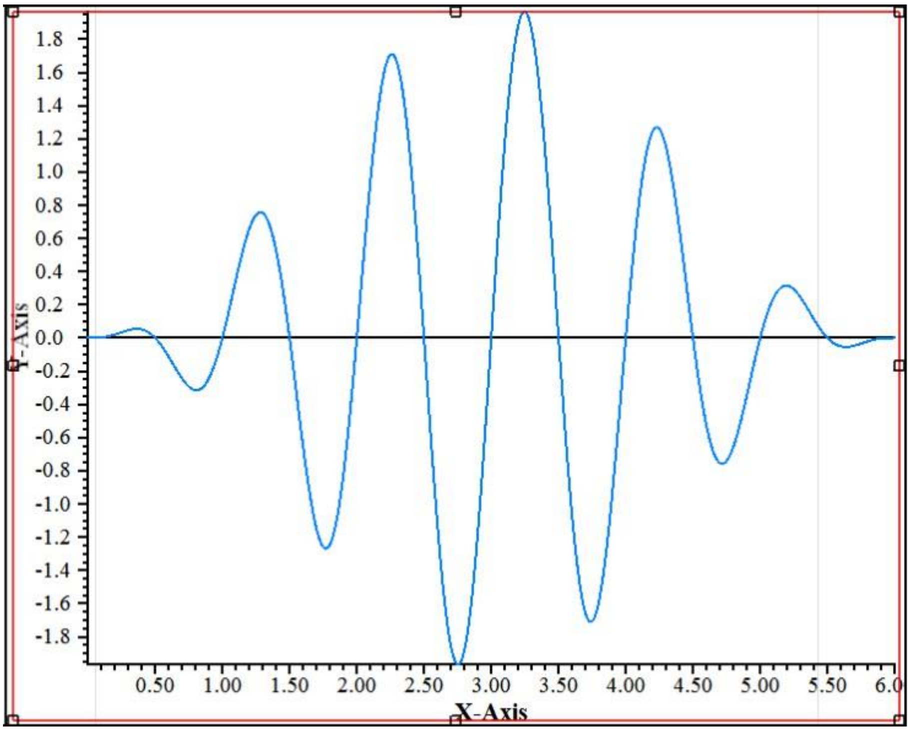


Figure 1. Accelerograms related to the seismic wave that transmits in x direction of the coordinate plane

The compressive wave and shear wave velocity in the soil are Cp = 349 (msec) and Cs =186 (msec) respectively. In order to evaluate the accuracy of the program and carried out modeling in this study, the model of Figure 2 was first examined (8). In this model, which has been examined by Wei and Cheng, a sandy trench with 33.7-degree slope has been modeled and analyzed and it has been stabilized by retaining pile. By comparing the shear stress distribution diagram obtained from the modeling results (Figure 3) which has been modeled by Wei and Cheng and modeling the same geometry and conditions in the software used in this study, the accuracy of the program and the modeling process can be proved.

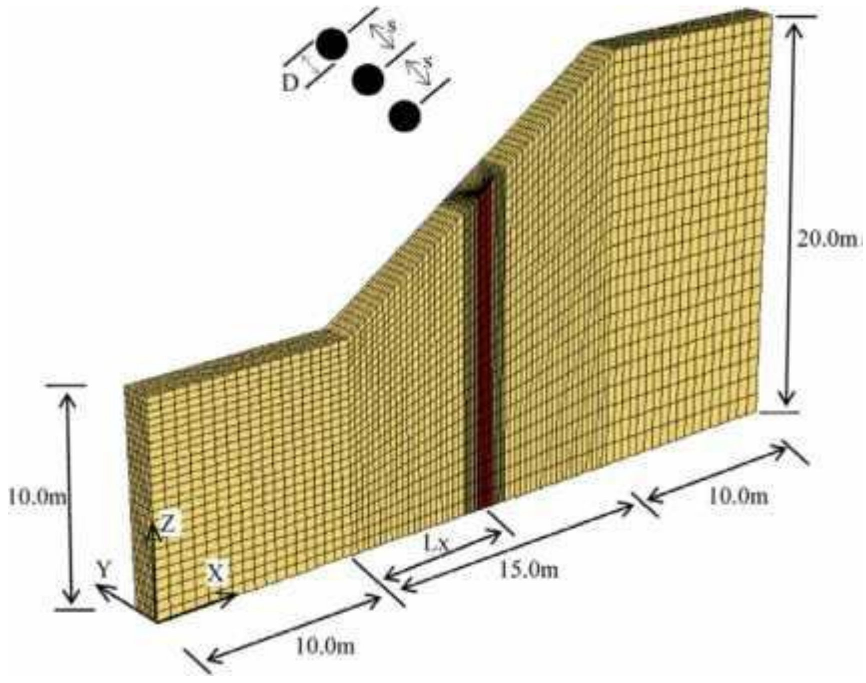


Figure 2. Slope model and finite difference mesh (8)

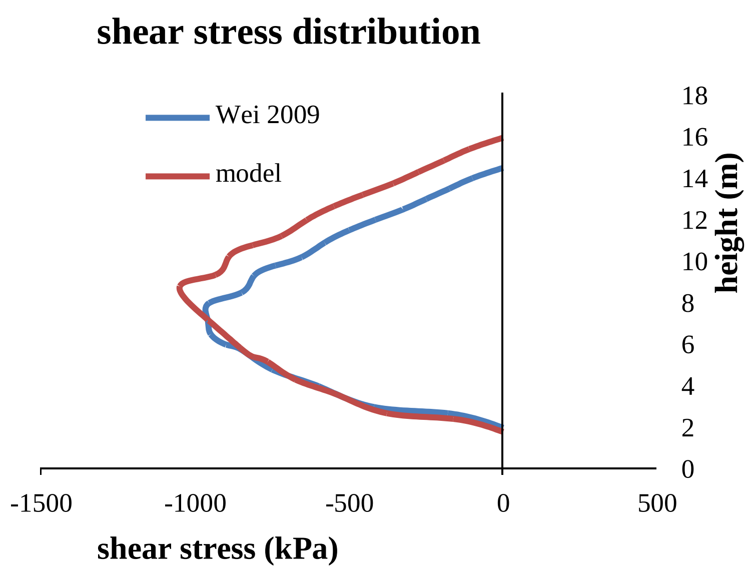


Figure 3. Comparison of Shear Stress Distribution by Wei and Cheng Model

4. NUMERICAL MODELING AND RESULTS ANALYSIS

The FLAC3D software was used (Figure 4) In order to evaluate the seismic behavior of the pile-reinforced trench. In this research, the effect of variable parameters on modeling results was investigated. For this purpose, with changes in parameters such as the diameter of the pile (D), the buried length of the pile (L) and the space of locating the piles (S) to each other, the outputs were evaluated. The space of locating the piles (S) to each other, that have been located in three different states; 3 meters, 4.5 meters and 6 meters, and the buried length of the pile (L) in two states of 15 meters and 10 meters were selected to examine the effect of the length of the buried pile on the results of the analysis. Also, the diameter of the pile (D) with 0.9 and 1.5 meters was selected to examine for its impact on the diameter of the pile in the analytical results.

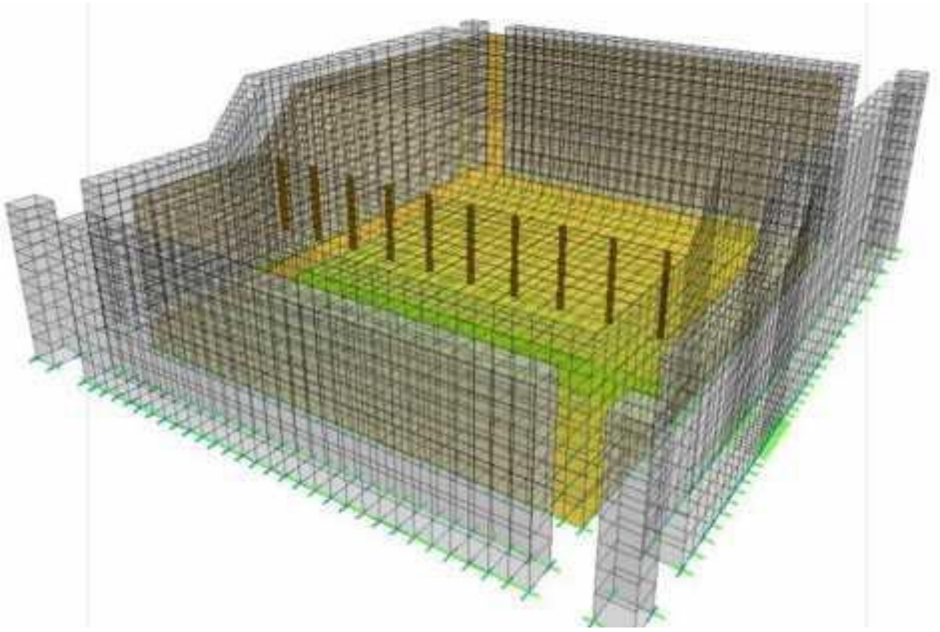


Figure 4. Sample of the pile-reinforced trench with a diameter of 0.9 m

Figure 5 illustrates the zoning and the sizes of the issue. As it can be seen, the sizes of the area on the right side of the geometry of the model are greater than 15, because the farther distances from the slope of the trench has not special significance in the analysis, so it can be zoned with larger sizes due to reduced computational time. Also in the present study, the slope is 45 degrees.

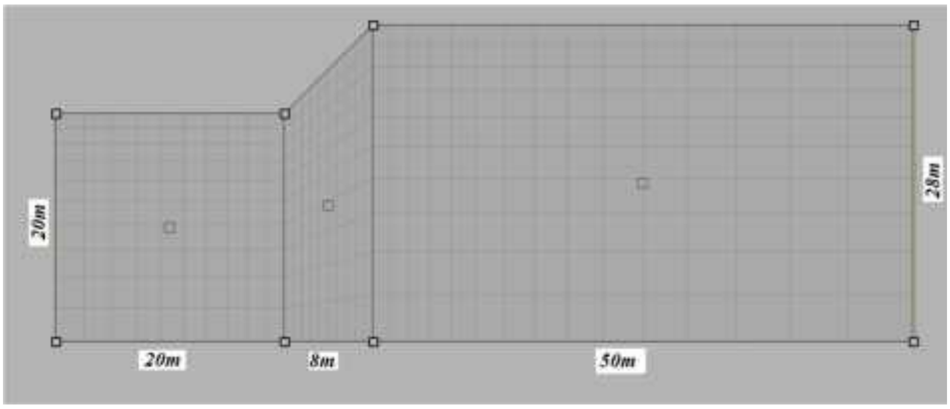


Figure 5. Zoning and sizes of the issue

The vertical displacement of the control model at different distances to the ridge of the trench is shown in Figure 6, that the most vertical displacement (subsidence) was 4.6cm at 3m behind the embankment span, and at the edge of the embankment span is 6.8cm; also the horizontal displacement of the maximum span is about 22cm, without observing the rupture that leads to landslides in the soil (Figure 7).

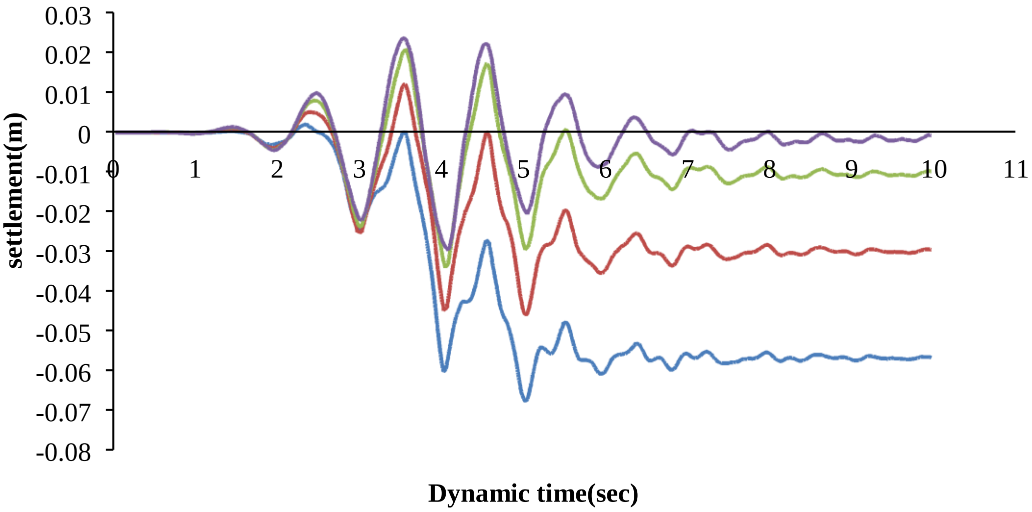


Figure 6. Vertical displacement of the behind soil of the ridge of the trench in the control model

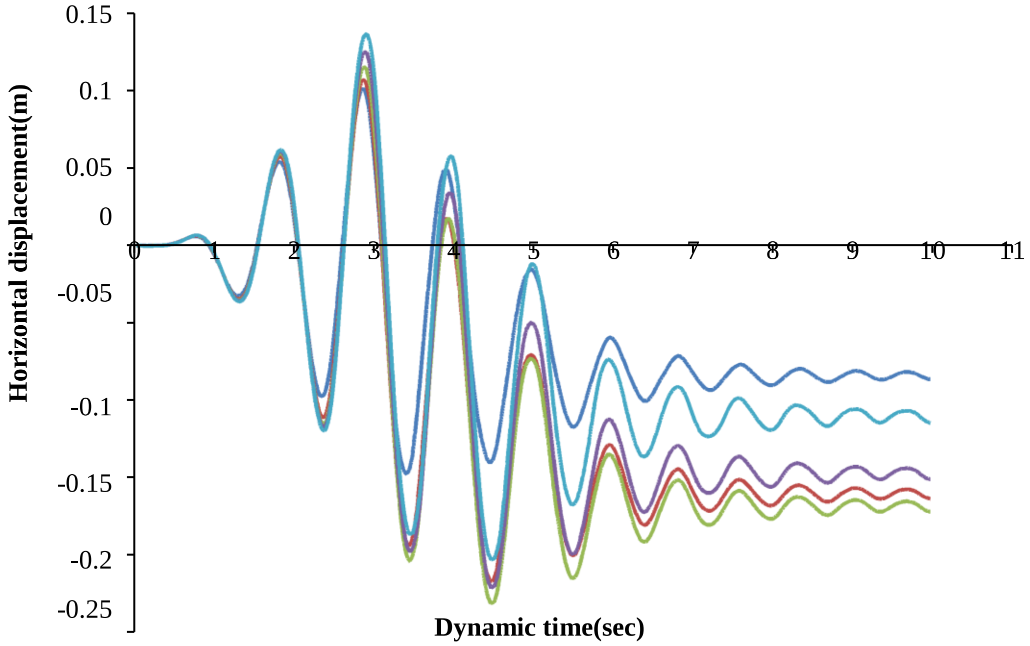


Figure 7. Horizontal displacement of the slope in the control model

In order to study the effect of the buried length of the piles (L), the diameter of the piles (D) and space of their locating to each other (S) in determining the optimal locating of the piling in the span of the trench, the evaluation points on the slope (to determine the amount of variation of the lateral displacement of the trench wall) as well as the behind soil of the trench span (to determine the amount of subsidence of the soil behind the trench span) are considered in the model. Thus, point of 4 were considered on the trench span to determine the location of the pile, as well as determining the lateral displacement of the trench span. To determine the vertical displacement (subsidence) of the soil behind the trench span, the four areas have been determined; 0m, 3m, 7m, and 11.5m, respectively, at the behind the trench span and in the center of the model, (Figure 8).

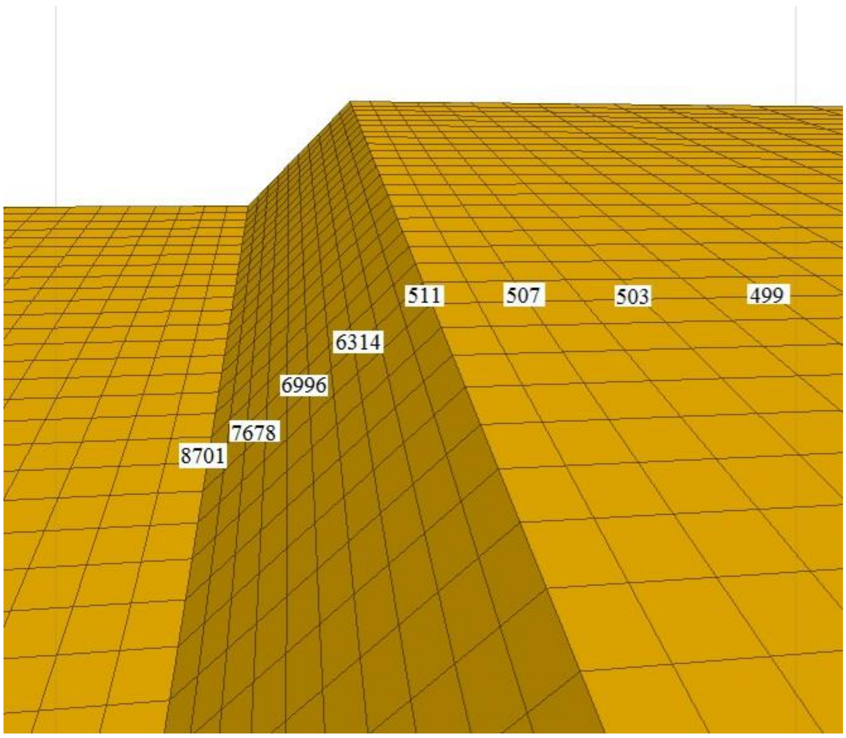


Figure 8. **The location of the assessment points on the model according to their characteristic number (ID)**

The effect of the locating of the pile with the diameter of the pile variable (D) on the reduction of displacement

5. VERTICAL DISPLACEMENT

In order to examine the locating of the pile with the variable of the pile diameter (D) on reducing the vertical displacements of the soil behind the ridge of the trench, the 507-evaluation point with a distance of 3m from the trench was analyzed. The other assessment points behind the trench have a similar behavior, because we know that with increasing distance to the trench, the displacements reduce, and with approaching to the ridge of the trench, the amount of the displacement increases due to the lack of restraint in the trench span. Figure 9 shows the observed maximum vertical displacement and the residual subsidence in area 507 (3m behind the trench).

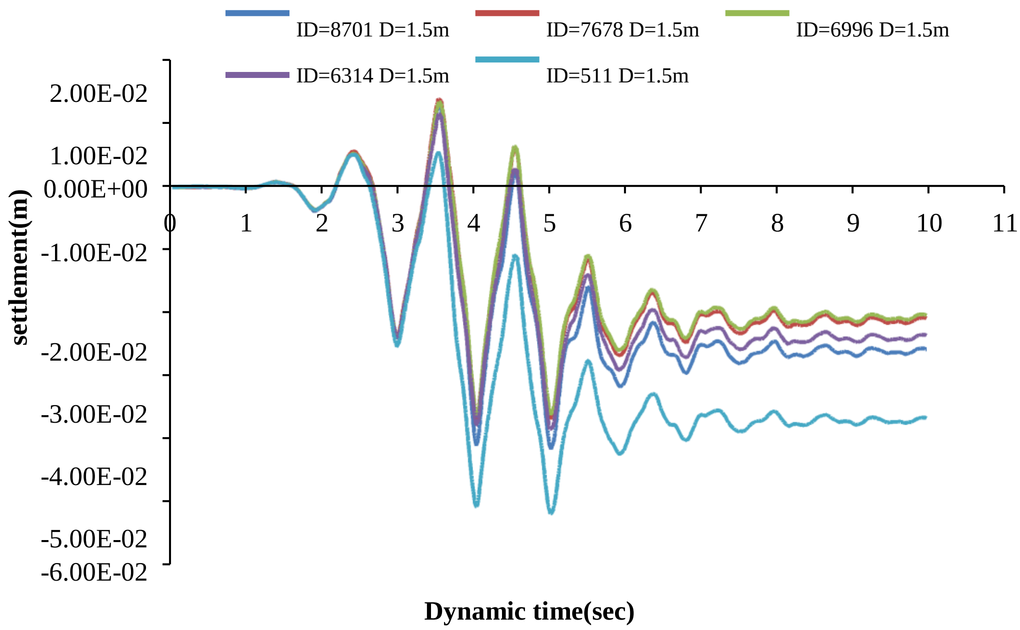


Figure 9. subsidence diagram, 3 meters behind the ridge of the trench at different location of the pile and with a diameter of 1.5m and the pile length of 15 meters

As seen in Figure 9, the subsidence of the residual subsidence of the point 507 decreases by 20% for the control model with enforcing in the length of the trench span, so that with enforcing in state 1 (bottom of the span), the displacement of the residual subsidence decreases maximum of 20% and 11.9% respectively. With the implementation of the pile by states' 2 and 3 (in quarter of the middle of the bottom of the span and its center), the amount of the subsidence is approximately equal, so that the maximum subsidence and the residual subsidence decreased by 24% and 30%, respectively, and by implementation of the pile above the center of the trench; states 4 and 5, the amount of vertical displacement (subsidence) of the residual subsidence to the control model decreases 19.3% and 13% respectively, also, the maximum vertical displacement arising from the seismic load in the locating states of the pile in the trench span in the state 4 has decreased by 12.6%, while in the 5th state where the pile has been implemented in the ridge of the trench, the maximum subsidence increased by 9.13% compared to the control models.

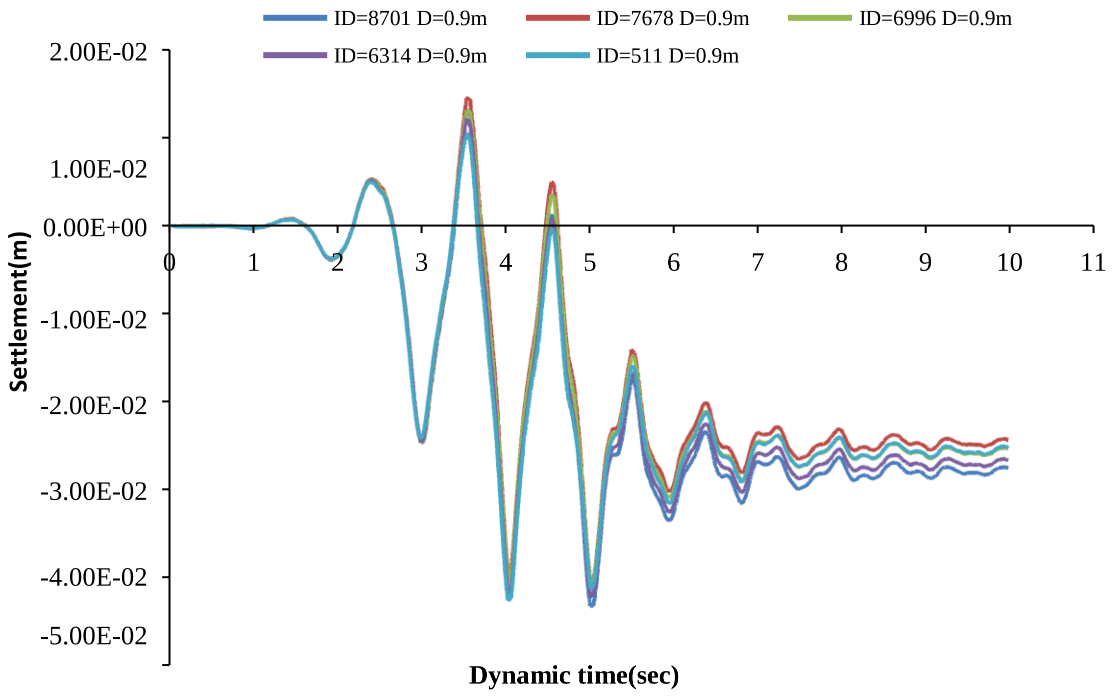


Figure 10. subsidence diagram, 3 meters behind the trench ridge at different location of the pile

The diameter of the pile is 0.9 meter and the length of the pile is 15 meters. As shown in Figure 10, the effect of the implementation of a pile with a diameter of 0.9m resulted to simulate relatively of the subsidence in the total state of the pile locating in the trench span compared with the control model and the implementation of a pile with a diameter of 1.5m. The implementation of a pile with a diameter of 0.9m in 3th and 4th locating state leads to a reduction subsidence of residual subsidence compared to the control model by14. 33%, while the maximum subsidence during the earthquake effect is equal to the subsidence amount of the control model that is 4.6 centimeters. It is also observed that with the implementation of a pile in state 1 (bottom of the slope); the subsidence of residual subsidence amount and the maximum subsidence compared to the control model has decreased by 10% and 7.82%. Implementation of a pile in state 2 (in the quarter of the middle of the bottom of the span) resulted to the subsidence of residual subsidence and the maximum subsidence by 18% and 16%, respectively, compared to the control model. By comparing the graphs of Figure 9 and Figure 10, it is observed that by increasing the diameter of the pile, the optimal area of the pile implementation in the slope of the trench to reduce the maximum subsidence and residual subsidence is 24% and 30% respectively, compared to the control model, and 2th and 3th states. However, by decreasing the diameter of the pile with 0.9 m, the optimum location of the pile in the reduction of the subsidence is limited to the bottom of the slope that is state 2 to reduce the 18% subsidence of residual subsidence and the maximum subsidence by 16% compared to the controlling model. In general, it can be concluded that regardless of the diameter of the pile, the optimum location of the pile is in the quarter of the middle of the bottom of the trench span.

6. HORIZONTAL DISPLACEMENT

As shown in Figure 11, the horizontal displacement of the trench span is shown in the control model. The maximum horizontal displacement is observed at the point 6996, that is, the middle of the trench span and the minimum horizontal displacement relates to the bottom of the span, that is, the point 8701. The maximum horizontal displacement from the earthquake load (not residual subsidence) was performed at the point 6996 in the middle of the trench span and at the point 7678 in the quarter of the bottom of the span and their displacements were 22 cm and 21 cm, respectively, without reaching to plastic deformation in the soil and rupture. Also, the minimum horizontal displacement of the trench span (from the earthquake load, not residual subsidence) was at the point
8701; bottom of the trench span, by 13.7 cm.

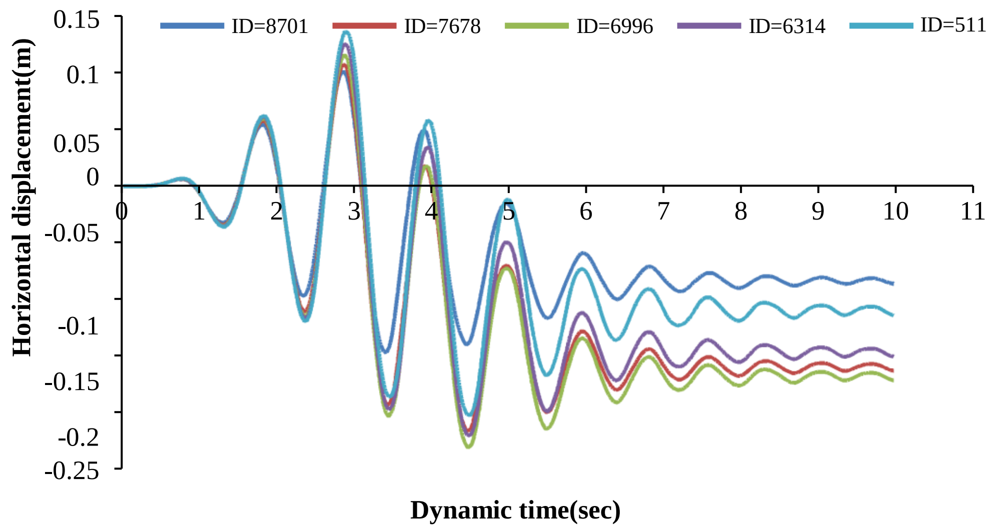


Figure 11. Horizontal displacement of the trench span in the control model

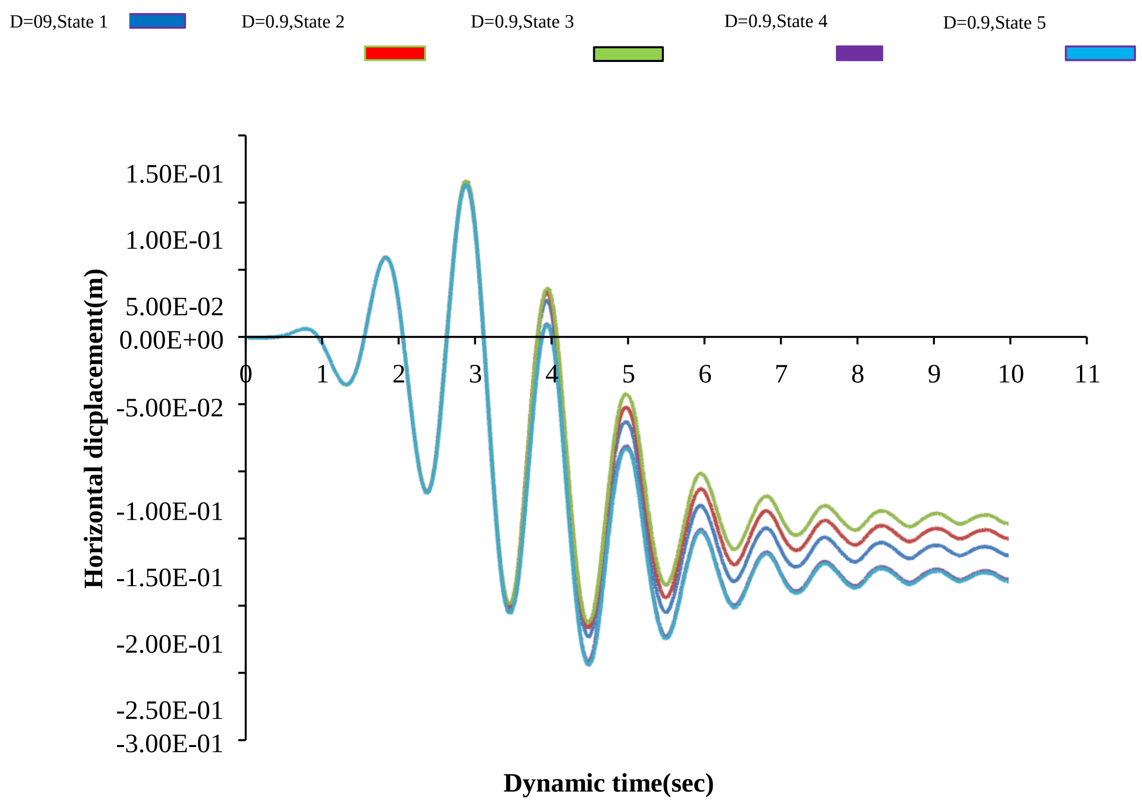


Figure 12. The horizontal displacement in the middle of the trench span with a pile with 0.9m diameter

The distance of the piling is 4.5 meters and its length is 15 meters (point 6996)

As shown in Figure 12, the maximum horizontal displacement and residual volume arising from the pile-enforced with a diameter of 0.9m has declined to 2.30% and 6.43%, respectively, compared to the horizontal displacement of the middle of the control model span, when the pile has been implemented by the state 1. In the case of implementing pile by state 2, the maximum lateral displacement and residual volume have been decreased to 5% and 14%, respectively compared to the control model. In the case of the pile implementation by the state 3 (center of the trench), the maximum lateral displacement and residual volume have been decreased to 5% and 21%, respectively compared to the control model. With the implementation of the pile by state 4 and 5, the maximum lateral displacement has been increased by 8.2% compared to the control model and the lateral displacement of the residual volume increased less than 1% compared to the controlling model.

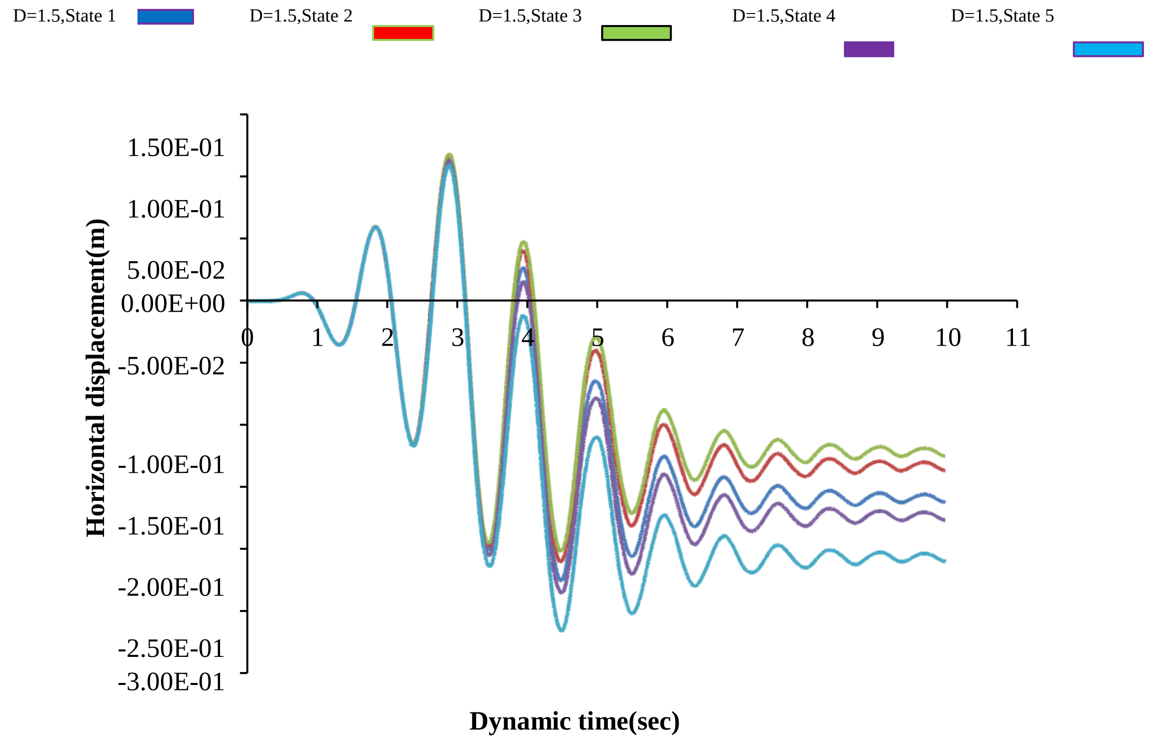


Figure 13. Horizontal displacement of the middle of trench span with a pile with 1.5 m diameter, The space between piles = 4.5m, length of the pile = 15m (at point of 8701)

According to Figure 13, the implementation of the pile in state 4 and 5 will lead to maximum horizontal displacement of the pile span in the middle of the span; whereas, with the implementation of the pile in the middle (state 3) and in the quarter of the middle of the bottom of the span (state 2), minimum horizontal displacement compared to the control model is a reduction of 25% approximately. Therefore, the reason for the reduction of the subsidence behind the ridge of trench in the diagrams of Figs. 12 and 13 has been to enclose the trench slop by the pile and the reduction of lateral displacement of the span and subsequently the reduction of the soil subsidence behind the ridge of the trench. By comparing the graphs of Figs. 12 and 13, it can be seen that with increasing the diameter of the pile and the implementation of the pile by state 2 and 3, the horizontal displacement of the trench span can be reduced to 25%. Reducing the lateral displacement of the span will lead to enclose the span and consequently reduction of 20-24 percent in soil subsidence behind of the trench ridge.

7. THE EFFECT OF THE PILE LOCATION WITH THE BURIED LENGTH (L) VARIABLE ON VERTICAL DISPLACEMENT (SUBSIDENCE)

As it is shown in **Figure 14** the pile implementation with 10 meter lengths by state 1 compared to the control model leads to decrease the maximum displacement of residual volume by 14.33% and 10.86%, respectively,. With the implementation of the pile in the middle of the span of the slope (state 3), the amount of vertical displacement of the residual volume and the maximum displacement has been decreased by 13.67% and 14.34%, respectively, and the reduced maximum displacement is related to the implementation of the pile with 10m length by state 2 (in a quarter of the middle of the bottom of the span), and maximum displacement of residual volume comparison of the control model is 25% and 14.34%, respectively and the implementation of the pile by state 5 (trench ridge) with a length of 10 meters leads to increase the vertical displacement (subsidence) at the point 507 by approximately 50%.

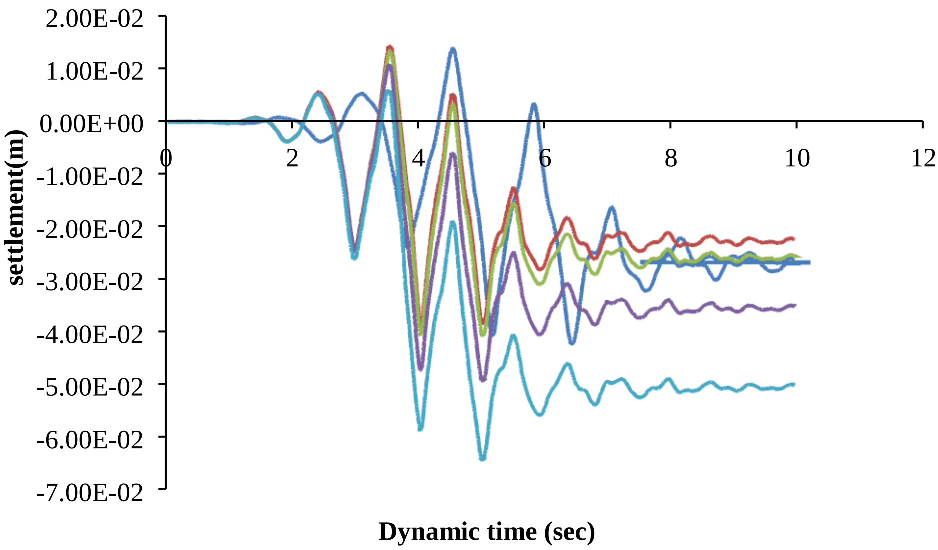


Figure 14. Vertical displacement (subsidence) in different states of the implementation with a 10 meter length pile, 1.5 meters diameter, and the 4.2 m space between of the pile

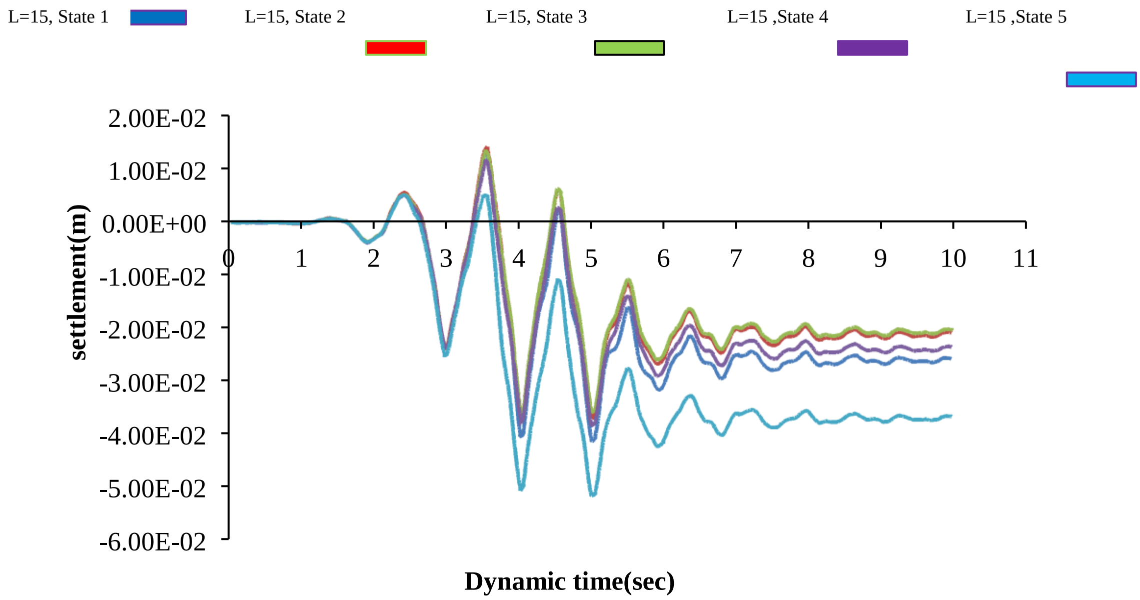
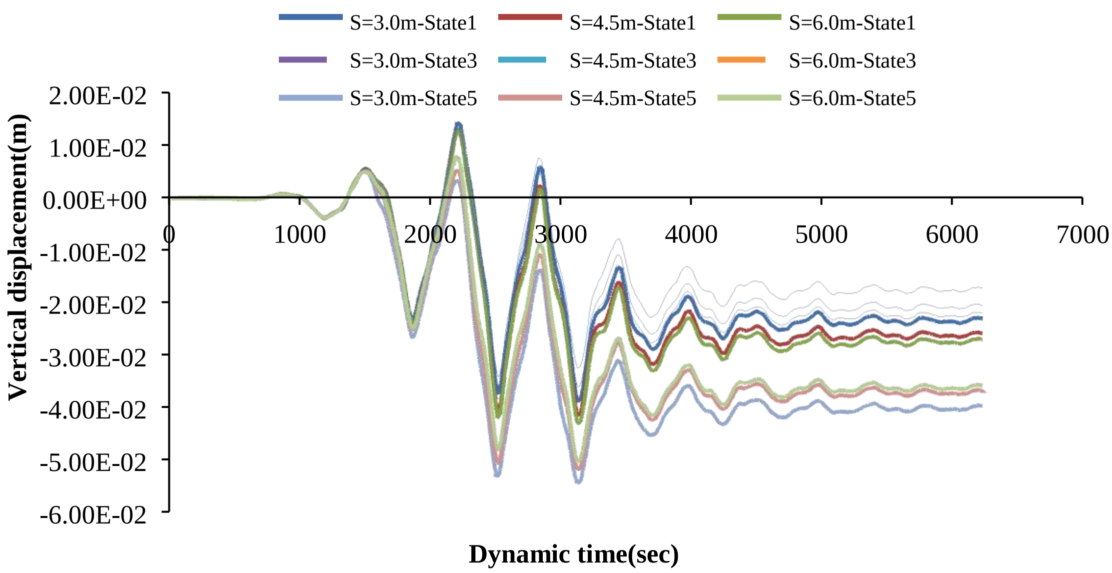


Figure 15. Comparing the effect of the pile length on decreasing vertical displacements (subsidence) in a different state of the implementation of the pile

Figure 15 shows the vertical displacement at the point 507 (3m behind the trench ridge), which provides the effect of the pile implementation with a diameter of 1.5m and a buried length of 15 meters. It can be seen that the residual subsidiary of point 507 with implementation of reinforcing over the trench span decreases by 20% compared to the control model so that with reinforcing in state 1 (bottom of the span), the displacement of residual volume and the maximum has reduced 20% and 11.9%, respectively. With the implementation of the pile by 2 and 3 states (in the quarter of the middle of the bottom of the trench span and its center), the amount of the subsidence is approximately equal, so that the maximum subsidence and the residual volume has decreased by 24% and 30%, respectively, and with the implementation of the pile above the center of the trench, that is, state 4 and 5, the amount of vertical displacement (subsidence) of the residual volume has decreased 19.3% and 13% respectively, compared to the controlling model. Also, the maximum vertical displacement arising from the seismic load declined to 12.6% in the states of the pile locating in the span of the trench, while in the state 5 where the pile has been implemented in the trench ridge, the maximum subsidence increased by 9.13% compared to the control module. Finally, it can be said that the pile with a constant diameter of 1.5m and the locating space of the piles to each other were 4.5m, with the increase in the length of the pile, the amount of residual subsidence and maximum increase by 24-30% compared to the control model. Effect of the location of the pile with the locating space variable (S) on the decrease of vertical displacement (subsidence) **Figure 16** shows the vertical displacement of the soil behind the trench span at a distance of 3 meters to the trench ridge, which is due to applying the seismic load. The charts have been also provided based on the 1.5m diameter of the pile and the buried length of 15 m.



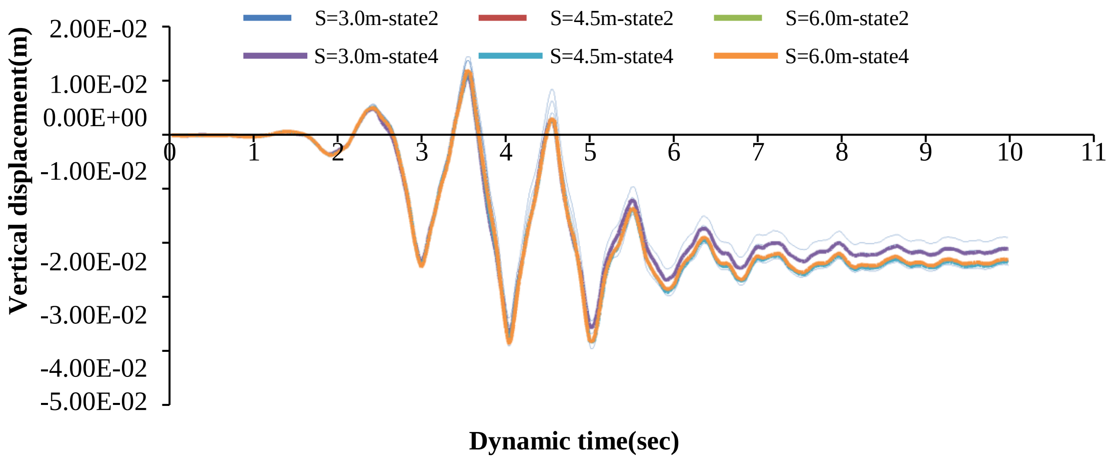


Figure 16. The amount of subsidence in the locating space (S) between the piles differs according to locating state of the pile on the trench

As it can be seen in Figure, the most critical condition for the implementation of the pile is state 5 (ridge of the trench), so that by implementing the piles at a space (S) of 3m from each other, the maximum subsidence during applying the seismic load and the residual subsidence increases 19.56% and 33.33%, respectively, compared to the control module. Also, the implementation of the pile in this area (the trench ridge) with a space of 6m from each other leads to increase by 8.7% and 20%, respectively in the maximum subsidence during applying the seismic load and the residual subsidence, compared to the controlling model. Therefore, the implementation of the pile on the trench ridge leads to critical conditions and decreases the shear resistance of the soil, and also creating a desire for the rupture in the trench span, as well as increasing the soil subsidence of the behind of the span compared to without reinforced conditions, and by reducing the space of pilling, the model will move forward towards more critical.

8. CONCLUSION

In this research, the effect of different parameters of the pile were determined such as the buried length of the pile (L), the diameter of the pile (D) and the locating space of the pile (S) to each other according to the locating space of the pile in the trench span (states 1-5). The results showed that with the implementation of a pile with a diameter of 1.5 meters, and with the implementation of a pile by states 2 and 3, the maximum amount of the reduced subsidence decreased by 30% at 3 meters behind the ridge, compared to the control model. With the implementation of a pile with 0.9m diameter, the displacement of the subsidence after the earthquake load in all states of the pile implementation (states 1-5) reduced approximately to 14.33% compared to the controlling model. Also, by increasing the diameter of the pile, the optimum area of the pile implementation is states' 2 and 3 in the span of the trench to reduce the maximum subsidence and residual volume sewage is 24% and 30%, respectively. By reducing the diameter of the pile, the optimum area of the piling was restricted to quarter to reduce the residual subsidence and the maximum soil subsidence behind the span is 18% and 16%, respectively, compared to the control model, in the quarter of the middle of the bottom of the span (state 2). Finally, it can be said, without considering diameter of the pile, the optimum location of the pile is in the middle (state 3) and in the quarter of the middle of the bottom of the span (state 2), which leads to decrease the residual subsidence, and the maximum is 24% and 20%, respectively, compared to the controlling model.

FUNDING/SUPPORT

Not mentioned any Funding/Support by authors.

ACKNOWLEDGMENT

Not mentioned any acknowledgment by authors.

AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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