Effect of Soil Structure Interaction on Pile and Raft Foundations in Liquefied Soil

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Abstract - *Designing of foundation of any structure is the most crucial part for any structure engineer as the whole stability of the building depends on that judgment. As the foundation is always hidden from our plain sight thus we cannot know what is happening below the ground level. Several parameters affects the stability of foundation ranges from settlement, filled up soil, ground water table, type of soil, etc. One thing is also crucial for foundation is the seismic affect on soil such as Liquefaction and Laterally spreading of Soil. Thus it encourages the Structural Engineers and Professors and Researchers to study and understand this phenomenon and thus it introduces the concept of Soil-Structure-Interaction. The SSI (Soil Structure Interaction) is the phenomena about the physical interaction of Soil Particles with the part of structure (majorly foundation) to attain an equilibrium condition. During the earthquake the soil with high water table and less bearing capacity tend to behave like a liquid which is called as liquefaction and thus the need of Soil Structure Interaction is necessary to analyze and design the foundation with the liquefaction effect in mind.*

Key Words: Soil Structure Interaction, Pile Foundation, Raft Foundation, Liquefied Soil, Laterally Spreaded, Soil Seismic Effect, Soil Properties

1. INTRODUCTION

There are many countries with various geographical features and topography and always prone to different type of natural calamities ranging from cyclone, tsunami, avalanches and most importantly earthquake. Every year a large number of people die and cost a huge loss in economy, but the reason of the destruction is mostly improper structures of buildings. People invest a lot of money in construction but mostly don't care to design buildings from proper structural engineers which results in loss of human and capital at times of seismic activities. Its hoax that the beams and columns are mainly important but in reality the load is transferred from slab to beam to columns and lastly to foundations which distributes the load to the soil. Thus we can say that foundation is the crucial part of any structure built on the surface of earth to withstand extra load at times of any seismic activity.

But at places where the soil bearing capacity is low and water level is high, at that places we need good judgments to design the footings as normal isolated or combine footings don't help so in these times thus we have to design either by pile foundation or raft foundation by keeping a close view of the condition of the site. As the soil structure interaction of these footings are very important to withstand the forces of the structure and withstanding at those time when the soil behaves as a liquid or popularly known as liquefied soil.

The foundation of a structure is the part of the structure which transforms the load on the soil on which it rests. It forms a very important part of the structure. The ground surface in contact with the lower surface of the foundation is called the base of the foundation. The ground on which the foundation rests is called the sub grade or foundation soil. A foundation should be designed to safely transmit the load of the structure on to sufficient area of the soil so that the stresses induced in the soil are within the safe limit. If a soil is overstressed, it may lead to a shear failure resulting in the sliding of the soil along a plane of rupture and thus result in the collapse of the structure. It is the need to bring about uniform settlements which should be within the tolerance limits of the superstructure.

Due to load of the structure of the soil below is compressed. The settlement of the soil depends on various factors like the intensity of the loading, the quality of soil, depth below the surface level and presence of level of water table. It is very necessary that the settlement of the various components of a structure should be same to prevent serious secondary stresses. To ensure uniform settlement it is necessary that the foundation area is so provided the intensity of soil reaction is the same under all the footings of structure.

A foundation should be designed such that there is no possibility of titling of the structure. If the foundation area of the structure is such that the centre of gravity of the loads does not coincide with the centre of gravity of the foundation area the consequent bearing reaction will be non-uniform. At the edge closer to the centre of gravity of the loads the pressure intensity will be higher resulting in a greater settlement of the soil at this edge. This will result in the titling of the structure in this direction. Hence, it is better to design the foundation area such that the centre of gravity of the loads will coincide with the centre of gravity of the foundation area so that the soil reaction will be of higher intensity. The foundation is broadly classified into shallow and deep foundations.

a) Shallow foundation:

If the depth of foundation is equal to or less than its width, the foundation is classified as a shallow foundation

Types of Shallow foundation:-

i. Isolated Foundation
ii. Combined Foundation
iii. Raft or Mat Foundation

b) **Deep foundation:**

If the depth of foundation is greater than its width, the foundation is classified as a deep foundation.

Type of Deep foundation:-

i. Pile Foundation

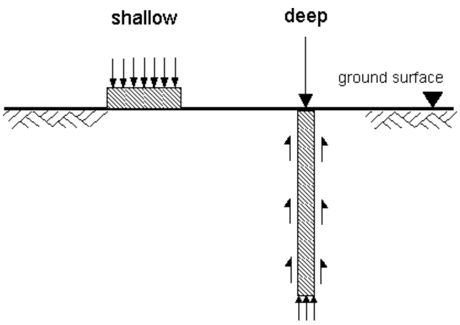
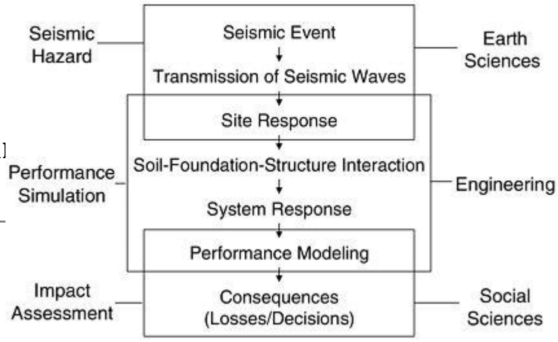


Fig (1) SHALLOW AND DEEP FOOTING

2. Soil Structure Interaction

The response of a structure during an earthquake depends on the characteristics of the ground motion, the surrounding soil, and the structure itself. For structures founded on the rock or very stiff soils, the foundation motion is essentially that which would exist in the soil at the level of the foundation in the absence of the structure and any excavation, this motion is denoted by the free-field ground motion. For soft soils, the foundation motion differs from that in the free field due to coupling of the soil and structure during the earthquake. This integration results from the scattering of waves from the foundation and radiation of energy from the structure due to structural vibrations. This interaction is popularly known as Soil Structure Interaction, Because of these effects, the state of deformation (particle displacements, velocities and accelerations) in the supporting soil is different from that in free field. As a result the dynamic response of the structure supported on soft soil may differ substantially in amplitude and frequency content from the response of an identical structure supported on a very stiff soil or rock. The coupled soil-structure system exhibits a peak structural response at a lower frequency than would an identical rigidly supported structure. The amplitude of Structural Response is affected by the



additional energy dissipation introduced into the system through radiation damping and material damping in the soil.

The SSI is an important phenomenon in the design process of the structure and for systems and components housed therein. The type of structure and its foundation determines the importance of SSI. SSI effects can usually be ignored for conventional structures without significant embedment. However for conventional structures , it is prudent to consider and evaluate the potential effects of SSI on structure , system and component design to assure oneself that excessive conservatism is not being introduced. SSI is most important for massive, stiff structures with mat/pile foundation or with foundation systems significantly stiffened by the structures load resisting system.

Fig (2) FLOW CHART OF SESIMIC EVENT

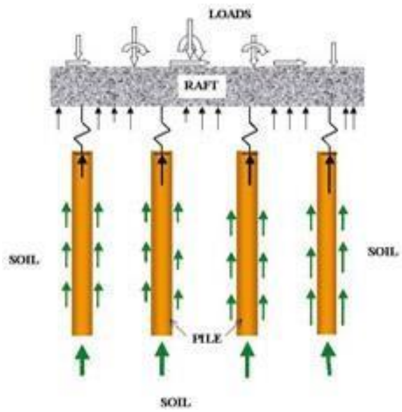


Fig (3) SSI IN RAFT AND PILE FOUNDATION

3. Seismic Effects:

When earthquakes occur, a building undergoes dynamic motion. This is because the building is subjected to inertia forces that act in opposite direction to the acceleration of earthquake excitations. These inertia forces, called seismic loads, are usually dealt with by assuming forces external to the building.

Earthquakes are usually caused when rock underground suddenly breaks along a fault. This sudden release of energy causes the seismic waves that make the ground shake. When two blocks of rock or two plates are rubbing against each other, they stick a little. When the rocks break, the earthquake occurs.

Seismic site effects are related to the amplification of seismic waves in surficial geological layers. The surface ground motion may be strongly amplified if the geological conditions are unfavorable (e.g. sediments). Although probably the most important, direct shaking effects are not the only

hazard associated with earthquakes, other effects such as landslides, liquefaction, and tsunamis have also played important part in destruction produced by earthquakes.
Effects are often classified as primary and secondary impacts. Primary effects occur as a direct result of the ground shaking, e.g. buildings collapsing. Secondary effects occur as a result of the primary effects, e.g. tsunamis or fires due to ruptured gas mains. Surface waves, in contrast to body waves can only move along the surface. They arrive after the main P and S waves and are confined to the outer layers of the Earth. They cause the most surface destruction. Earthquake surface waves are divided into two different categories: Love and Rayleigh.

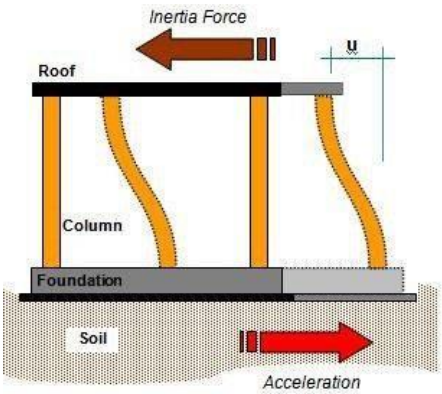


Fig (4) BUILDING BEHAVUOUR DURING SEISMIC ACTIVITY

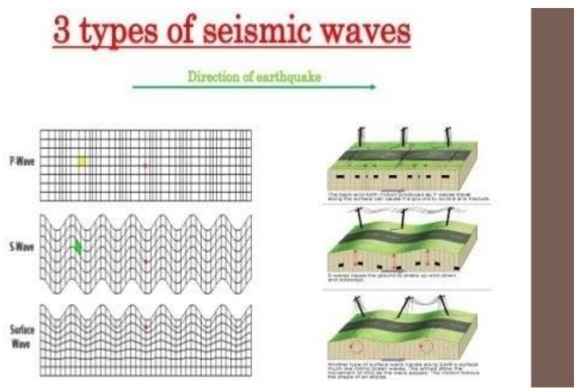


Fig (5) TYPE OF SEISMIC WAVES

4. Liquefied Soil:

During earthquake s the shaking of ground may cause a loss of strength or stiffness that results in the settlement of buildings, landslides, the failure of earth dams, and other hazards. This process leading to such loss of strength or stiffness is called soil liquefaction. It is a phenomenon associated primarily, but not exclusively, with saturated cohesion less soils.

The adverse effects of liquefaction take many forms. Some are catastrophic, such as flow failures of slopes or earth dams, settling and tipping of buildings and piers of bridges, and total or partial collapse of retaining walls. Others are less dramatic, such as lateral spreading of slightly inclined ground, large deformations of the ground surface and settlement and consequent flooding of large areas, even these latter effects have in many earthquakes caused extensive damage to highways, railroads, pipelines and buildings.

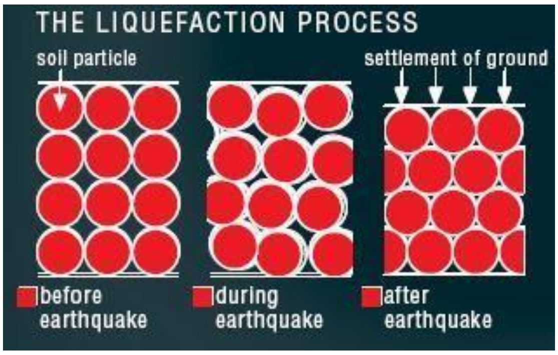


Fig (6) SOIL PARTICLES DURING LIQUEFACTION PROCESS

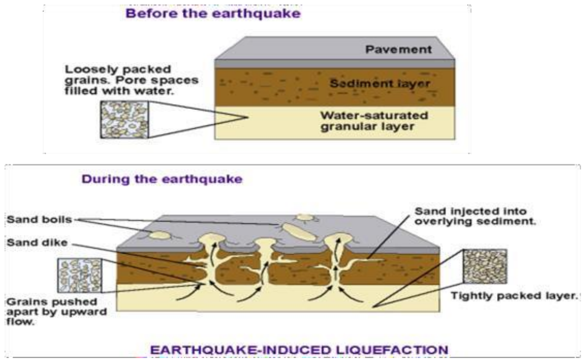


Fig (7) COMPARATIVE SOIL LAYER DURING AND AFTER

5. Effect of SSI on Pile:

"It is necessary to predict precisely the structure response considering soil structure interaction for implementation of performance-based design. Soil structure interaction during earthquake, however, is very complicated and is not always taken into account in seismic design of structure. Especially pile foundation response becomes very complicated because of nonlinear interactions between piles and liquefied soil."(Miyamoto & Tanaka, 2004)

"The non-linear dynamic response of a multi-column bridge pier has been evaluated to assess the potential for both kinematic and inertial response. The following conclusions may be drawn:

- Pile bending moments are strongly influenced by the type of analysis: linear or linear equivalent site response analysis and linear or non-linear kinematic interaction analysis.
- The maximum pile bending moment and moment variation along the pile shaft are considerably affected by the amount of non-linearity associated with different seismic events.
- Ground Motion Duration (GMD) does not significantly affect the non-linear seismic response of the pile.
- The kinematic effects strongly influence the pile response both at the head and at greater depth especially in soft soil deposits (Vs = 100 m/s).
- The inertial effects are important only in the upper part of the pile." (Tombari et al., 2008)

"Some limitations are given for the analyses, such as relying on a purely elastic structural modeling, as well as the idealization of a single degree of freedom, whereas structures, in reality, do not represent such conditions. Prediction of maximum bending moments had a limitation regarding seismic input signals of relatively high frequencies (small wavelengths) since the kinematic demand of the modeled piles was underestimated and thus larger curvature ϕ values (bending moments) were generated." (*Dynamic Soil-Structure Interaction of Piles in Soft Soils*, 2020)

6. Effect on Raft:

"The model is used to evaluate the effects of soil-structure interaction on the maximum base shear force, overturning moment and displacement for the MRF multi-story buildings. The analysis demonstrates that soil-structure interaction has a significant effect on the base forces and roof displacement of the building compared to the typical assumption in which interaction would be neglected. When the ground is stiff enough, the dynamic response of the structure will not be influenced significantly by the soil properties during the earthquake, and the structure can be analyzed under the fixed base condition. When the structure is resting on a flexible medium, the dynamic response of the structure will be different from the fixed base condition owing to the interaction between the soil and the structure. It is concluded that the dynamic soil-structure interaction plays a considerable role in seismic behavior of mid-rise building frames including substantial increase in the lateral deflections and interstorey drifts and changing the performance level of the structures. Thus, considering soil-structure interaction effects in the seismic design of mid-rise moment resisting building frames, particularly when resting on soft soil deposit, is essential".(Raheem et al., 2014)

7 Conclusions

The Piles and Raft both have their pros and cons but if we combine these two the limitations are very less. Thus a new concept of foundation arises **The Piled Raft** and very swiftly it became the choice of engineers for the foundation of any type of structures with heavy loading.

"The piled raft foundation system has recently been widely used for many structures, especially high rise buildings. In this foundation, the piles play an important role in settlement and differential settlement reduction, and thus can lead to economical design without compromising the safety of the structure. In several design cases, the piles are allowed to yield under the design load. Although the load capacity of the pile is exceeded, the piled raft foundation can hold additional loads with controllable settlement. Thus, accurately determining the settlement of the foundation is critical and for this the designers must consider the role of the raft and the role of piles in combination, as well as the interactions between the foundation's components. "(Nguyen et al., 2013)

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9. BIOGRAPHIES

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