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Influence of Ali Al -Gharbi Earthquake on Braced Excavation in Silty Clay Soil (Numerical Study)

Hadeel Khaleel Abd Al-Ameer, Hassan Obaid Abbas*

Department of Civil Engineering, University of Diyala, 32001 Diyala, Iraq

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ABSTRACT

The design of the braced excavation system is one of the important and necessary matters for the implementation of various projects. The braced excavation system is used to support excavations in temporary projects, so there are shortcomings in the study of this aspect, although sometimes there are many projects that take long periods of time especially the projects of underground tunnels and high buildings. This was the main reason for the study. Therefore, the possibility of exposing the drilling system to earthquakes is great, especially in seismically active areas. If the drilling system is exposed to an earthquake, it can cause great human and material losses, so it must be designed against earthquakes so that ensure complete collapse and failure does not occur. This study aims to investigate the behavior of braced excavations under the influence of the Ali Al-Gharbi earthquake in both x- and y- directions. A numerical study is carried out on braced excavation system of (14×6) m and depth 9m using software Plaxis 3D. The braced excavation system consists of three type of bracing system with three levels of strut and wales connected with sheet pile wall to support sides of excavation and prevent them from collapsing. The results of study showed that the horizontal displacement of braced excavation system is (100-155) % more than vertical displacement (settlement) with seismic time when system is subjected to Ali Al-Gharbi earthquake in both directions with the other factors remaining constant. The stiffness of sheet pile wall also play an important role increases and decreases lateral displacement in both direction. Also, the results showed that the movement of of braced excavation system depends on several factors like as type of soil, time acceleration and the direction of earthquake. Settlement of Ali Al-Gharbi earthquake in Y- direction is 13% more than in X-direction.

1. Introduction

In congested urban area, deep excavation is desired for the construction of underground transport systems, utility pipelines, basements of high rise buildings, etc. These excavations are created vertically beneath the ground surface due to limited space. The excavation faces must be protected by temporary bracing systems to reduce the excavation area, to maintain the stability of the excavation sides, and to ensure that the movements will not cause damage to the neighbouring structures or to facilities in the surrounding ground, [1]. The retaining walls are supported and constructed at different levels by horizontal struts that extend between the opposite sides of the excavation to support near-vertical excavated faces laterally. In temporary cases, sometimes these retaining walls are only sheet pile walls, but reinforced concrete walls are used when they become a permanent part of the structure, [2]. Despite the critical importance

* Corresponding author.
E-mail address: temimi71@yahoo.com
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of the excavation support systems, most designers and contractors have limited experience in its design and construction and rely heavily on experience. A major design consideration when construction facilities in congested urban areas is the potential damage to buildings adjacent to the excavations. In addition to the vertical load, braced excavations are subjected to horizontal stress through constructions that are exposed to earthquake forces. As the phenomenon of earthquakes is deemed one of the most hazardous natural disasters that threaten life and changed the shape of our planet. Earthquakes are natural disasters that are caused by the sudden release of energy from the earth's crust leading to the occurrence of seismic waves that occur without warning and causes damage to any structure or building through settlement, loss of bearing capacity of soil- foundation system and ground cracking, [3]. In comparison to the static case, one of the most difficult challenges in civil engineering is seismic risk mitigation, and geotechnical earthquake engineering can play an important role in this challenge, [4].

As a result, to achieve cost-effective and safe designs, foundation engineers should be keep advisedly of technological advancements in these domains or be well informed in these fields. Much work needs to be done in order to develop seismic methodologies for evaluating seismic bearing capacity and earthquake-induced permanent displacements in braced excavations, [5]. In compressible or softer soil, braced excavation are usually required to increase bearing capacity and decrease differential settlement. The forces on braced excavation change during an earthquake due to ground deformation caused by the seismic load. In recent years, most of the braced excavations failures have been caused by soil liquefaction, but studies on damage in non-liquefiable soil are very rare, [6]. Recently, to build underground facilities in all type of soils and due to the simple technique, cost-construction effectively, minimization of the excavation area and ensuring soil movement in a way that does not cause damage to the structure or neighbouring facilities, braced excavation technique was used to obtain stability by laterally supporting the straight vertical faces by a sheeting and bracing system until the structure is built. However, many cases of collapse of braced excavation due execution or design flaws have been documented, [3, 4]. The study of braced excavation is complex and sophisticated study, requires a holistic approach to address the design of braced excavation problem. According to [7], the design of braced excavation in soft soil is depend on two distinct, but interrelated requirements: (1) Enough support system is needed for carrying out excavation stability and (2) Takeover of ground movements without adversely affecting the neighbouring structures. The devastation caused by major earthquakes around the world was reason enough to investigate the seismic behavior of braced excavations, and lateral vibration is the most dangerous in the design and analysis of these excavations, [8, - 10]. Structures resting or facilities on braced excavations continue to collapse after strong earthquakes that are founded on or through liquefied soil. It has been discovered that some failures of the braced excavation cannot be explained by the current design methods that use Rankine or Coulomb’s theory in calculating the lateral earth pressure because the implementation of braced excavation differs from the implementation of the other type of constructions, as well as difference in wall rotation of braced excavation, where we find that the wall rotation increase with depth and this is not suitable with the Rankine method. In an earthquake, the apparent superstructure remained undamaged, but the structure or the facility as a whole tilted or moved laterally, [11]. The study by [12] conducted numerical analyses of sheet pile wall, finding that as a seismic wave propagation through the soil it quickly mobilized shear forces in the soil adjacent to the propped sheet pile wall, when compared with the static condition it caused a significant increase in lateral displacement and bending moment in the wall, as well as an increase in axial forces in the struts. Also, the study by [13] achieved a numerical analysis of flexible, embedded cantilever retaining walls in a dry, sandy soils using FLAC and two seismic histories. They noticed that the earthquake resistance to the permanent body motion of a retaining wall could be expressed in terms of critical horizontal acceleration, which was calculated in an iterative method based on the limit equilibrium. Also, they found the bending moment was large though the earthquake due to instantaneous contact-stress distribution.

A study by [14] conducted dynamic centrifuge tests on reduced-scale models of sheet pile walls. They observed that residual bending moment (after vibration) and the permanent displacements (during vibration) not only depended on the entire acceleration time history but also on present earthquake intensity. A study by [15] conducted several centrifuge test on propped cantilever retaining wall in dry sand. They noticed that no significant excessive displacement during the earthquake to the retaining wall if the retaining wall had previously been subjected to displacement due to a pervious earthquake more severe than the current earthquake. Braced excavation stability and adjacent ground surface depends on the stiffness, number and horizontal and vertical spacing of the struts and on the embedment depth and stiffness of the retaining wall, [16]. Most of the problems that grow from excessive ground movements greatly affect the performance braced excavations, primarily braced excavation design for dynamic load resistance is based on limiting deflection criteria that take into account the safe operation of the superstructure, [17]. Therefore, the accurate engineering analysis of the behavior of braced excavations under anticipated static and dynamic working loads becomes a critical step in the satisfactory performance of braced excavations, and through experimental studies and tests of the dynamic behavior of braced excavations in both soft clay and loose soil to medium soil. It is observed that the amplitudes of the accelerations, settlement, and bending moment increasing as the frequency of the ground motions increase [11, 17].

As may be seen from the above discussion, the studies on the sheet pile walls under seismic condition are very limited. The main reason for this limitation in studies is that these types of structures are impermanent in nature. However, at the present time, many cases of construction projects and facilities last from 5 to 6 years, so it is required to design underground bracing systems, especially in the case of earthquakes in earthquake-prone zones, [2]. The city of Diyala is a seismically active area, therefore; a seismic site characterization study is required to accurately predict the location of ground movements. Diyala governorate is sensitive along the seismic line that extends between the Arab and Iranian plates because it is extended along that line. It also has a natural topography such as, comprising mountains, plateaus, and plains, as well as different types of soils, including sandy, rocky, and clay soil types, [18]. The aim of the present study is to investigate the influence of the seismic load (Ali Al-Gharbi earthquake) on the lateral displacement and vertical settlement of the braced excavations embedded in silty clay soil in Baquba city.

2. Numerical Model

Numerical analysis methods are frequently used to predict ground deformations and to determine design criteria for excavation work. These predictions are of great importance, especially in urban areas, because of their prime need to ensure the safety of existing buildings.

2.1 Formulation Problem of Study in Plaxis-3D 2021 Program

The excavation support is a very important issue for the safety of the building and its workers due to the serious threat to life posed by a potential earth collapse, according to this investigation, the behavior of excavation support should be taken into account especially if the soil is soft to medium silty clay and with a water table 1m from the ground surface.

The case study of the soil–excavation system was formulated in Plaxis with the boundary conditions which is explained in paragraph 2.3 for the finite element method for braced excavation into soil media (14×6×30) m as illustrated in Figure 1.

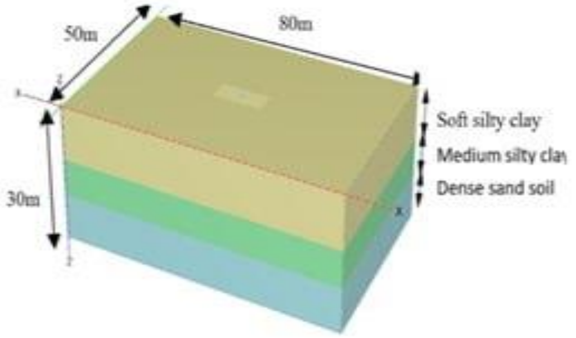

Figure 1. The geometry of soil layers

A pit was made with coordinates [(33,22,0),(47,22,0),(47,28,0),(33,28,0)] inside the above-mentioned soil model as shown in Fig. 2, and select points in mid of sheet pile wall [A(33,25,0),B(40,22,0),C(47,25,0),D(40,28,0)]. where the first type of support is the sheet pile wall of the four sides of the pit, was installed with a depth of 9 m inside silty clay soil of 12 m depth, and then the second type of support is the wale which used on three levels, the first level of wale is 1 meter from the ground surface and the second level of the wale is 3.5 m from the ground surface and the third and final level is 6 m from the ground surface. After that the struts were used and implemented in three levels, the first level is 1m from the ground surface and each level contains 5 struts, each strut is 3 m away from the other. Figure 2 shows the four selected points located on the top in the middle of each sheet pile wall. These points are chosen to investigate horizontal and vertical displacement during happened of Ali Al-Gharbi earthquake.

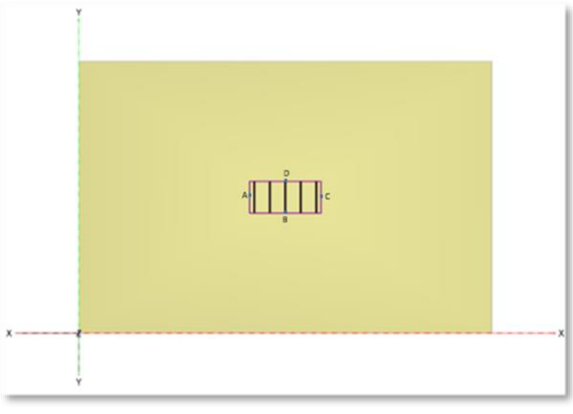

Figure 2. The excavation plan and selected points in this study

2.2 Constitutive modeling

Plaxis software is a set of general boundary conditions to the actual geometry model. Where it also includes the creation of the Geometry model, material properties, mesh generation, calculations, and results evaluation. The first step to generation a finite element model is to create a geometry model. Each cluster provides properties that can be used to simulate the behavior of soil and structure objectives and was modeled employing 10 nodes of tetrahedral elements with rigid interface strength of the soil–excavation system. This study's model consists of two parts: material soil and braced excavation. Completely an elastic perfectly plastic soil domain with three layers (Mohr Coulomb model). Another component of the model is braced excavation, which is based on isotropic elasticity and is molded with use three types of bracing, where the first type is a plate element of sheet pile wall, the second type is beam element of wale and the third type is also beam element of strut. After completion the implementation, the geometry component, and the bracing system parameters are assigned to the corresponding geometry component the mesh generation is generated. The values of the bracing system parameter and soils used in this study are shown in Tables 1 and 2.

2.3 Earthquake Loading and Boundary Condition

At the bedrock level of the model, the input motion used in this study is defined as dynamic surface displacement (displacement multipliers). The acceleration time history for the earthquake selected in this search is Ali Al-Gharbi that is happened in 25/9/2015 in Iran with maximum acceleration (g) is 0.1 and the magnitude (M_w) is 4.9M_L, which is applied along the X- and Y- directions at the bottom boundary of the 3D model in m/s^2 and s respectively, as illustrated in Figure 3. In reality, seismic waves propagate indefinitely through the soil. Based on this fact, and to avoid the sudden reflection of these waves on the model boundaries inside the soil body, absorbent boundaries are generated by selecting the standard absorbent boundaries (viscous boundary) in the Plaxis program. The absorbent boundaries are applied at the lateral sides and the bottom boundary in this model.

Table 1: Properties of Bracing System Components, [19]

Property	Strut	Wale	Sheet pile wall	Unit
Thickness	-	-	12.7×10^{-3}	m
Elastic Modulus, E	2×10^{8}	2×10^{8}	2×10^{8}	kN/m^2
Poisson's Ratio(υ)	-	-	0.3	-
Unit Weight (γ)	78	78	78	kN/m^3
Area	0.01125	5.38×10^{-3}	-	m^2
Moment of Inertia(I_3)	1.826×10^{-4}	8.356×10^{-5}	-	m^4
Moment of Inertia(I_2)	6.31×10^{-5}	6.04×10^{-6}	-	m^4

Table 2: Properties of Soil Layers for the Numerical Analysis, [20]

Property	Soft Silty Clay	Medium Silty Clay	Dense sandy
Elastic Modulus, E (MPa)	10	50	90
Poisson's Ratio, υ	0.4	0.4	0.3
Unsaturated Unit Weight, γ_{unsat} (kN/m^3)	15	16	17
Saturated Unit Weight, γ_{sat} (kN/m^3)	19.39	19.62	20
Cohesion, c (kPa)	40	82	-
Friction Angle,(φ)	-	-	35
Interface Strength (R_{inter})	Rigid	Rigid	Rigid
Damping Ratio, ξ	0.01	0.01	0.005

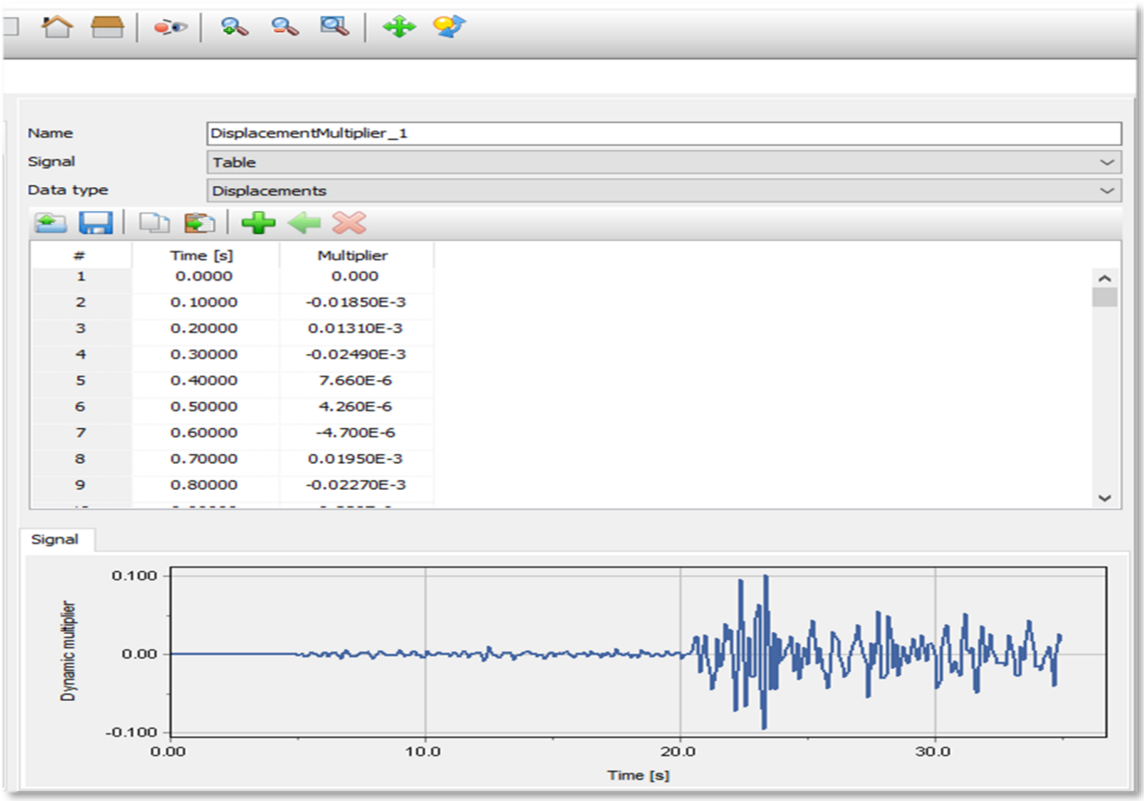

Figure 3. Acceleration Time-History of the Ali Al-Gharbi Earthquake

2.4 Mesh generation and calculations

The PLAXIS application makes use of an unstructured mesh that is generated automatically using global settings to divide the geometry of the soil - excavation into elements for performing finite element calculations.

In this investigation, a medium-mesh was chosen to avoid lengthy calculations of time with fine or very fine-mesh as demonstrated in Figure 4. After completing the generation of the finite element mesh, the proper finite element calculations are carried out. The calculation process is divided into multi phases. -In the initial phase (Initial Stress Generation): the initial stress of the soil body can be determined based on the weight of the material and its history of formation depending on the Ko procedure. Based on Jacky's empirical expressions, where K_o is related to the friction angle as, (3D PLAXIS Manual, 2020), and the default K_o value for Mohr-Coulomb is appropriate:

$$K_o = 1 - \sin\emptyset \quad (1)$$

- Second phase: braced excavation stresses will be calculated using the plastic calculation method, according to the theory of deformation.

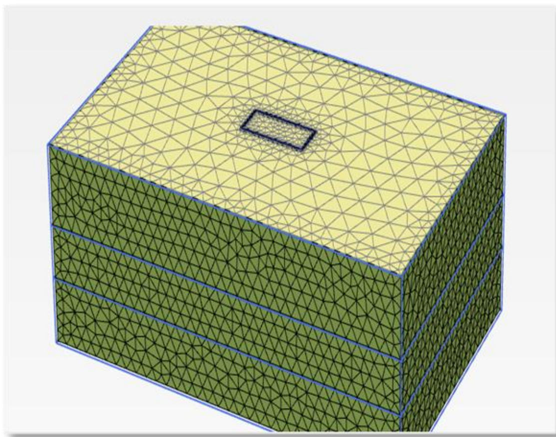

Figure 4. Finite element mesh for braced excavation system

Finally, the phase for the dynamic calculations: a dynamic analysis following a series of plastic calculations on the structural model, as well as a dynamic selection calculation after creating dynamic load multipliers to calculate the earthquake stresses with a dynamic time interval equal to 160 (s), where only first 35 (s) were taken for the study because of the difficulty and delay that occurs in Plaxis 3D if the entire shock time was taken. After the analysis carried out for the soil-excavation system, the variations of the settlement and horizontal displacement of the braced excavation system is observed.

3. Analysis of results

It is clear from Figure 5 that the values of lateral or horizontal displacement approaches to zero during the firsts 21 sec of earthquake due to the peak ground acceleration for earthquake which is very small in this period. After that the lateral displacement of points A and C begin to be fluctuated with time and move in negative direction of x- axis and reached approximately 0.23m and 0.19m for points A and C respectively. On the other hand, the lateral displacement of points B and D is increased slightly and continuously until reached 35 sec. The points A and C are located on top of middle of sheet pile walls which are perpendicular to the direction of Ali Al-Gharbi earthquake. The locations of points B and D on top and middle of sheet pile walls which are in the parallel to the direction of Ali Al-Gharbi earthquake. The values of lateral displacement of points A and C are more than points B and D. This is due to the stiffness of sheet pile which is high when sheet pile wall is parallel to the direction of earthquake and versa is correct too.

It is noticed from Figure 6 that the vertical settlement values are very small during 21 sec for all points A, B, C and D. After that the settlement of all mentioned points begins to increase and reached maximum value of 0.09 m at 35sec. The fluctuation of settlement variation after 21sec is small and approximately is similar for all points. In general, the values of settlement is less than horizontal displacement, this is due to the force created by the excavation- soil system mass inertia during shaking doubles the acceleration intensity. These forces make the excavation soil system with the soil to move as a large block under the shaking effect of earthquake. The direction of earthquake is generally predominated in horizontal direction.

It is obvious from Figure 7 that the values of lateral or horizontal displacement goes to zero during the first 21 sec of earthquake for all points due to the low of peak ground acceleration for earthquake in this period. Subsequently, the lateral displacement of points B and D begin to be fluctuated with time and move in negative direction of Y- axis and reached approximately 0.22m and 0.19m for points B and D respectively. Meanwhile, the lateral displacement of points A and C is increased slightly, low oscillating and continuously until reached 35 sec. in this case, the points A and C are located on top of middle of sheet pile walls which are parallel to the direction of Ali Al-Gharbi earthquake. The locations of points B and D on top and middle of sheet pile walls which are perpendicular to the direction of Ali Al-Gharbi earthquake. The values of lateral displacement of points A and C are less than points B and D. This is due to the stiffness of sheet pile which is sizable when sheet pile wall is collimated to the direction of earthquake and versa is correct too.

As noticeable from Figure 8 that the vertical settlement values are very small and goes to zero during 21 sec for all points A, B, C and D. Subsequently, the settlement of all mentioned points begins to heightening and reached maximum value of 0.11 m at 35sec. The fluctuation of settlement variation after 21sec is low and approximately is similar for all points. In general, the values of settlement is less than horizontal displacement, this is due to the force created by the excavation- soil system mass inertia during shaking doubles the acceleration intensity. These forces make the excavation soil system with the soil to move as a large block under the shaking effect of earthquake. The direction of earthquake is generally predominated in horizontal direction. The upper layer of soil is soft and this is caused the excavation system to move easily as block in horizontal direction.

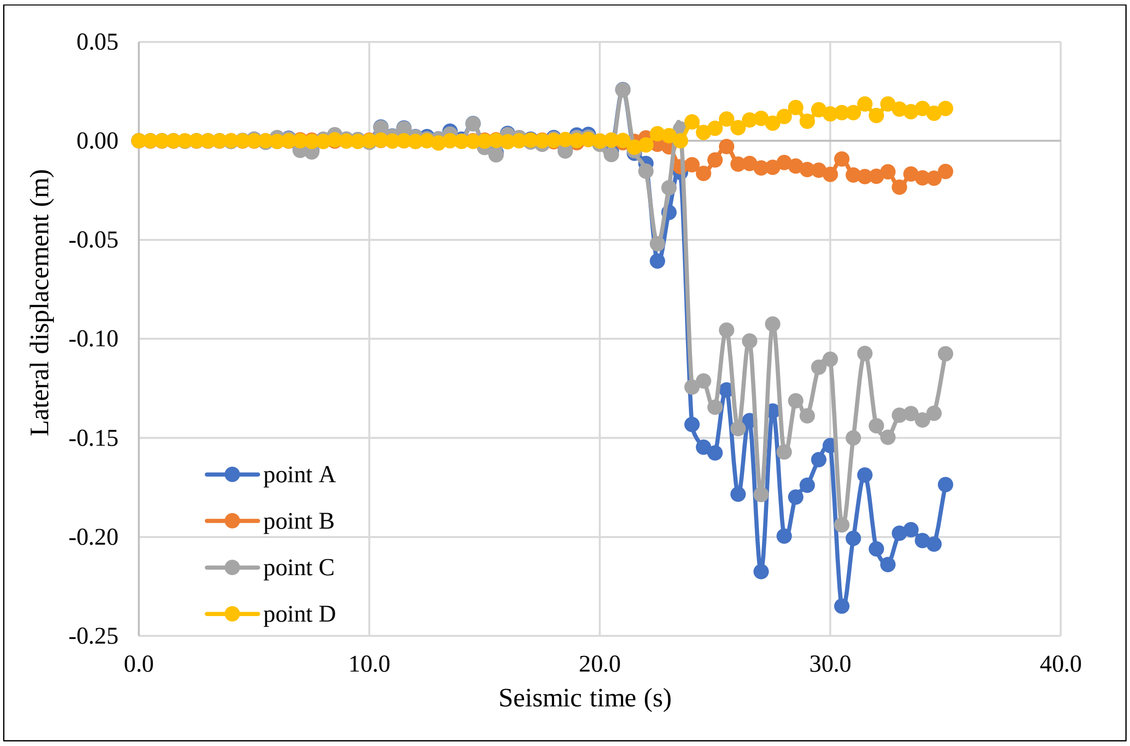

Figure 5. Lateral displacement and seismic time relationship in (x) direction.

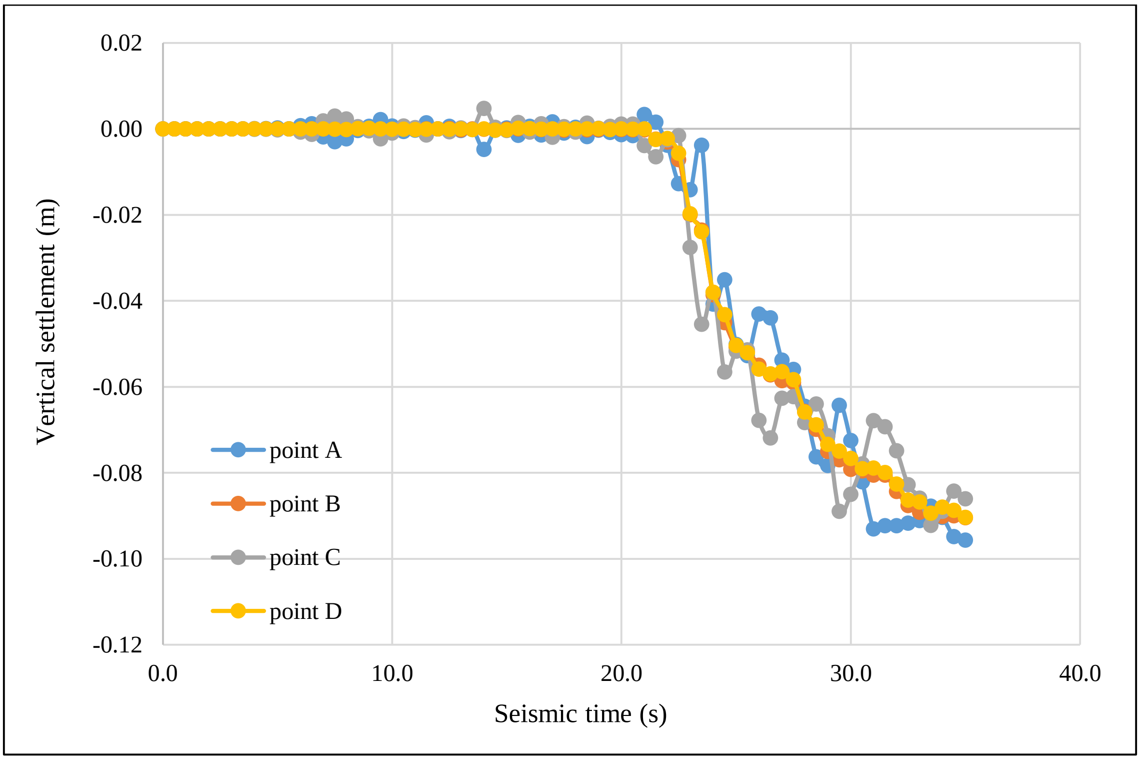

Figure 6. Vertical settlement and Seismic time relationship in (x) direction.

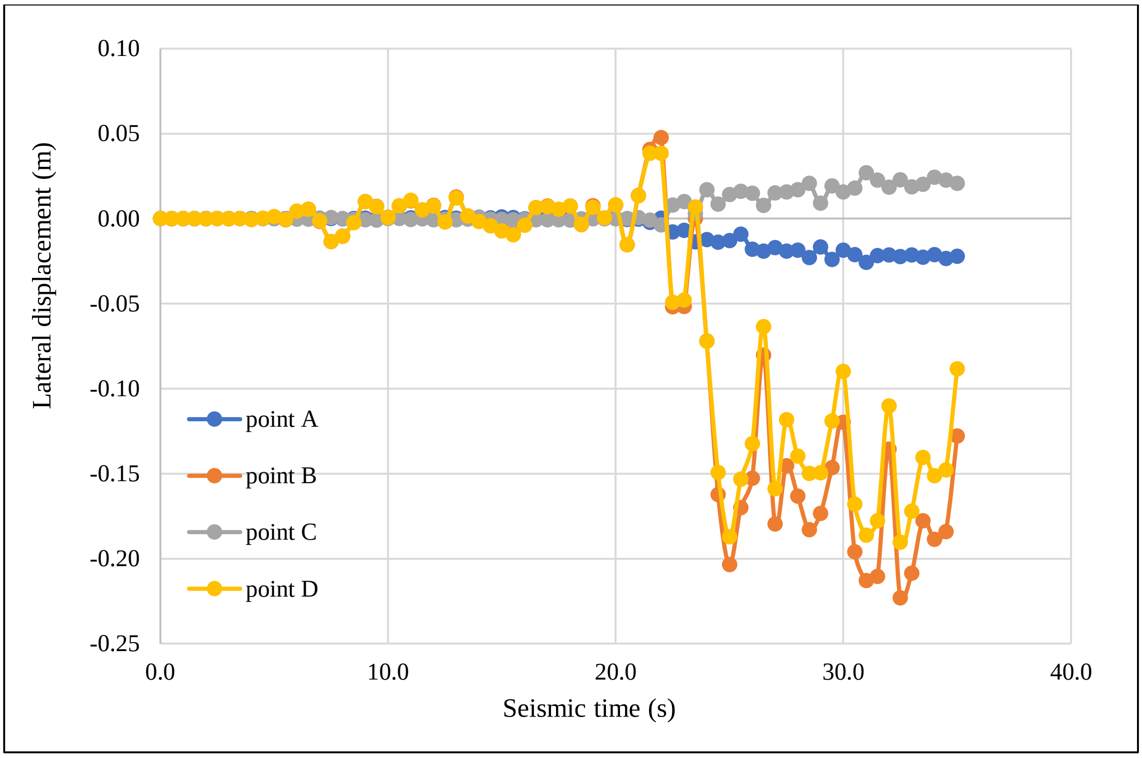

Figure 7. Lateral displacement and seismic time relationship in (y) direction.

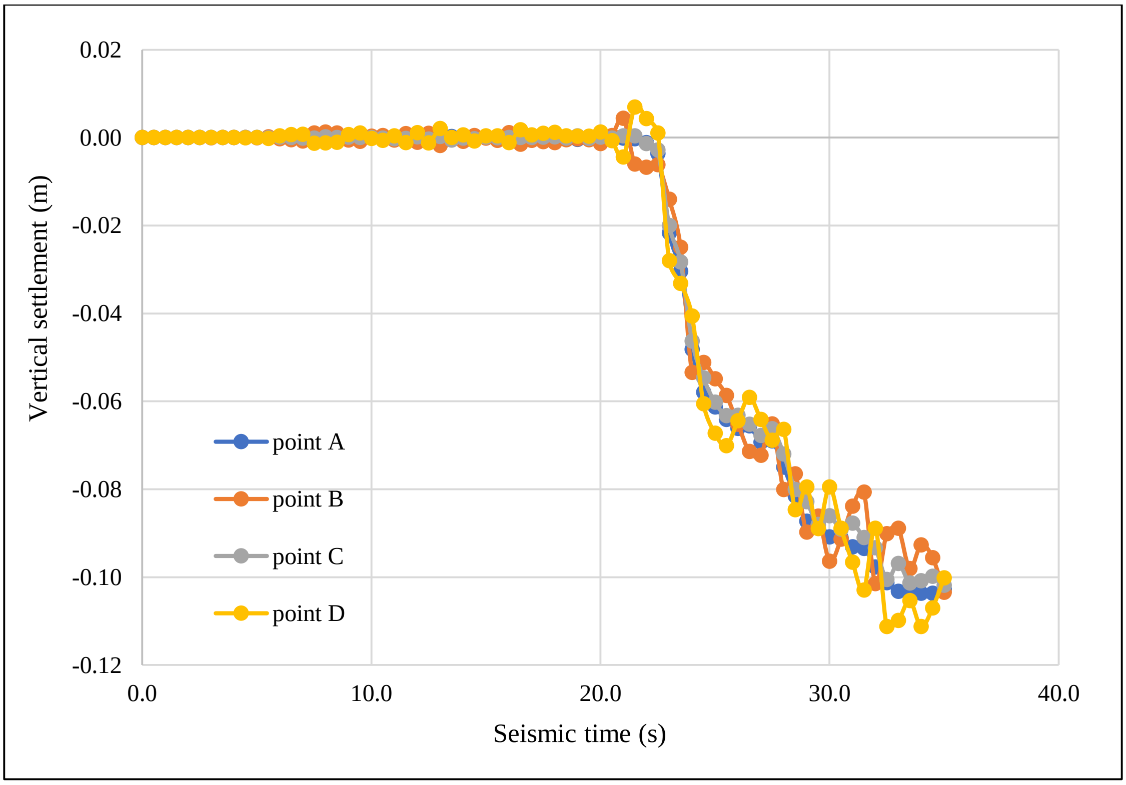

Figure 8. Vertical settlement and Seismic time relationship in (y) direction.

4. Conclusions

1. The horizontal displacement of braced excavation system is (100-155) % more than vertical displacement (settlement) when system is subjected to Ali Al-Gharbi earthquake, While if another earthquake is used, both the horizontal displacement and the vertical displacement may not behave the same way.
2. The sheet pile wall is affected largely to earthquake excitation when it is perpendicular to the direction of earthquake.
3. The movement of braced excavation system in soft silty clay is easily in horizontal direction when system is subjected to Ali Al-Gharbi earthquake.
4. The values of lateral displacement of points A and C are more than points B and D in x- direction , while in y-direction lateral displacement of points A and C are less than points B and D. This is due to the stiffness of sheet pile which is sizable when sheet pile wall is collimated to the direction of earthquake and versa is correct too.
5. The vertical settlement values in x-direction are very small during 21 sec for all points A, B, C and D. After that the settlement of all mentioned points begins to increase and reached maximum value of 0.09 m at 35sec but in y- direction the vertical settlement values are very small and goes to zero during 21 sec for all points A, B, C and D. Subsequently, the settlement of all mentioned points begins to heightening and reached maximum value of 0.11 m at 35sec.
6. The stiffness of sheet pile which is high when sheet pile wall is parallel to the direction of earthquake and versa is correct too.
7. The stiffness of sheet pile wall Play an important role increases and decreases lateral displacement in both direction.
8. In general, the values of settlement is less than horizontal displacement, this is due to the force created by the excavation- soil system mass inertia during shaking doubles the acceleration intensity.

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