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Study on liquefaction of soil following an Earthquake

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***Abstract* - Liquefaction is the phenomena when there is loss of strength in saturated and cohesion-less soils because of increased pore water pressures and hence reduced effective stresses due to dynamic loading. It is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. Liquefaction occurs in saturated soils, that is, soils in which the space between individual particles is completely filled with water. This water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. Prior to an earthquake, the water pressure is relatively low. However, earthquake shaking can cause the water pressure to increase to the point where the soil particles can readily move with respect to each other. Earthquake shaking often triggers this increase in water pressure, but construction-related activities such as blasting can also cause an increase in water pressure. When liquefaction occurs, the strength of the soil decreases and, the ability of a soil deposit to support foundations for buildings and bridges is reduced.**

***Index Terms* - Liquefaction of soil, Liquefaction in earthquake, Methods of reducing liquefaction hazards, Soil improvement methods, Suitable foundation for liquefiable soil.**

I.INTRODUCTION

Liquefaction is the phenomena when there is loss of strength in saturated and cohesionless soils because of increased pore water pressures and hence reduced effective stresses due to dynamic loading. It is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. Liquefaction occurs in saturated, saturated soils are the soils in which the space between individual particles is completely filled with water. This water exerts a pressure on the soil particles that. The water pressure is however relatively low before the occurrence of earthquake. But earthquake shaking can cause the water pressure to increase to the point at which the soil particles can readily move with respect to one another. Although earthquakes often triggers this increase in water pressure, but activities such as blasting can also cause an increase in water pressure. When liquefaction occurs, the strength of the soil decreases and the ability of a soil deposit to support the construction above it. Soil liquefaction can also exert higher pressure on retaining walls, which can cause them to slide or tilt. This movement can cause destruction of structures on the ground surface and settlement of the retained soil. It is required to recognize the conditions that exist in a soil deposit before an earthquake in order to identify liquefaction. Soil is basically an assemblage of many soil particles which stay in contact with many neighbouring soil. The contact forces produced by the weight of the overlying particles holds individual soil particle in its place and provide strength.

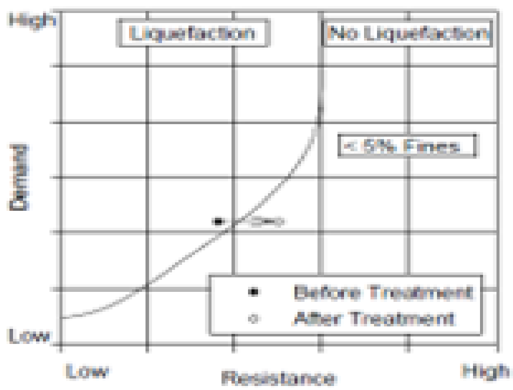
A. EVALUATION OF LIQUEFACTION SUSCEPTIBILITY

During cyclic undrained loading, like those imposed by earthquake shaking, almost all saturated cohesionless soils are subjected to significant pore pressure build-up. If there is shear stress reversal, the effective stress state can drop rapidly to zero. When a soil element reaches the condition of essentially zero effective stress, the soil has very little stiffness and large deformations. This phenomenon is generally referred to as liquefaction Semi-empirical procedures for evaluating liquefaction potential of cohesionless soils during earthquakes basically consist of analytical approaches to explain experimental findings of past case histories, and the development of a suitable in-situ index to represent soil liquefaction characteristics.

B. METHODS OF REDUCING LIQUEFACTION HAZARDS

- By Avoiding Liquefaction Susceptible Soils.

- Build Liquefaction Resistant Structures.
- Improve the Soil
- Construction on liquefaction susceptible soils is to be avoided.
- The soil at a particular building site according to the various criteria's available to determine the liquefaction potential of the soil in a site
- The structure constructed should be liquefaction resistant
- The mitigation of the liquefaction hazards by improving the strength, density and drainage characteristics of the soil.



Effect of treatment on liquefaction potential

C. SUSCEPTIBILITY OF SOILS TO LIQUEFACTION IN EARTHQUAKES

Liquefaction is most commonly observed in shallow, loose, saturated cohesion less soils subjected to strong ground motions in earthquakes. Unsaturated soils are not subject to liquefaction because volume compression does not generate excess pore water pressure. Liquefaction and large deformations are more associated with contractive soils while cyclic softening and limited deformations are more likely with expansive soils. In practice, he liquefaction potential in a given soil deposit during an earthquake is often evaluated using in-situ penetration tests and empirical procedures.

Since liquefaction phenomena arise because of the tendency of soil grains to rearrange when sheared, any factor that prevents the movement of soil grains will increase the liquefaction resistance of a soil deposit. Particle cementation, soil fabric, and again are some of the important factors that can hinder soil particle movement. Stress history is also crucial in determining the liquefaction resistance of a soil.

D. GROUND FAILURE RESUILTING FROM SOIL LIQUEFACTION

National Research Council (The Liquefaction.1985) lists eight types of ground failure commonly associated with the soil liquefaction in earthquakes:

- Sand boils resulting in land subsidence accompanied by a relatively minor change.
- Failure of retaining walls due to increased lateral loads from liquefied backfill or loss of support from the liquefied foundation soils.
- Ground settlement, generally linked with some other failure mechanism.
- Flow failures of slopes resulting in large down slope movements of a soil mass.
- Buoyant rise of buried structures such as tanks.
- Lateral spreads resulting from the lateral movements of gently sloping ground.
- Loss of bearing capacity resulting in foundation failures.
- Ground oscillation involving back and forth displacements of intact blocks of surface soil.

II. LITERATURE REVIEW

When dense sands are sheared monotonically, the soil gets compressed first and then it gets dilated as sand particles move up and over one another. When dense saturated sands are sheared impeding the pore water drainage, their tendency of volume increase results in a decrease in pore water pressure and an increase in the effective stress and shear strength. When dense sand is subjected to cyclic small shear strains under undrained pore water conditions excess pore water pressure may be generated in each load cycle leading to softening and the accumulation of deformations. However, at lager shear strains, increase in volume relieves the excess pore water pressure resulting in an increased shear resistance of the soil. After initial liquefaction if large deformations are prevented because of increased undrained shear strength then it is termed, limited liquefaction (Finn 1990). When dense saturated sands are subjected to static loading, they have the tendency to progressively soften in undrained cyclic shear achieving limiting strains which is known as cyclic mobility. (Castro 1975; Castro and Poulos 1979). Cyclic mobility should not be confused with liquefaction. Both can be distinguished from the very fact that a liquefied soil displays no appreciable increase in shear resistance regardless of the magnitude of deformation (Seed 1979) Soils undergoing cyclic mobility first soften subjected to cyclic loading, but later when monotonically loaded without drainage stiffen because tendency to increase in volume reduce the pore pressures. During cyclic mobility, the driving static shear stress is less than the residual shear resistance and deformations get accumulated only during cyclic loading. However, in layman's language, a soil failure resulting from cyclic mobility is referred to as liquefaction. Robertson (1994) termed this, cyclic liquefaction. It involves some deformation occurring while static shear stresses exceed the shear resistance of the soil (when the state of zero effective stress is approached). However, the deformations stop after cyclic loading ends as the tendency to expand quickly results in strain hardening. This type of failure in saturated, dense cohesion less soils is also referred to as liquefaction but with limited deformations. According to Selig and Chang (1981) and Robertson (1994), a dilative soil can attain a state of zero effective stress and shear resistance. Cyclic loads may produce a reversal in the shear stress direction when the initial static shear stress is low i.e., the stress path passes through a condition which is known as state of zero shear stress.

III. BACKGROUND

Buildings constructed on loose soil pitch and tilt easily when liquefaction occurs, since the soil no longer supports the structures' foundations. In contrast, structures anchored to bedrock or stiff soils in earthquake-prone areas suffer less damage, because less vibration is transmitted through the foundation to the structure above. In addition, buildings anchored to bedrock have a reduced risk of pitching and tilting.

One of the most severe episodes of liquefaction in modern times occurred in China during the Tangshan earthquake of 1976. Some scientists estimate that an area of more than 2,400 sq. km (about 925 sq. miles) was subjected to severe liquefaction, which contributed to the extensive damage that took place in the southern part of the city.

The liquefaction of the soft lake sediment upon which central Mexico City was built amplified the effects of the 1985 earthquake, the epicentre of which was located hundreds of miles away. In addition, the liquefaction of the ground beneath the Mission and Market districts in San Francisco during the 1906 earthquake caused several structures to pitch and collapse. These districts were built on poorly filled reclaimed wetlands and shallow-water areas.

Loma Prieta earthquake of 1989: soil liquefaction

An automobile crushed under the remains of an apartment building in the Marina District, San Francisco, California. The first and second floors are no longer visible because of structural failure and sinking due to liquefaction during the Loma Prieta earthquake in 1989.

Loma Prieta earthquake of 1989: sand volcano

The four-foot vent of a sand volcano generated by soil liquefaction in a California strawberry field during the Loma Prieta earthquake in 1989.

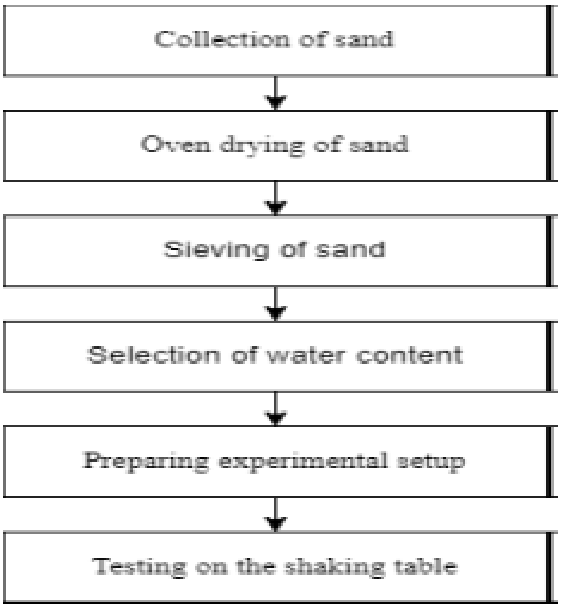
In addition, liquefaction may also cause landslides. For example, during the Alaska earthquake of 1964, the liquefaction of a sandy layer of soft clay beneath Turnagain Heights, a suburb of Anchorage, caused a landslide in the mass of ground above that destroyed approximately 75 homes and disrupted utilities.

IV. EXPERIMENTAL STUDY

The following methodology was adopted for this project of Study of Liquefaction of soil following an earthquake which is totally based on trial-and-error method:

Objective:

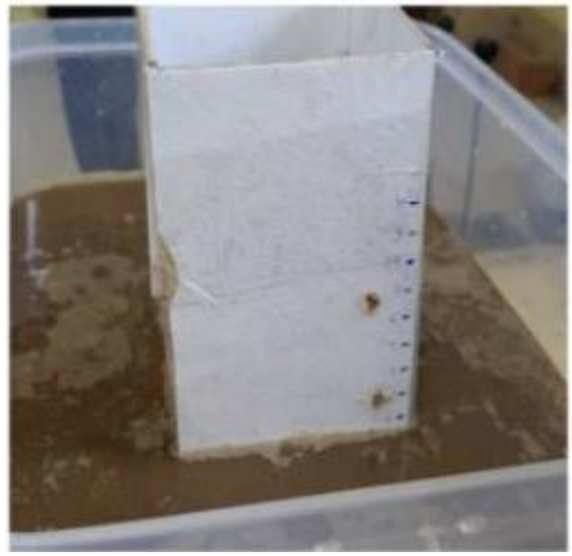
- To determine how liquefaction takes place
- To study the effects of liquefaction
- To determine at what water content liquefaction takes place
- To determine remedial measures for liquefaction prone areas
- To determine the type of foundation suitable for areas with soil prone to liquefaction.



A. For Raft Foundation

Water Content	Weight of sand	Weight of water	Remark
0%	12 kg	0 kg	No settlement, No liquefaction
5%	12 kg	0.6 kg	No settlement, no liquefaction
10%	12 kg	1.2 kg	No settlement, no liquefaction
15%	12 kg	1.8 kg	No settlement, no liquefaction
20%	12 kg	2.4 kg	Minute settlement, Visible dampness of soil
25%	12 kg	3.0 kg	5 mm settlement, Top layer of the soil fully damp
30%	12 kg	3.6 kg	Settlement of 20mm, Complete liquefaction

Table 1 : Raft foundation observations



Raft foundation building model tested at 30% water content showing complete liquefaction with a settlement of 20mm

B. For Pile foundation

Water Content	Weight of sand	Weight of water	Remark
0%	12 kg	0 kg	No settlement, No liquefaction
5%	12 kg	0.6 kg	No settlement, no liquefaction
10%	12 kg	1.2 kg	No settlement, no liquefaction
15%	12 kg	1.8 kg	No settlement, no liquefaction
20%	12 kg	2.4 kg	Minute settlement, Visible dampness of soil
25%	12 kg	3.0 kg	5 mm settlement, Top layer of the soil fully damp
30%	12 kg	3.6 kg	Collapse of building, Complete liquefaction

Table 2 : Pile Foundation Observations

V. RESULT

1. From Table 1 and Table 2 we can conclude that liquefaction does not take place if the water content of the soil is less than 30 %.
2. In raft foundation even after liquefaction takes place the structure only sank and did not collapse so it can be concluded that raft foundation is safe for buildings in liquefaction prone areas.
3. In pile foundation when liquefaction took place, entirety of the structure collapsed, so pile foundation should not be preferred in case of high rise building different methods should be used to make pile

foundation safer as raft foundation is not recommended for high rise structures.

VI. DISCUSSION AND CONCLUSION

Soil Improvement methods are most commonly employed to reduce or eliminate the effects of liquefaction. Most of these techniques have advanced over the years, typically by trial and error. Though widely used, the traditional mitigation methods have limitations like environmental impact, disturbance to existing structures when subjected to vibrations and deformations, size of the area to be treated etc. Lately, new concepts like passive site remediation, microbial geotechnology, induced partial saturation have been proposed. New methods of liquefaction mitigation such as colloidal silica grouting, bentonite suspension grouting, bio cementation, air injection, biogas, and mitigation using geomaterials have been developed based on these concepts.

To simulate the liquefaction effect on soil, it is recommended to use a shaking table as it is easy to perform and it depicts the same scenario as an earthquake. The test specimen of different foundations are tested on the shaking table. The specimen used is of the cuboidal shape of size 100mm x 100mm x 150mm where we observed that when subjected to vibrations, one specimen with raft foundation observed some amount of settlement whereas the other specimen with pile foundation had collapsed.

For liquefaction to occur, soil must be cohesion less, loose, saturated and there must be a dynamic force like earthquake. The critical depth for development of liquefaction is less than 12m.

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