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Displacement Analysis of Soft Soils under Earthquake Effect

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Abstract – Soft soils, just like liquefiable soils, pose a major problem in the field of geotechnical engineering. Excessive displacements that occur due to soil-related problems are generally described as liquefaction. Especially in regions located on the earthquake zone, excessive settlements due to loss of bearing capacity in soft soils cause serious losses of life and property. In recent years, due to population growth, its use has become mandatory in areas with soft soil. For this reason, analyzing and examining the behavior of soft soils during earthquakes has become an important issue. In this study, a soft clay soil sample was analyzed under earthquake effect using Plaxis 2D, a finite element program. Acceleration time parameters of the earthquake that occurred in Izmir, Turkey on October 30, 2020 were used in dynamic analyses. Dynamic analyzes were carried out by applying the limit bearing capacity value (BC) obtained in the study as a distributed load on the soil at certain rates (25%, 50%, 75%, 100%). As a result of dynamic analysis, graphs were created with the displacement values taken from the midpoint of the foundation plate, and important information was obtained about the behavior of soft clay soils under earthquake effects. As a result, it has been shown through analysis that the excessive displacements that occur in the soil during the earthquake are not only due to liquefaction, but also pose a major problem in soft soils.

Keywords – Bearing Capacity, Displacement, Soft Soil, Earthquake Effect, Finite Elements.

I. INTRODUCTION

When you do a brief research on the subject of liquefaction, it is noticeable that there are a lot of studies. However, when it comes to soft soils, it is seen that there are very few studies in the literature, especially on earthquake effects. In parallel with the development of computer hardware in recent years, many finite element-based software have made significant progress, which is one of the positive developments in the scientific world. Plaxis 2D, a finite element program in the field of geotechnical engineering, is one of the most preferred software both in the commercial and academic fields.

There are studies examining the settlements occurring in soils under the effect of seismic loads [1]. In a similar study, liquefaction, settlement and bearing capacity losses of a clay layer with liquefaction potential under the effect of seismic load were examined [2]. In a study on slopes, the seismic displacement of a foundation on the slope was examined and it was concluded that the grading reduced the seismic displacement [3]. When all of these and similar studies in the literature are reviewed, it is seen that soft clay soils have high bearing capacity and excessive settlements under the influence of earthquakes [4].

II. MATERIALS AND METHOD

In studies conducted with numerical analysis programs, if there is an earthquake load in the system, the model size is of great importance. In order to ensure the accuracy of the results obtained from the analysis, the width and depth of the soil model must be determined accurately. In a study on the effect of model size in numerical analyses, it was observed that the results obtained started to decrease at values chosen below 40 meters wide [5]. In dynamic analyses, model depth is as important as model width, and when the studies on the subject are examined, model depths of 40 meters are generally preferred, considering that the bedrock is 40 meters below ([6]–[10]).

In this study, a width of 60 meters and a depth of 40 meters were preferred, adhering to the model dimensions in the literature. Since the soil model will be exposed to earthquake effects, the HSsmall material model, which also includes hysteretic (material) damping, was preferred in dynamic analyses. It has been reported that this material model can imitate damping in the elements forming the soil, and therefore it is believed that it would be more accurate to use it in dynamic analyzes [11].

III. FINITE ELEMENT ANALYSIS

A. Determination of carrying capacity

The material parameters of the soft clay soil used in the analyzes performed in the Plaxis 2D program are given in Table 1.

Table 1. Material parameters of soft clay soil (HS small)

Parameters	Soft clay
Drainage condition	Undrained
Dry unit volume weight, γk (kN/m^3)	16,0
Saturated unit volume weight, γd (kN/m^3)	17,5
Permability, kx,ky (m/gün)	1x10^{-10}
Secant stiffness, E_{50}^{ref} (kN/m^2)	2500
Tangent stiffness, E_{oed}^{ref} (kN/m^2)	2500
Elastic loading/unloading stiffness, E_{ur}^{ref} (kN/m^2)	5000
Stress dependent hardness of the soil, power (m)	1
Poisson ratio, ν	0,25
Cohesion, c, (kN/m^2)	10
Angle of internal friction, ϕ (°)	0
Earth pressure coefficient at rest, K_0	0.95
Maximum shear modulus, G_{0ref}	2x10^4
Shear strain, γ_{07}	5x10^{-5}

The soft clay soil model created using the material parameters given in Table 1 was modeled at a depth of 40 m and a width of 60 m. In the analysis, a 4-meter wide plate foundation was placed in the middle of the soil model to act as if the static load was transferred through a foundation. The limit bearing capacity of the soil was determined by applying the displacement load (0.1 m) in the Plaxis 2D program and used in bearing capacity calculations on this plate foundation. In the next stage, 25%, 50%, 75% and 100% of the limit bearing capacity were given as distributed load on the 4-meter plate foundation located in the middle of the soil model. Additionally, in addition to the distributed load, the Izmir earthquake was applied to the base of the soil model and the displacements occurring at the midpoint of the foundation depending on acceleration and time were determined. The sample soil model used in the analyzes is given in Figure 1.

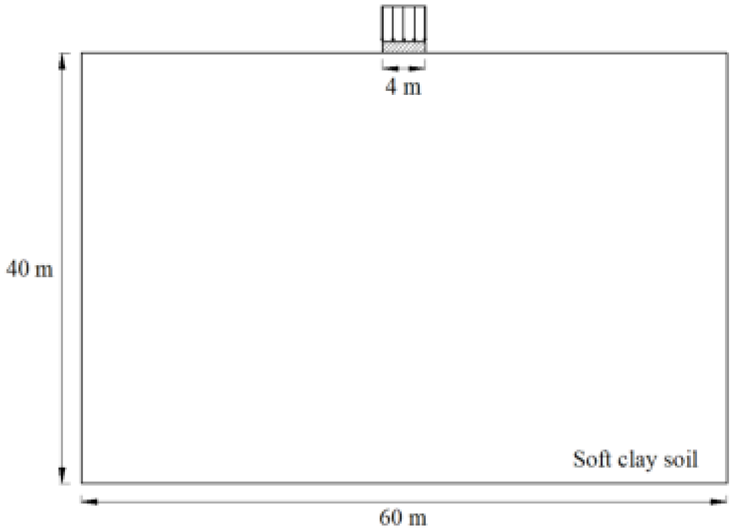

Figure 1. Sample soil model used in analysis.

In order to calculate the analysis results more precisely, the mesh density was selected as "fine". Even though increasing the mesh density in the processor-intensive Plaxis 2D program causes an increase in analysis times, the use of intensive mesh density is recommended by the program manufacturer to obtain realistic results. Generally, in these and similar programs, sparse mesh density can be used in preliminary analysis to get faster results. The mesh definition of the soil model is given in Figure 2.

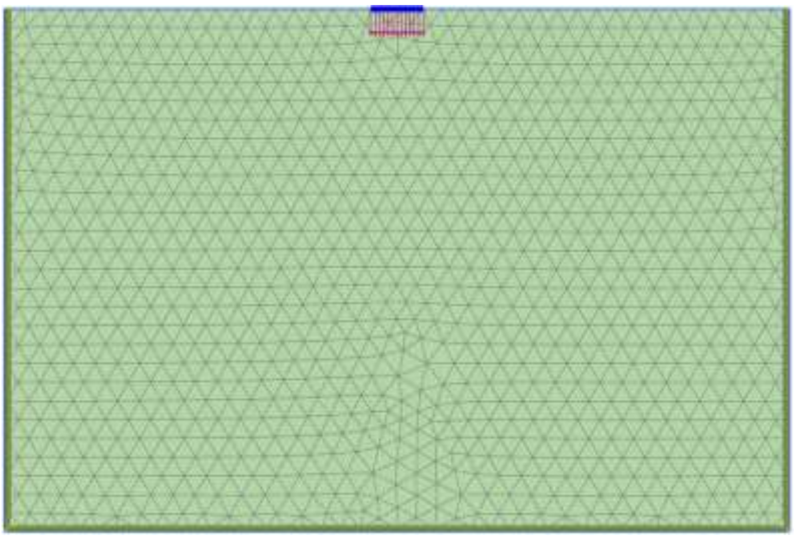

Figure 2. Mesh defined version of the soil model

In the static analyses, the vertical stress value (Fy) corresponding to a 0.1 m displacement load was obtained as 160.3 kN/m^2 for a 4-meter foundation, and by dividing this value by the foundation width, a bearing capacity value of approximately 40 kN/m^2 was reached. The view of the soil model after static analysis and its contour diagram are given in Figure 3a and Figure 3b, respectively.

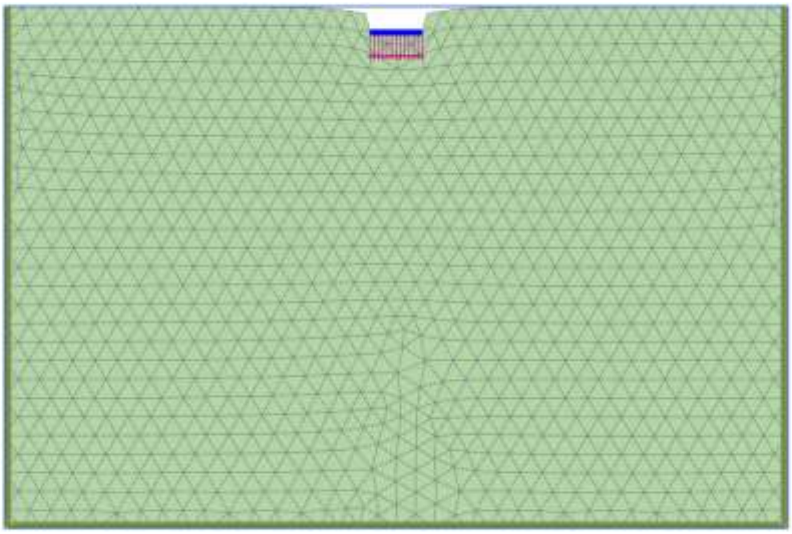

Figure 3a. Appearance after static analysis.

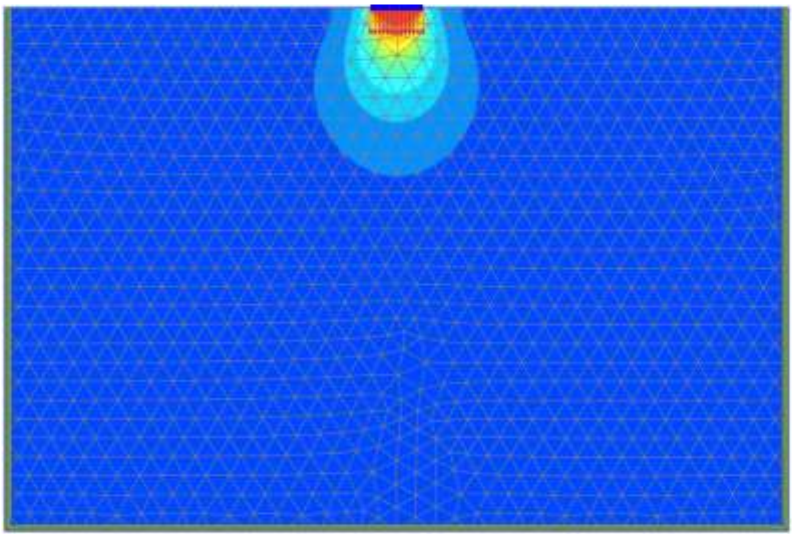

Figure 3b. Contour diagram after static analysis.

The displacement amounts occurring at the midpoint of the foundation after a distributed load of 25%, 50%, 75% and 100% of the bearing capacity are given in Table 2.

Table 2. Displacements resulting from static analysis

Amount	Load (kN/m^2)	Displacement (cm)
%25 BC	10	0.31
%50 BC	20	1.79
%75 BC	30	4.53
%100 BC	40	9.60

When the displacement amounts in Table 2 resulting from the static analysis are examined, it is seen that the displacement in the soil remains at acceptable levels (9.60 cm), even though a distributed load equal to the full bearing capacity is applied to the foundation.

B. Determination Of Displacements Occurring Due To Earthquake Effect

In order to simulate the earthquake effect, dynamic analyzes were made using the acceleration-time record of the earthquake that occurred in Izmir on October 30, 2020, from the base of the soil model. The acceleration-time graph of the Izmir earthquake used in the analysis can be seen in Figure 4. In these analyses, the distributed loads obtained from the bearing capacity (BC) applied to the foundation and the displacement amounts that occurred after the earthquake are given in Table 3.

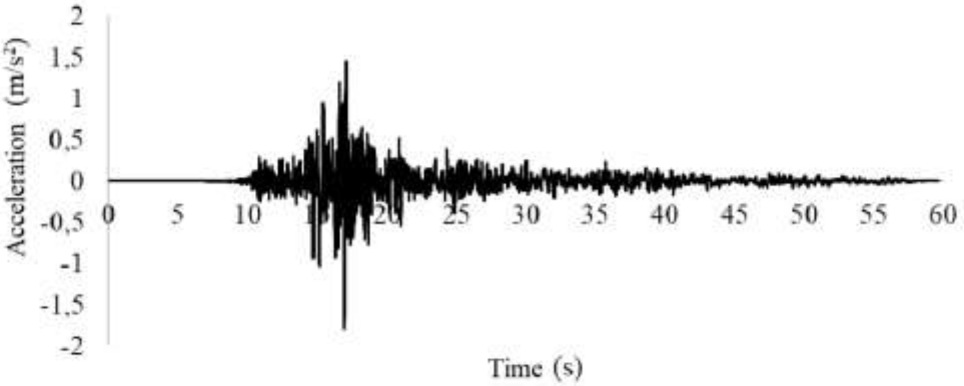

Figure 4. Izmir earthquake acceleration-time graph

In order to shorten the dynamic analysis times, the first 25 seconds of the Izmir earthquake, which includes the accelerations affected, were used.

Table 3. Displacements resulting from dynamic analysis

Amount	Load (kN/m^2)	Displacement (cm)
%25 BC	10	2.60
%50 BC	20	12.01
%75 BC	30	24.65
%100 BC	40	46.26

When the displacement amounts in Table 3, obtained as a result of the analyzes carried out under the influence of the Izmir earthquake, are compared with the displacement amounts in Table 2, obtained as a result of the static analyses, it is seen that the displacements in the soil due to the effect of the earthquake exceed the acceptable limits. Contour diagrams of the vertical displacements occurring in the soil model as a result of the dynamic analyzes made under the effect of the Izmir earthquake with the loads given in Table 3 are shown in Figure 5a, Figure 5b, Figure 5c and Figure 5, respectively, according to 25%, 50%, 75% and 100% of the bearing capacity. It is given in 5d.

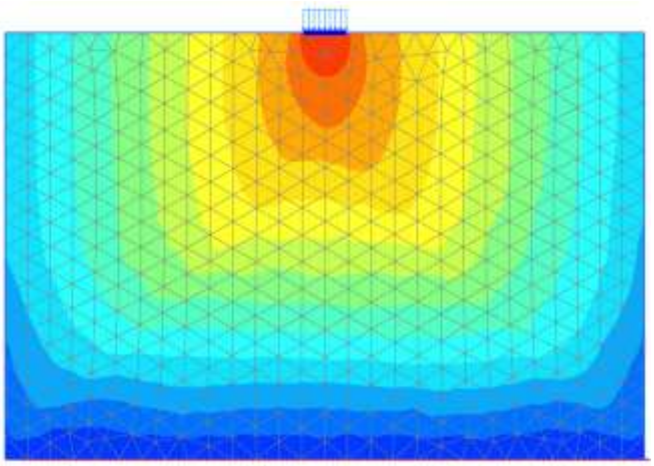

Figure 5a. Vertical displacements after dynamic analysis (25% BC)

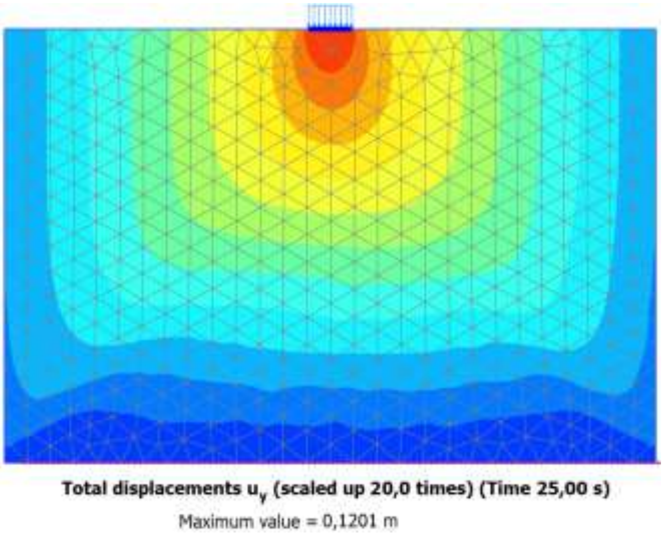

Figure 5b. Vertical displacements after dynamic analysis (50% BC)

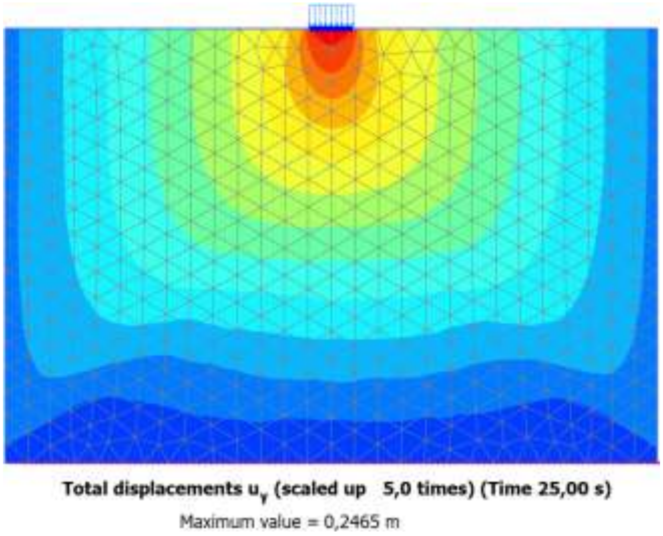

Figure 5c. Vertical displacements after dynamic analysis (75% BC)

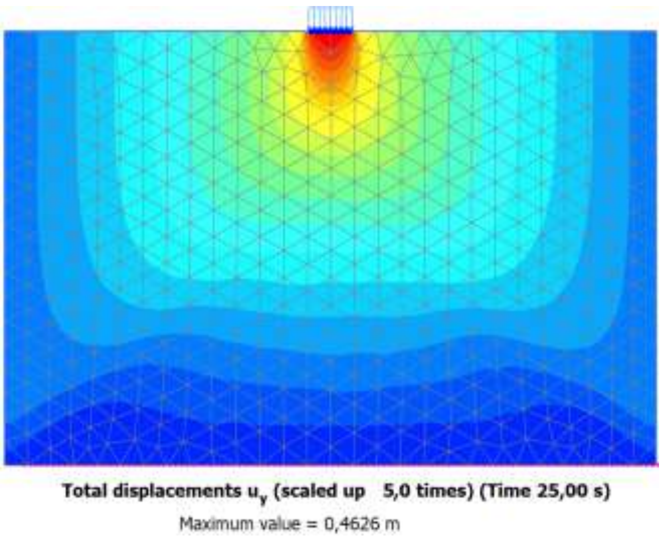

Figure 5d. Vertical displacements after dynamic analysis (100% BC)

When the contour diagrams are examined, it is seen that the bearing capacity of the maximum vertical displacements reaches very high values at 50% and beyond. In the contour diagram in Figure 5d, which shows the distributed load applied to the full amount of bearing capacity, it can be seen that a very large displacement of 0.4626 meters occurred at the midpoint of the foundation after the earthquake. The graphic version of the time-dependent displacements in the soil model during the earthquake is shown in Figure 6.

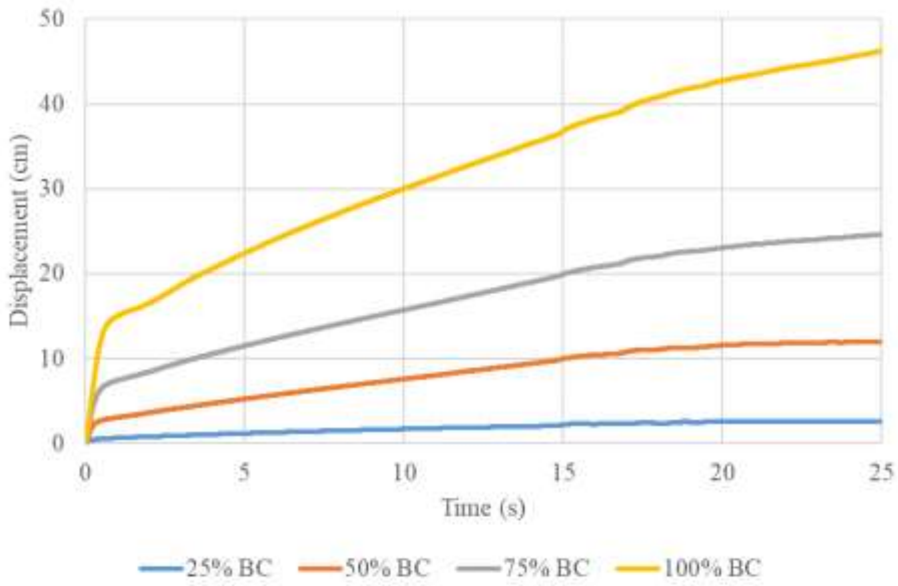

Figure 6. Time dependent displacements

When the time-dependent displacement amounts in Figure 6 are examined, it is seen that there is a rapid increase in displacements shortly after the earthquake begins. In the chart; It is clearly seen that the displacements occurring at the midpoint of the foundation are at an acceptable level when the loading is applied at 25% of the bearing capacity, and it goes well beyond the acceptable limits at the loadings of 50%, 75% and 100%.

IV. RESULT

In the static analyzes carried out in the first stage of the study, it was observed that the displacements occurring in the soil due to the distributed load effect remained at acceptable levels at 25%, 50%, 75% and 100% of the bearing capacity applied to the foundation plate. However, as a result of the dynamic analysis carried out under the influence of the Izmir earthquake, it was observed that very high displacements occurred at the midpoint of the foundation due to the increase in the amount of distributed load. This situation clearly shows that determining the safe load only by carrying capacity calculation or static analysis is not sufficient. Especially in soil types that contain high amounts of soft clay, also called alluvial soils, the safe load amount should be decided after testing with a computer software that can perform dynamic analysis. In the currently used methods, earthquake analyzes are made superficially and the safe load amount is decided, and this causes the safe load amounts to be used to be determined incorrectly. As a result, in our country, which is located in the earthquake zone, and in regions with soft clay soils, which we frequently encounter around the world, it is of vital importance to carry out comprehensive dynamic tests before the construction of the structure and, if deemed necessary in the light of the results obtained, to improve these soils using an appropriate improvement method.

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