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Effect of Piles Installed Beneath a Building on the Horizontal Component of the Seismic Load Acting on the Structure

Keywords
Earthquake, layer, vibration, seismic, wave, acceleration, accelerogram, experiment, graph, soil, seismic stiffness, intensity.

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Abstract
Considering the influence of soil conditions on the intensity of seismic effects, it can be observed that the damage sustained bybuildings varies significantly depending on the groundconditions. This study investigates the influence of pilesinstalled beneath a building on the horizontal component of theseismic load acting on the structure. Furthermore, the variationof seismic effect with depth is examined.

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INTRODUCTION

It is well known that the horizontal component of the seismic force acting on a building during an earthquake depends on the category of the soil layers at the construction site, their sequence of occurrence, and, consequently, the overall ground conditions. Analyses of the consequences of past earthquakes indicate that, even under earthquakes of the same intensity, the extent of damage to buildings differs considerably depending on the soil conditions. The results demonstrate that identical structures constructed on different soil conditions within the same area may experience different levels of damage. For example, following the December 7, 1974, Tonankai (Japan) earthquake, the percentage of damage observed in timber structures located at equal distances from the epicenter was reported as follows: 26.1% on water-saturated clay soils, 3.5% on sandy soils, and only 0.2% on rock foundations.

The influence of soil conditions on earthquake intensity can be attributed to two principal factors. The first is the dynamic characteristics of the upper soil layer overlying the bedrock. The second is the degradation of the soil during seismic vibration, which results in a reduction of its load-bearing capacity.

Under the action of seismic waves, the vibration of the bedrock generates oscillatory motions in the overlying soil layers with different dynamic characteristics, depending on their dynamic stiffness. It is well established that seismic waves propagate through hard bedrock at greater velocities and with relatively small amplitudes. However, when these waves enter soft and weak near-surface sedimentary deposits, such as clay, sand, and silty soils, their propagation velocity decreases significantly. As the kinetic energy associated with wave velocity decreases, part of this energy is transformed into potential energy, resulting in an increase in the vibration amplitude and, consequently, in the intensity of ground motion.

When the thickness of the upper soil layer is sufficiently large and its natural vibration characteristics coincide with those of the exciting force (i.e., the vibration of the underlying bedrock), resonance occurs. Under resonance conditions, the vibration amplitude of the upper soil layer becomes considerably greater than that of the underlying bedrock (the first layer). The amplification of ground motion in the upper soil layer relative to the deeper layers has been confirmed by both theoretical analyses and experimental investigations.

Figure 1 illustrates the acceleration response of seismic waves propagating through an eight-layer soil profile composed of different soil types, where the first (lowest) layer consists of rock. The acceleration in the bedrock layer is taken as 100 cm/s² (Gal).

Figure 2(b) presents the accelerogram of ground motion in the same eight-layer soil profile, originally proposed by H. Kobayashi, in which the first layer is rock. The vibration was generated artificially within the rock layer. This accelerogram corresponds to the El Centro (USA) earthquake accelerogram, scaled to a maximum acceleration of 100 Gal.

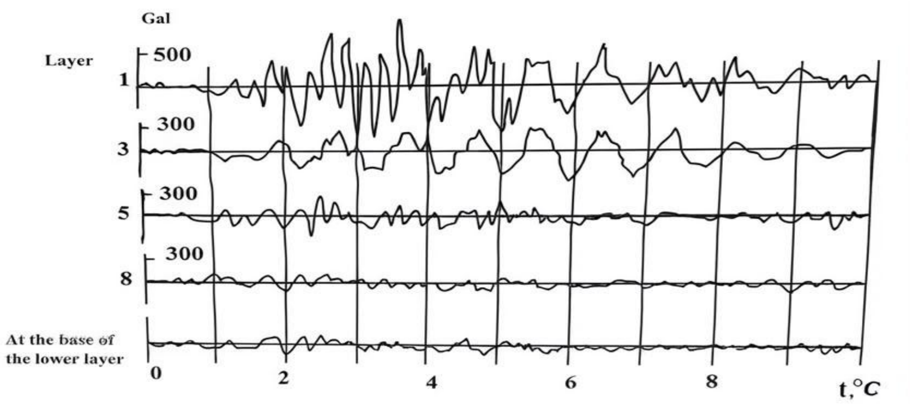

Figure.1

The acceleration of the input motion was specified as 100 cm/s² (100 Gal). Figure 1 presents the theoretically derived accelerogram of ground motion in an eight-layer soil profile, where the first (lowest) layer consists of bedrock, as proposed by H. Kobayashi. The seismic motion was generated artificially within the bedrock layer. The input accelerogram was selected to correspond to that of the El Centro (USA) earthquake, with the maximum acceleration scaled to 100 Gal.Under these conditions, the acceleration at the ground surface reached approximately 1000 Gal. This significant amplification is primarily attributed to the dynamic characteristics of the overlying soil layers. A similar experimental study was conducted in Japan. For this purpose, a 37 m-deep borehole was drilled, and acceleration records were obtained simultaneously at the bottom of the borehole and at the ground surface while the ground motion was generated artificially. The intensity of the induced vibration was relatively low. Figure 2 presents the accelerograms recorded during the experiment.

As can be observed from the recorded data, the acceleration measured at the ground surface is considerably greater than that recorded at the bottom of the borehole, demonstrating the amplification of seismic motion within the overlying soil layers.

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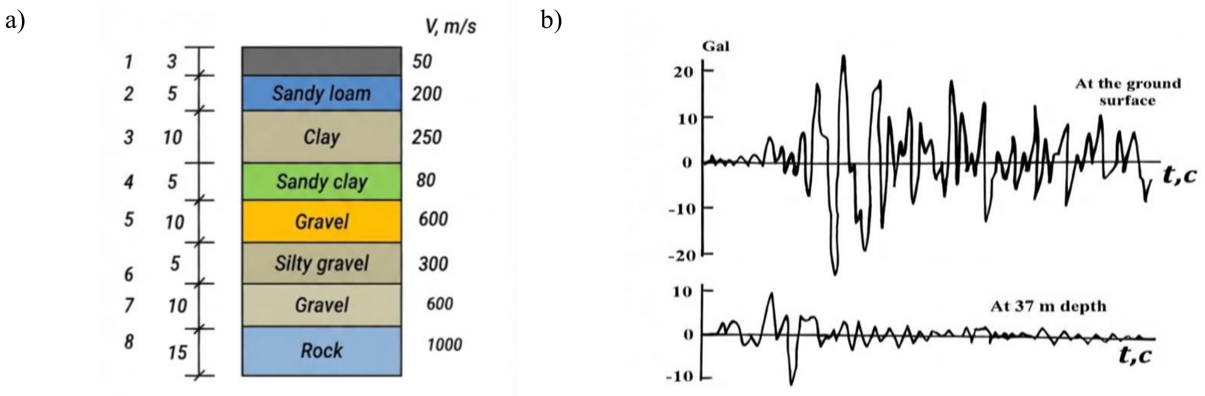

Figure.2

The recorded accelerograms indicate that the acceleration measured at the ground surface is significantly greater than that recorded at the bottom of the borehole. This observation demonstrates the amplification of seismic ground motion within the overlying soil layers. It can be concluded that a dense underlying soil or rock layer amplifies the intensity of ground vibrations in the weaker soil layers above it. Owing to this phenomenon, soils are classified into different categories according to their seismic characteristics. Based on the analysis of earthquake damage and recorded seismic responses, the increase in seismic intensity as a function of soil category, denoted by ΔJ , has been established.

$$\Delta J = 1{,}67 \cdot [lg(v_0 \cdot \rho_0) - lg(v_n \cdot \rho_n)]$$

Where (v0 and vn) denote the propagation velocities of seismic waves in granite (the reference soil) and in the soil under consideration, respectively, andρ0 and ρn represent the densities of granite and the soil under consideration, respectively. If several soil layers with (different values of ϑi·ρi) overlie the bedrock, the average seismic stiffness within the upper 10 m of the soil profile is determined as follows:

$$(v_n \cdot \rho_n)_{average} = \sum_{i=1}^{n} v_i \cdot \rho_i \cdot H_i / \sum_{i=1}^{n} H_i$$

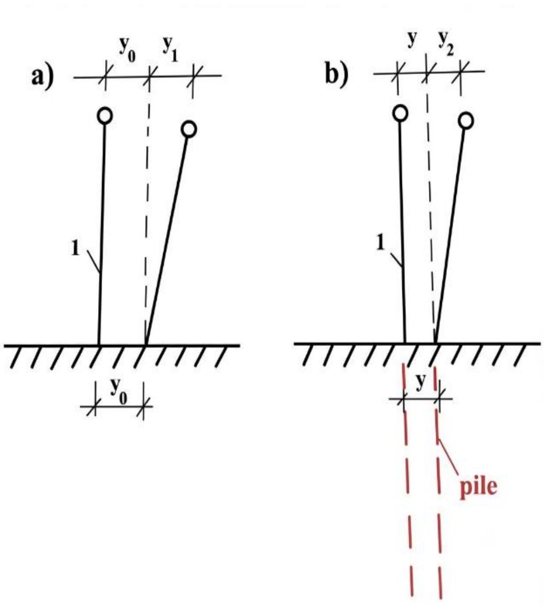

Figure.3

Considering the above discussion, it can be concluded that, during an earthquake, the displacement of the ground surface varies depending on the category of the surface soil. The intensity of the seismic load acting on a structure

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depends on the magnitude of the ground displacement experienced at the building foundation. The smaller the ground displacement, the lower the seismic intensity acting on the structure.

One of the most effective methods for reducing foundation displacement is the use of piles installed beneath the building. If the horizontal displacements of identical buildings founded on the same soil conditions are compared during an earthquake, it can be observed that the displacement of a building without piles is considerably greater than that of a similar building supported by piles (see Figure 3(a, b)).

As illustrated in Figure 3,y0>y and y1>y2

y0 – is the horizontal displacement of the building foundation caused by ground motion in the case of a building without piles.

y – is the horizontal displacement of the building foundation caused by ground motion in the case of a building supported by piles.

y1- is the additional displacement of the building without piles resulting from the inertial forces generated by the foundation displacement.

y2- is the additional displacement of the piled building resulting from the inertial forces generated by the foundation displacement.

This phenomenon can be explained as follows:

During an earthquake, a pile cannot undergo a rigid-body translation while remaining parallel to its initial position, because the displacement at the pile head is considerably greater than that at the pile toe. As the building tends to move together with the surface soil, it exerts an upward pulling force on the piles, tending to extract them from the surrounding soil. A considerable portion of the seismic energy is dissipated in overcoming the pile–soil interaction, resulting in a reduction of the building displacement.It should also be noted that, during ground motion, the piles are subjected not only to axial pull-out forces but also to bending. As the stiffness of the piles increases, the horizontal displacement of the structure decreases. However, in the present study, the influence of pile stiffness on the structural displacement has not been taken into account.

The inertial force developed in the building for both cases can be expressed as follows.

For the case of a building without piles:

$$m\cdot y0''+y1''=S0$$

For the case of a building supported by piles:

$$m\cdot y''+y2''=S$$

whereS0 and S are the inertial forces acting on the structure.

Since **m·y0">m·y"**

it follows that **m·y1">m·y2"**

where:

m·y0" - represents the displacement y1 generated in the structure by the inertial force,

m·y" - is greater than the displacement y2 generated in the structure by the inertial force.

Therefore, it can be concluded that the magnitude of the seismic load acting on the structure is reduced. Consequently, piles installed beneath a building reduce the magnitude of the horizontal component of the earthquake load acting on the structure.

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