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Numerical modeling and seismic behavior analysis of strip foundation on sandy soils

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ABSTRACT

The present study studies and evaluates the interactions between the states of structure-soil interaction for strip foundations reinforced with pile pedestals under dynamic loads such as earthquakes. To do this, first design of strip foundation on sandy soil attempted to understand the geotechnical behavior for foundation under dynamic loading. The strip foundation is regular procedure that used to improve the dynamic response for earthquakes. As methodology, finite element method and Plaxis software was used to simulate the displacement and deformation condition of the soil-structure interaction. According to the results, the program was successfully implemented to model the strip reinforced foundations in saturated sandy soil under dynamic loading.

1. Introduction

All structures are ultimately placed on the ground, so the performance of foundations is one of the most important issues in the field of soil mechanics and foundation engineering. Foundations can be affected by static, dynamic, or a combination of loads (Azarafza et al., 2014). Dynamic loads occur for a variety of reasons, which can be caused by an earthquake, the application of cyclic loads with different number of cycles, or any type of load that is related to time. A severe dynamic load can cause a lot of damage to geotechnical structures such as liquefaction, slope instability, deformation of retaining walls and damage to foundations by reducing bearing capacity and increasing subsidence. When a load is applied to the foundation, the stress state near the foundation floor gradually changes from elastic to plastic, with the plastic flow starting from the corner of the foundation and as the load increases, the plastic area expands on a curved surface to That it completely covers the soil under the foundation (Azarafza and Ghazifard, 2016; Kassas et al., 2021; Żyliński et al., 2021). Unlike static bearing capacity of foundations, the dynamic bearing capacity of foundations has been less studied, due to the complexity of the nature of dynamic force and soil behavior under the influence of these forces (Das and Ramana, 2010).

In cases of total shear failures, the soil rupture occurs completely and the foundation deviates to one side and the failure occurs suddenly. The main shear failure state is the most critical state of rupture and the equation of ultimate compressive strength of the soil is obtained based on this type of rupture. Wu et al. (2019) proposed a solution for the dynamic response in foundations designed in saturated soils exposed to transient loads. Also, plastic durability analysis for the final bearing capacity of the foundations in

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these soils has also been provided by them (He et al., 2021). This method has been generalized to determine the bearing capacity of foundations designed in c-φ soils under transient horizontal loading by Motallebiyan et al. (2020). In both works, the level of rupture is assumed for rotational foundation (foundation rotates in effect with transient). However, it is possible for a foundation to break vertically with a punch and locally due to a transient vertical load (Nguyen and Pham, 2018). Richards et al. (1993) proposed a method for estimating the vertical displacement of strip foundations by assuming the behavior of the soil as a rigid plastic material. In this analysis, the rupture level in the soil mass is similar to the type of Terzagi failures proposed to evaluate the final static bearing capacity for strip foundations (Das and Ramana, 2010).

Generally, the dynamic bearing capacity of surface foundations in sandy soils can be related as following (Towhata, 2008):

- For shallow foundations on sandy soils exposed to an acceleration of $13 \geq a_{max}$, total shear failure may occur in the soil.
- Foundations on sandy soils subject to acceleration equal to a_{max} <13 g, the nature of shear failure in the soil is local.
- The difference in the nature of soil failure is related to the internal strength of the soil at the moment of rupture under dynamic loading. Internal soil strength has almost the same effect as overhead pressure on dynamic loading, which causes shear rupture in soil.
- The minimum dynamic final bearing capacity of surface foundations on dense sands in the interval between static to sudden loading can be calculated using the friction angle, φ_{dy} (Vesic, 1973).
- Increasing the final load capacity at high loading speeds is indicates the fact that soil particles in the fracture zone always follow a path with the least resistance to rupture. This result in higher shear strength of the soil is leads to an increase in final bearing capacity.
- In the case of foundations on loose and saturated sands that are prone to liquefaction, these results may give an unreliable prediction of the final bearing capacity.
- Rapid increase of final bearing capacity in dense saturated sands at fast loading rate, due to the development of negative water-pore pressure in the soil, needs to be corrected.

By applying dynamic load (t_r), the amount of settling created increases rapidly. When the load peak (Q_{dmax}) is reached, the settling rate decreases with time. During the application of the load, the amount of subsidence continues until it reaches its maximum value (S_{max}) at the moment (t_{dw}). At the end of the load application period (t_{de}) it finds some rebound session which desire to return to the original state (Alzabeebee, 2020).

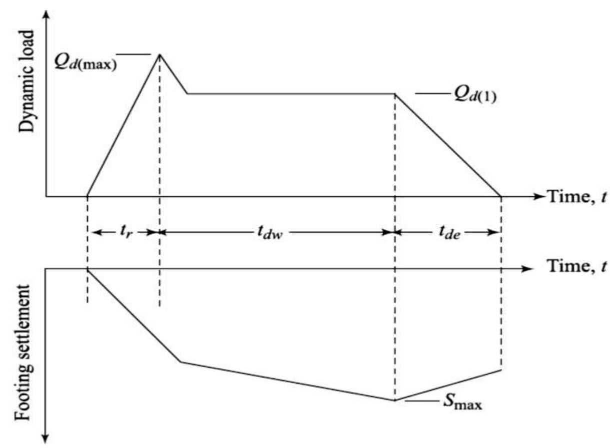

Figure 1. Dynamic loading conditions for foundations (Elghazouli, 2010)

2. Material and Methods

Today, with the development of technology and the introduction of computer science in geo-engineering topics, especially geotechnical engineering, the use of this device to solve engineering topics has become more practical. As in many geotechnical designs, the use of computers is now considered a principle. The application of computer applications in soil mechanics analysis is expanding dramatically. Soils such as non-cohesive soils and sands have always been considered because of their unique behavior. In this section, the geotechnical behavior and soil mechanics of sands are investigated with the help of computer modeling under dynamic conditions. The excellent adaptation of Plaxis software in soil analysis, especially non-stick soils, has caused this approach to be widely used in geotechnical analysis. In line with its main purpose, this article has used finite element numerical analysis method and Plaxis software.

Plaxis software is two-dimensional analysis software for the analysis of stability, deformation, subsidence, compaction, consolidation and leakage under static and dynamic conditions in the field of geotechnics (Towhata, 2008). Explaining the algorithm and working procedure of this useful numerical software is not included in the dissertation space. Therefore, in this section, only the expression and modeling of the behavior of the foundations performed in non-stick sandy soils (according to the purpose of the strip foundations) under dynamic loads is discussed and an evaluation is attempted which suitable for stress distribution, plastic deformation, displacement during an earthquake in the foundation (Kassas et al., 2021).

Soil dynamic conditions can be analyzed and finite element methods and finite element codes using Plaxis software by considering some assumptions. In dynamic analyzes by Plaxis, three important conditions for dynamic boundary conditions, elastic viscous boundaries, mesh-grade and spatial freedom degrees must be considered and met (Oka and Kimoto, 2012). Boundary conditions and the allocation of behavioral criteria are the most important part in modeling soil structures under dynamic conditions (Das and Ramana, 2010).

In order to achieve a correct modeling of the conditions governing the massif, in this study, most of the parameters considered in the dynamic analysis of granular soil (sands) are proposed and applied in the model (Ouria et al., 2020). Therefore, the model is prepared and implemented in four stages: geometric modeling of the mass, boundary conditions, assignment of properties and definition of behavioral models, and mechanical modeling under seismic conditions. Since the study of the behavior of strip foundations requires its analysis in terms of earthen plates, modeling approaches in two analytical sections related to transverse and longitudinal cross-section with the focus of the strip reinforced by concrete pedestals. Be. In order to conservatively analyze and have a suitable view for special conditions, the sandy soils involved in the foundation range are considered to be completely saturated.

Geometric modeling: Soils are widely used as materials in design and construction. In other words, it can be said that geotechnical structures are made and executed from soil, with soil and in soil. Therefore, the presence of soil is an inescapable possibility in all projects. On the other hand, due to the high seismicity of Iran, the occurrence of multiple earthquakes is considered quite natural. Therefore, there are favorable conditions for creating various crises such as liquefaction, divergence, sales, etc. in granular soils. In order to cover the problem and investigate in the most critical conditions possible, we tried to collect information about the collision and the importance of non-stick soils and based on statistical analysis and the normal distribution function on the data and normalize them the most important type of collision to be considered as the basis of geometric modeling in this study.

Border conditions and free borders: Oka and Kimoto (2012) proposed boundary conditions based on fixing the lateral boundaries of meshes and nodes for the ability to control and reduce the reflection of waves under seismic conditions and the return of seismic waves on the body of the mass. This reduces the amount of computational error under the time of the earthquake (which usually applies the maximum time range of vibration and vibration in the model). The process described for damping control presented by these researchers is very effective and is widely used in civil and soil-related works. This type of boundary condition is used in one-dimensional wave propagation analysis and is able to absorb propagated waves from internal sources (reflective waves as a result of dynamic loading, drilling and explosion). Also, the behavioral model used in this study is the Mohr–Coulomb model. This behavioral model based on failure under normal and shear stresses in two-dimensional and three-dimensional, makes it possible to analyze the rupture in both tensile and compressive (Tsegaye, 2010). Figs. 2 and 3 provide the information about the geometrical modeling with boundary conditions.

Material properties: In order to determine the behavioral properties and to determine the behavioral model for the model of material selection of the mass body, based on studies and in order to generalize the analysis, the range of sandy loam soils (C = 0) has been selected. Table 1 shows the input parameters of Plaxis software for assigning properties to the mass. Figs. 3 and 4 provide information about the materials properties in models.

Mechanical modeling: the prepared model was evaluated to introduce the deformation and displacement in the model.

Table 1. Input parameters for modeling

Materials	Parameter	Units	Value
Foundation	γ_{unsat}	kN/m^3	19.00
	γ_{sat}	kN/m^3	19.00
	E_{ref}	kN/m^3	10000000
	υ	-	0.2
	C_{ref}	kN/m^3	712
	φ	Degree	54.9
	ψ	Degree	0.00
Sand	γ_{unsat}	kN/m^3	20.00
	γ_{sat}	kN/m^3	18.00
	E_{ref}	kN/m^3	1000
	υ	-	0.3
	C_{ref}	kN/m^3	0.00
	φ	Degree	35
	ψ	Degree	0.00
Reinforcers	EA	kN/m	20000000
	EI	kNm^2/m	12000000
	D	m	120000
	W	kN/m/m	0.456
	υ	-	8.3
Dynamic loading	ML	Righter	3.3
	PGA	g	0.3
	Time	cm/sec	± 6

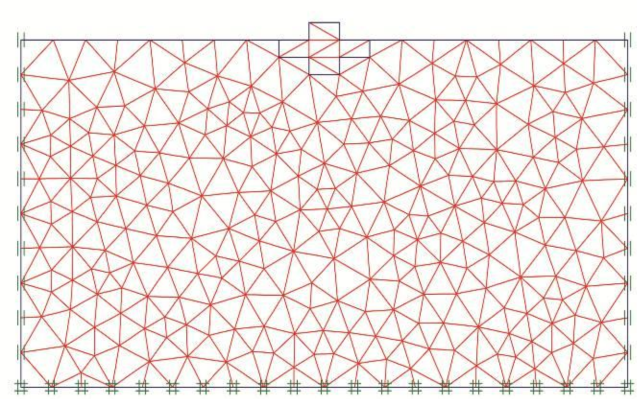

Figure 2. The provide cross-section geometrical model with boundary condition

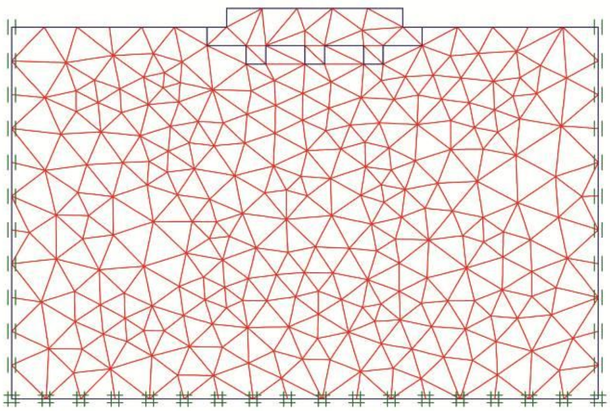

Figure 3. The provide main-section geometrical model with boundary condition

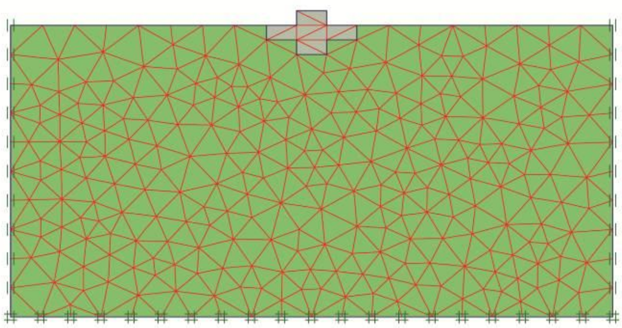

Figure 4. The cross-section material properties on prepared model

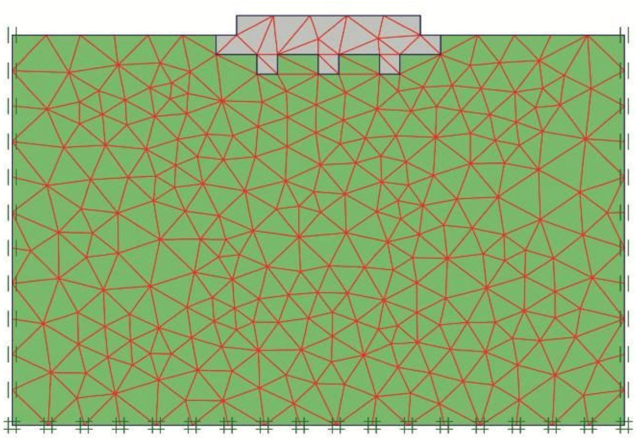

Figure 5. The main-section material properties on prepared model

3. Results and Discussions

In order to perform dynamic modeling in cross section, first the geometric model is drawn based on the cross section of the foundation which is armed by the lower pedestal. After drawing the geometric model, boundary conditions, property allocation and behavioral model for the mass are defined based on Table 1 and the model is solved under saturation under dynamic conditions. These results are as follows.

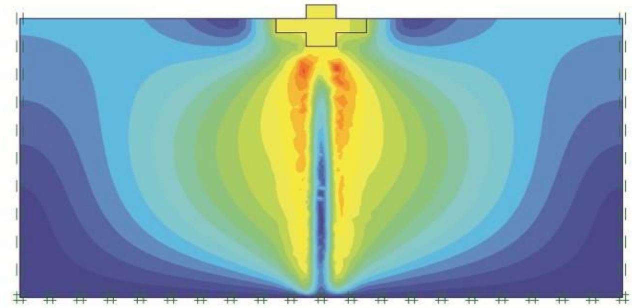

Figure 6. The cross-section's total displacement model

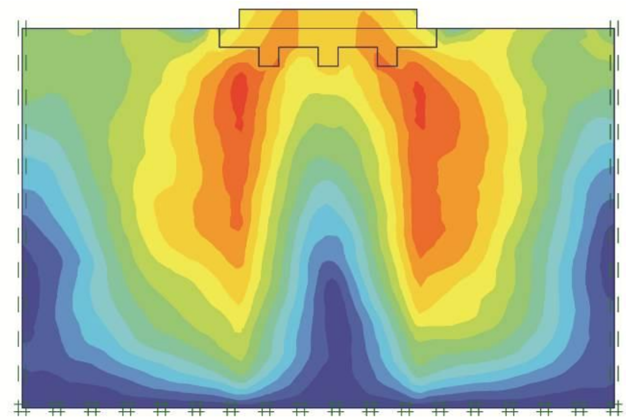

Figure 7. The main-section's total displacement model

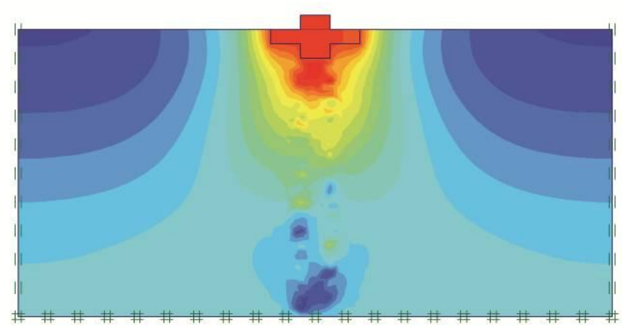

Figure 8. The cross-section's shear displacement model

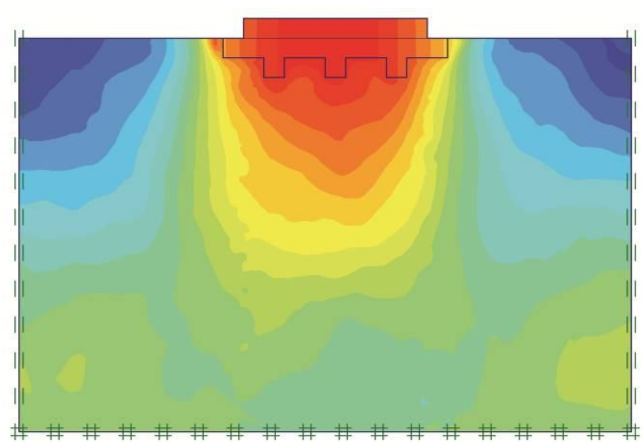

Figure 9. The main-section's shear displacement model

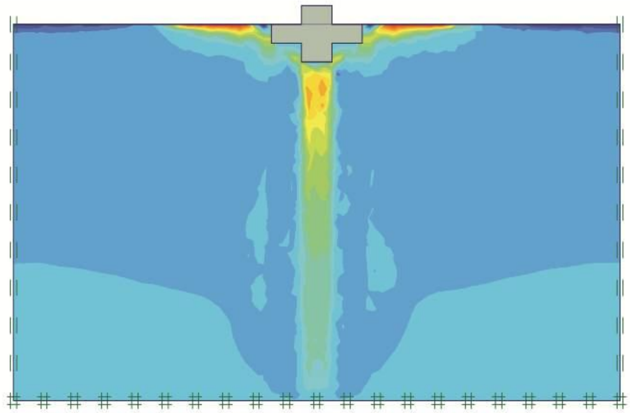

Figure 10. The cross-section’s shear stress model

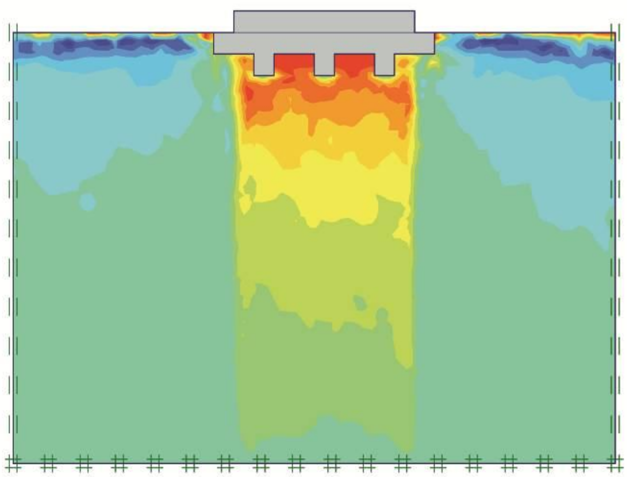

Figure 11. The main-section’s shear stress model

As mentioned, the modeling performed for the dynamic analysis of the strip foundation has been done as a two-stage analysis in two different sections of the foundation, with good validity. Observing the results of the above simulation, it can be stated that the implementation of such a pile on sands if the earthquake is more than 3.3 Richter on the scale of torque and the acceleration limit is 0.3 g occurs, rupture occurs in the foundation range. This rupture is local and will have the greatest impact on the cross section. Creative effect in longitudinal section due to the involvement of most pedestals is inhibited to a good extent and prevents the rupture of the foundation. Also, according to the displacement situation in both sections in the band foundation, it can be stated that the most probable rupture in the foundation is of the rotational type and the destruction of the foundation will be due to bending and creating longitudinal torque in it. This situation is shown in Figs.12 and 13.

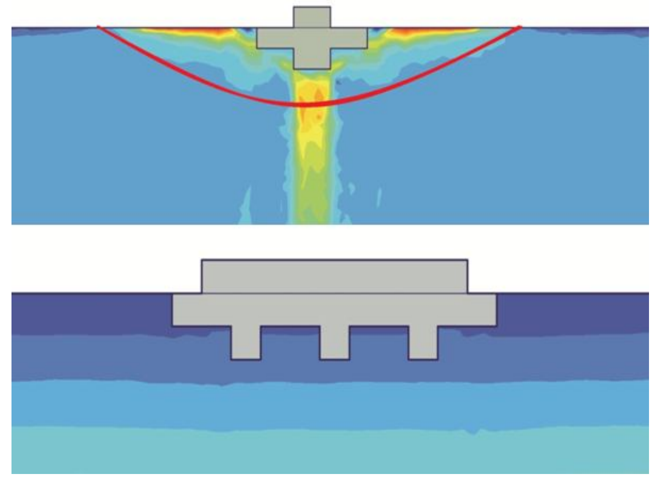

Figure 12. Dynamic failure status in strip foundation

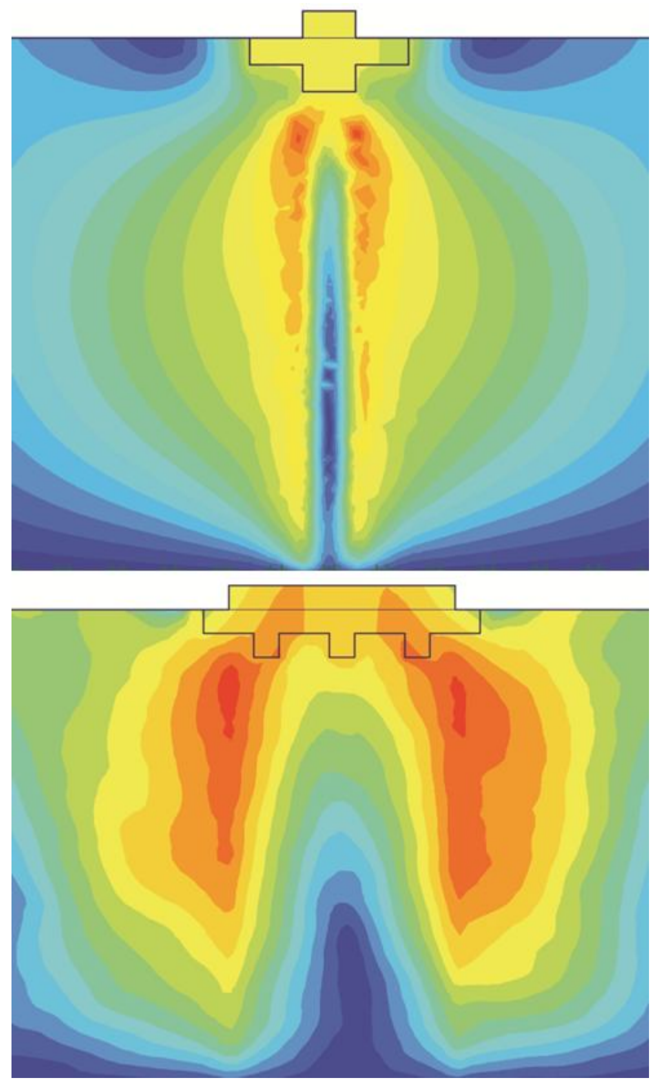

Figure 13. The nature of the failure in a strip foundation

4. Conclusion

The results of this research can be categorized and expressed as follows:

A) In Iran, due to the high seismic hazards, the use of dynamic analysis in foundation engineering designs minimizes the risks of structural rupture and foundation construction under earthquake conditions.

B) Non-cohesion sands or soils due to the inability of the soil to create intergranular adhesion under constant saturation conditions and the presence of dynamic load with reduced resistance and, if susceptible, phenomena such as liquefaction, sales, It benefits from shedding, popping, boiling, etc.

C) Stress-strain behavior of sands against axial loading varies depending on its density and specific gravity. Soils that have a consolidated history and are denser have a more pronounced behavior curve and a measurable yield point and break point than loose ones.

D) Loose saturated sands show very high plastic behavior under lower dynamic and compressive loads. One of the most important behavioral responses to such conditions is the phenomenon of soil mass creep.

E) Plaxis software, due to its high advantages in the analysis of granular soils, has a suitable response for under dynamic conditions and loading of different types of foundations.

F) Observing the results of the above simulation, it can be stated that the implementation of such a pile on the sand in the event of an earthquake greater than 3.3 Richter on the scale of torque and maximum acceleration g If 0.3 occurs, a rupture occurs in the foundation range. This rupture is local and will have the greatest impact on the cross section.

G) According to the modeling, the effect created in the longitudinal section due to the greater involvement of the pedestals is restrained to some extent and prevents the rupture of the foundation.

H) Considering the displacement situation that occurred in both sections in the band foundation area, it can be stated that the most probable rupture event in the foundation area is of the rotational type and the foundation destruction will be due to bending and creating longitudinal torque in it.

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