

Study of Effective Factors in the Seismic Isolation of Foundation Using the Sand

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Abstract – In order to construct buildings resistant against earthquake in seismic area, the use of dampers is necessary to reduce the damaging effects of earthquakes on structures by decreasing shear force applied to the foot of the column, rotation, subsidence and horizontal motions of the foundation and structure. In this research, it is tried to evaluate the rotation, subsidence and horizontal motions of the foundation by putting a layer of soft sand under the singular foundation of a part of a six-storey building and by performing El Center Accelerogram and the rate of effect of soft layer on reducing the effect of shear force of columns foot and compare and study this case with the corresponding values without the presence of sand. Also the effects of changes of parameters such as shear modulus and internal friction angle of the soil and shear modulus, thickness and angle of internal friction of sand were investigated. The results show that the use of soft sand reduces the considerable amount of shear force applied to the foot of the columns and the structure relative displacement to foundation. Due to creating the possibility of slipping between foundation and the bed, the values of relative displacements and rotation between the bed and foundation are increased comparing to values of relative displacements and rotation without the presence of sand.

Keywords – Dampers, Seismic Isolation, Relocation of Buildings, Reducing the Rotation.

I. INTRODUCTION

Since our country located in seismic area and the main faults are superficial and the depth of earthquakes are less than 10 kilometers, this reason has caused the less intensive earthquakes have higher destructive effects to deep faults with high intensity are largeness. Certainly finding ways to reduce the harmful effects of earthquakes is important. Thus, providing simpler methods, more practical and less costly to reduce the harmful effects can be interesting and useful. In the researches done, mainly two different methods have been proposed to counter the force of the earthquake in structures. First, providing enough stiffness against seismic force that at present this method is used, and its realization relates to the designing resistant structure and needs to spend more costs and consume more materials. Second, we can dissipate the seismic energy by providing more flexibility in foundations by creating to the energy dissipation systems such as viscoelastic systems (elastomers). These systems, due to their complexity, the need for maintenance, and high costs are not generally applicable, although there are different models and structures have been designed with these systems. But for common construction systems, due

to the problems of these systems, they are not commonly used and using this type of slip dissipation is very low in sub-structures.

In this research, the probability of using sand to separate the structure from the earth, and also the effect of using sand on the rate of displacements and rotations of foundations, reducing the shear forces acting on foot of columns, and tensions acting on soil have been studied. Structures, foundations, sand and soil layers of the bed have been modeled as three-dimensional platform using FLAC3D software [1], and are shown in Fig.1.

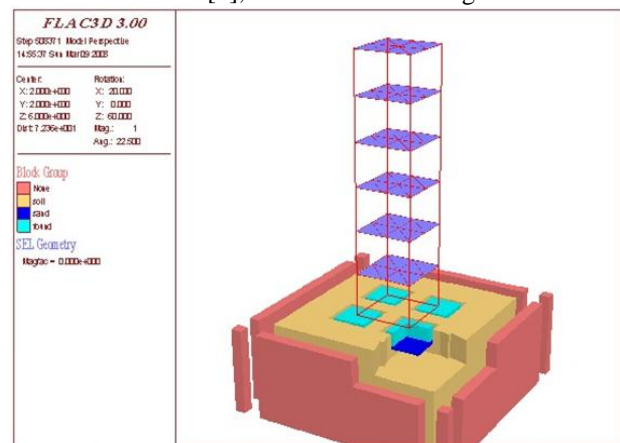


Fig.1. Three-dimensional model of structure, foundation, soil-sand and quiet and free field boundaries

In this software the probability of recording the history of the various functions, such as displacement, velocity and tensions and forces in different regions is available. So, the probability of investigating the equilibrium of the structure, foundation, and soil-structure interaction is possible at any moment.

Advantages of the system used in this study are the simplicity, low cost and applicability that also can generally be used. In addition, this system is not active in low velocities, and acts as a fuse when velocity is more than a limit; and in active mode, creating the possibility of slipping between foundation and its underlying bed causes relative separating of the structure from the bed.

II. FORMATION OF THE SEPARATION THEORY

The thought of seismic separation or separation and protection of buildings from seismic ground motions is not very new, but it is a history about 100 years. But its practicality requires a lot of researches that have been possible in the light of numerical methods for computer

analysis. Thus, it is not surprising that until recently only a few buildings have been built based on this theory.

In 1986 to make resistant the buildings against earthquake, Kelly proposed the use of talc layers (gypsum) to separate the floors of earthquake motions [2]. Tokyo Imperial Hotel is a notable and important structure in the history of separation the structure from the ground that was built in 1921 by Frank Lloyd Wright. The hotel building was built on a thin layer of hard soil that is located on an underlying layer of sludge. This hotel passed successfully the Tokyo earthquake of 1923. Later, Wright, in his autobiography (1977), writes that 60 to 70 feet of sludge in underlying and 8 feet surface hardened soil kept building.

Another example of the proper functioning of structures against earthquake is in Long Beach earthquake in 1923, which some naked brick houses were only slightly damaged due to slipping on the beams grid of floor level. The same thing also happened in Tangshan earthquake in 1976 and a brick building remained undamaged because of its slipping on the foundation. It should be mentioned that this slipping was unintentionally due to insufficiency of the joints of the structure and foundation.

III. CONSIDERATIONS IN DYNAMIC SIMULATION

When modeling in Flac3D, in order to dynamically analyze the properties of dynamic load and meshing limits, the type and size of element, the rate of damping, and the type of dampers and how they are considered in bed of foundation-structure, and the necessity of transmit of waves through the studied limit should be considered.

In order to remove the reflection of waves in the boundaries of models, using conditions of free field boundary boundaries or quiet boundary is recommended. In the bottom (bedrock) boundaries can be considered flexible or rigid depending on the place of construction. Dynamic loading in Flac3D can be considered as: Acceleration history, velocity history, tension history or pressure, and force history or performed as dynamic input information in the directions x, y and z, or normal and shear boundary model directions.

One limitation when using loading as acceleration history is the impossibility of acting the quiet boundary conditions (viscous) on the boundaries. Therefore, in order to apply the seismic motions in a viscous boundary, the tension loading is performed. Recording the velocity according to equations (1) and (2) become a record of tension and is applied to the quiet boundary, and a wave velocity becomes the performed tension as follows:

$$\sigma_n = 2(\rho C_p) v_n \quad (1)$$

$$\sigma_s = 2(\rho C_s) v_s \quad (2)$$

Where σ_n is the applied vertical tension, σ_s is the applied shear tension, ρ is density, C_p is the velocity of propagation of P wave in environment, C_s is the velocity of propagation of S wave in environment, and V_n is the vertical component of velocity, and V_s tangential

component of velocity. Values of C_p and C_s are calculated from the following equations:

$$C_p = \sqrt{\frac{k + 4G/3}{\rho}} \quad (3)$$

$$C_s = \sqrt{\frac{G}{\rho}} \quad (4)$$

Quiet boundary is suitable to model the environmental soil mechanic problems for analyzing the unlimited space. Although, in static analysis, the elastic or fixed boundaries can actually be located at a distance from the intended area (by presenting the boundary element method). But in dynamic problems, using quiet boundary in the border causes to reflect the propagated waves outward the model, and does not allow the enough radiation of energy inward the model.

Because the damping of material absorbs more energy from reflected wave, using the large model can minimize this problem. But this solution causes to increase the volume of calculations. Thus, the alternative solution is to use the quiet boundaries.

Viscous boundaries that were created by Lysmer and Kuhlemeyer [3] in 1969 are used in Flac3D. It is based on using the independent dampers in normal and tangential directions of the model boundaries. This method is almost completely effective in absorption of volumic waves which hit the boundary with angle of higher the 30 degrees. For waves with hitting angle of less than 30 degrees, or surface waves, energy absorption is done incompletely. But, this system has this advantage that it is not a function of time and its impact on finite element modeling and finite differences has proved. When dynamic source is embedded within the model using quiet borders is the best option if the source is performed as a boundary condition toward up or down, in this case the free field boundary is recommended.

A numerical analysis of the vibrating surface structures such as dams, requiring isolation from the region of a material near the foundation. Information on vibration is usually entered as propagation of shield waves upward through the field located in lower parts. Boundary conditions on the sides of the model should be applied and performed for states of free field boundaries in the absence of adjacent structures of the model. The boundaries should be located at focal distance to minimize wave reflection and become similar to state of free field.

However, for soils with high damping, this can be achieved in relatively little distance [4] but, if the damping is low. To reach this distance may be impossible, the only alternative is to use free field boundary, and it should be placed at a distance that boundaries protect their non-reflective property, and the waves shed from the structure outward are absorbed appropriately.

Natural dynamical systems have some degree of inner vibration energy dissipation that are due to internal friction between particles and the possibility of common landslides. In FLAC3D, we can dynamically analyze both quasi-static and dynamic methods by considering the damping in both methods. But static method requires more damping to achieve faster convergence in the equations. In

dynamic analysis, damping simulated by numerical method should be in the size and shape that natural systems energy is reduced when influenced by the dynamic force. In rock and soil, natural damping is largely hysteric and frequency independent [5].

Cundall [1] believes that at least due to two reasons, hysteric damping is problematic. Firstly, many of the simple hysteresis functions cannot amortize all components equally when many waveforms are combined. Secondly, the hysteresis functions result in path dependence that makes interpretation difficult. However, if in a model, structure of natural materials includes adequate hysteresis behavior, it will not require any additional damping and models available in dynamic hysteresis program of FLAC3D is adequate.

In programs with the ability of time analysis, Rayleigh damping is used to provide damping which is almost in the range of frequencies independent of frequency. However, Rayleigh damping has two viscous sectors in which the absorbed energy is frequency-dependent. Frequency-dependent effects are adjusted so that die away at the desired frequencies. These two components, one is mass-dependent and other is stiffness-dependent that FLAC3D allows the user to use each of the components alone or in combination. In the low frequencies, component is mass-dependent and a high frequencies, component is stiffness-dependent. Rayleigh damping at principle, is used in elastic media analysis for the natural oscillation damping system. The second type of damping is local damping which is considered in the context of static analysis in FLAC3D; this damping may be used dynamically. Local damping is as an approximate way to consider hysterical damping in dynamic issues.

But when waveform complexity increases, in other words, when the number of components of frequency

increases, this damping increasingly causes the unrealistic results. The third form of damping is called artificial viscosity and is presented in FLAC3D; in this form of damping, damping functions and strain-dependent shear modulus are directly used together in the simulation. This issue causes a direct correspondence between equivalent linear method and complete nonlinear method be done without matching in selection of structural models.

IV. MODEL SPECIFICATIONS AND MATERIALS USED IN THIS STUDY

Since the mass and its place and also structural stiffness, forces and the type of section of columns have an important role in dynamic analysis, in order to conduct this research a 6-story building with 3 meters height for each storey, 4 meters distance for columns with 4 singular 2x2 foundations and depth of 1 meter with column section was considered to take into account the geometric asymmetry effect and study the effect of sand layer on the foundation and structure rotations with the weight of different stories.

Also, the types of columns materials, concrete and ceilings as concrete slab with different thicknesses were considered in order to not be uniform the mass distribution in height. Since the height of the model to its width is more than 4, and certainly the tensions under foundation will be elastic, so the results of this part of the research is not an applied result and is not discussed. For the foundation and the soil, hysteric damping with Rayleigh damping of 5 % and for the structural part, local damping was considered. Physical characteristics of soil, foundation, and sand have been presented in table (1).

Table 1: Characteristics of soil and sand

Materials	ρ (N/m ³)	K (N/m ³)	C (N/m ²)	ϕ (deg.)	δ (deg.)	E (N/m ²)	ν	G (N/m ²)
Soil	1900	2.4e7	22000	31	-	21e6	0.35	8e6
Sand	1600	1.4e7	-	13	1	13.4e6	0.34	5e6

To analyze the problem, first the model static analysis was performed under static loads, and after determination of the amount of deformations and tensions in dynamic analysis phase, the provided load was applied as acceleration history of the El Centro earthquake.

In order to downsize to the model and absorb the reflection under conditions of the dynamic loading, quiet boundary and free field boundary was used; and to study the soil-structure interaction until the end of the seismic motion and even after that, the time of analysis was increased up to 20 seconds.

By applying only hysteric damping, it was observed that the waves are not damped even after 50 seconds, and vibration continues with constant amplitude. Therefore, about 5% of Rayleigh damping was applied for soil. The values of its parameters were considered based on interval time of soil and rate of damping. This model of damping is soil-dependant, and determination of frequency parameter

should be done precisely in order to be created the necessary damping. The reason for more increasing of analysis time was the use of damping component of stiffness that by considering only 10% of the damping for observed mass damping component, the amplitude of vibrations was reduced, and after 17 seconds the model stopped moving. This time was increased to 20 seconds to study soil-structure interaction until the end of the earthquake.

V. PRESENTATION OF DYNAMIC RESULTS

Since the height of the model to its width is more than 4, the foundations are mainly influenced by elastic tensions, thus the shear and pressure tensions under these foundations are not problematic, and the results of the values of foot of columns, relative displacement of the last storey to foundation and its bed as well as relative

rotations, average subsidence of the foundation due to axial compressive force of the columns in two states of presence of sand and without the presence of sand under the foundation have been studied.

Results show that shear force of foot of column, horizontal displacement, subsidence of foundation and column axial forces decrease, but the range of the horizontal displacement of rotation of the foundation increases, and the reason of decreasing horizontal displacements is the friction between the foundation surface and the sand, and the reason of decreasing the subsidence is the swelling of the sand.

Thus, by reduction of shear force of foot of column and axial force, the foundation bearing capacity against dynamic loads can also be increased.

Also, in table 2 the maximum relative displacement of the last stage (storey) to bed and foundation as well as

relative displacement of foundation to bed at two cases of using sand and without sand have been presented. As can be seen, in the case of without using sand, relative displacement between bed and foundation does not occur, and as a result, the displacement of last stage to the foundation and bed is the same. In the case of using sand, the relative displacement between bed and foundation occurs. Its maximum displacement is about 11 centimeters, but after ending the seismic motion, this amount is about 8 centimeters. Relative displacement of the construction last stage to foundation is as interval, and becomes zero after ending the vibration. Relative displacement of the last stage to bed is the sum of these two displacements.

The maximum relative displacement of the last stage to foundation with sand is 7.5 cm and without sand is 15 cm, that is, two times.

Table 2: The maximum relative displacement of the last stage to foundation and bed, and the values of residual of rotating and displacement after the end of loading

Rotation after loading (Rad)		Rotation (Rad)		Foundation relative to stage (cm)		Relative to stage (cm)		Relative to foundation (cm)	
With Sand	Without Sand	With Sand	Without Sand	With Sand	Without Sand	With Sand	Without Sand	With Sand	Without Sand
-0.003	0	+0.002	+0.0001	7.5	0	17.5	15	7.5	15
		-0.003	-0.0015						

It was also observed that the rotation range of the foundation with sand is between -0.003 to -0.002 radian that after the end of vibration remain as -0.0003 radian. In the case of without sand, this domain ranges between -0.0015 and $+0.001$ which is half the amount when sand is present. After the end of vibration, the rotation of foundation without sand equals to the value before vibration, while the rotation of foundation with sand differs from initial value. The results of the response spectrum showed that using sand does not make any change in the range of response acceleration. With an increase in friction angle of the sand layer, the relative displacement between the foundation and the bed is reduced (Fig. 2).

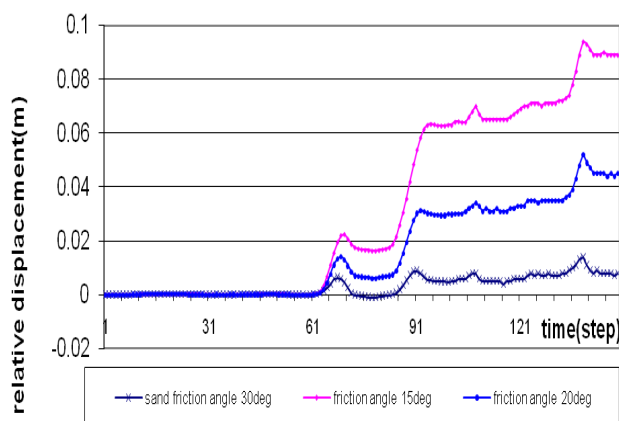


Fig.2. Relative horizontal displacement between foundation and sand layer for different sand friction angle

In addition, it was shown that with an increase in friction angle of the sand layer, the rotation of foundation increases. Furthermore, it was depicted that with an increase in friction angle of the sand layer, the absorption capability of shear force of foot of column increases. In Fig. 3, It is demonstrated that with an increase in friction angle of the sand layer, the shear force of foot of column increases.

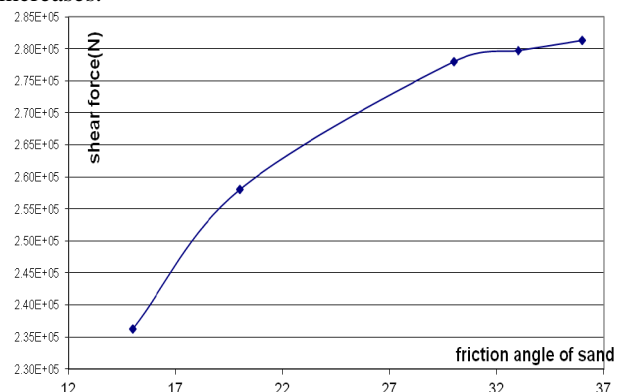


Fig.3. Shear force of a column for different friction angle of sand layer.

In another results, it was shown that with increasing thickness of the sand layer, subsidence of foundation is reduced. In addition, it was demonstrated that with increasing the thickness of the sand layer, the rotation of foundation is reduced. In Fig. 4, it is depicted that with increasing the thickness of the sand layer, the shear force increases. For thicknesses over 38 cm , the shear force of foot of column more increases.

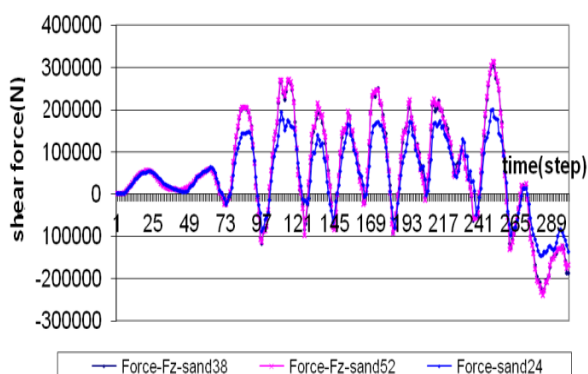


Fig.4. shear force for different thickness of of sand layer

The results show the effect of increasing thickness and angle of sand on the shear force of foot of column. With an increase in friction angle and thickness of the sand layer, shear force increases. For thicknesses more than 38 cm shear force does not increase. Fig. 5 also demonstrate that with increase in thickness and friction angle of the sand layer, the rotation of foundation increases.

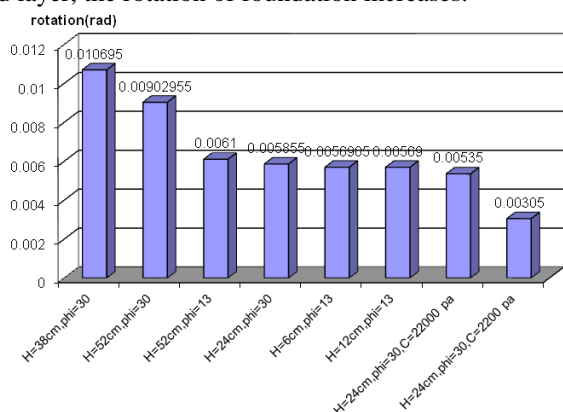


Fig.5. Foundation rotation for different thickness and friction angle of sand layer

According to our data, we showed that with increase in thickness of the sand layer, the normal tension under the foundation increases. In addition, it was demonstrated that with the increase in shear modulus and shear modulus of sand, the subsidence of the foundation increases; and for high rate shear modulus, the increase will not change. Fig. 6 depicts that with the increase in shear modulus of sand layer, the rotation of the foundation decreases.

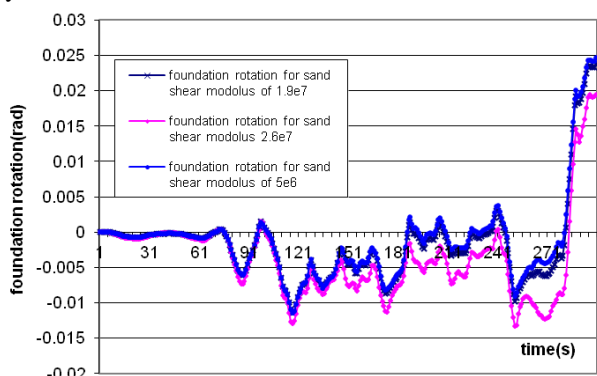


Fig.6. foundation rotation for different sand shear modulus

It was demonstrated that with an increase in friction angle of soil, the subsidence of the foundation decreases. In addition, it was shown that with an increase in friction angle of the soil, the rotation of the foundation decreases. It was also observed that with an increase in friction angle of the soil, shear force of foot of column increases. Fig.7 shows that with an increase in friction angle of soil under foundation, the distribution of normal tension becomes more uniform.

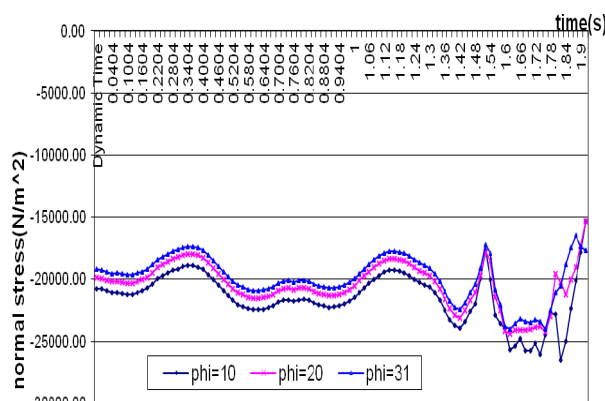


Fig.7. Normal stress for different friction angle of soil

With an increase in friction angle of the soil under foundation, shear force of foot of columns increases. Thus, by an increase in friction angle of sand layer under foundation, relative displacement between foundation and bed decreases. the scope and the rate of rotation of the foundation increases and shear force of foot of column and its domain increases.

Also, with an increase in sand thickness, the rate of subsidence of foundation decreases, and the rotation of foundation is reduced. Shear force increases, and the rate of normal tension and its domain increases.

With an increase in shear modulus of sand, foundation subsidence decreases and from a value onwards, with increase in the shear modulus, any change does not occur in the rate of subsidence and rotation of foundation. With an increase in the soil internal friction angle, the rate of subsidence and rotation of the foundation as well as the shear force of foot of columns and distribution of normal tension under the foundation increases (Fig. 8).

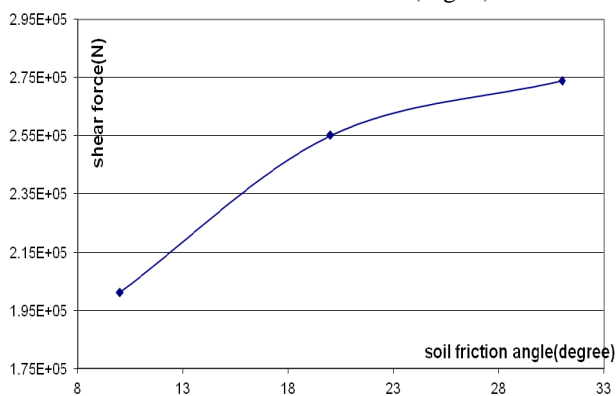


Fig.8. Shear force of column for different friction angle of soil

In addition, with an increase in shear modulus of the soil, shear force of foot of column increases, and the rate of subsidence of the foundation decreases; and with a decrease in shear modulus of the soil, the range of rotation of foundation and domain of vertical subsidence of foundation increases.

VI. CONCLUSIONS

By selecting a layer of fine sand (fly sand) with a thickness of about 10 cm, a significant decrease of about 50% in rate of shear force exerted on the building can be created. According to the maximum horizontal displacement as well as persistent relative horizontal displacement between the ground and the foundation, considering a rate of one percent height as an interruption seam unto edge of the ground limit, this kind of separating system is recommended, and in case of observing code 2800 for crossing seams, any problem does not occur.

Using sand causes to increase the rotation of foundation and decrease the subsidence of it. Also due to reduction of lateral force and reduction of anchor applied to the building, designing the columns will be more economical. With increasing the actual friction angle of the soil, the rate of subsidence decreases, with increasing friction angle of sand under the foundation, the relative displacement between foundation and soil decreases, with increasing sand layer thickness, shear force of foot of the columns increases; and increasing the shear modulus of sand will increase shear force of foot of the columns. And with increasing the shear modulus of soil, the rate of the foundation subsidence decreases.

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