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Soil Liquefaction and It's Remedial Measures

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Abstract: **Fundamental response of sandy soil to seismic forces turnout as a mainstream issue, which depends upon numerous factors. Failure of earth under foundation specifically loose saturated sand, due to the phenomenon called liquefaction, has been responsible for tremendous loss of property and life in the past, all over the world. That is why; geotechnical engineers are trying their best to explore the conditions favouring this phenomena and methods to tackle this problem. As the frequency of severe earthquakes manifolds in recent years, a thorough study and understanding of liquefaction is the need of the time, in order to minimize the losses. This paper reviews the phenomenon of liquefaction and various protective measures to avoid circumstances advocating liquefaction. This focus underlines structural engineering measures like spread foundation, revetments, as well as non-structural engineering methods like soil solidification and replacement methods, lowering water table by various measures, confining the soil, dissipation of pore water pressure, and shear strain restraint method. This research draws upon mostly primary sources includes published letters, and a complete collection of little reviews. This review published techniques put forward by The Japanese Geotechnical Society after extensive liquefaction failure during 1964's earthquake and lesson learnt at Kobe during 1995 Hyogo-Ken-Nanbu earthquake.**

***Index Terms*—Liquefaction, soil, protective measures, earthquake**

I. INTRODUCTION

Researchers all over the world have started extensive study of Liquefaction in the wake of the two catastrophic earthquakes of 1964, the 1964 Nigata and 1964 Great Alaska Earthquakes. After that a ton of methods, procedures, theoretical concepts and nomenclature/terminologies have been introduced as a modern engineering branch. Over the years, the scope of this subject has evolved to great extent, which makes it an imperative aspect of geotechnical engineering practices.

Basically, liquefaction refers to "phenomenon in which a part/mass of soil losses its shear strength to a great extent, such that it behaves like a liquid, when subjected to shock, cyclic or monotonic loading, until the shear stresses on that part of soil are same as the reduced shear resistance[1]." In common usage, liquefaction is defined as the formation of liquefied state from solid state, mainly due to excess pore water pressure and reduced effective stress. The susceptibility of soil to change its volume, mainly due to shear stress, results in liquefaction.

Soils which are mainly susceptible to liquefaction are poorly drained silts and loosely packed sandy soils. However, fine grained clayey soils are also liable to liquefaction failure in exceptional cases, as figured out in 1999 kocaeli earthquake.

Considering the adverse effects of this problem, many protective measures have been proposed from time to time. A number of remedial measures are discussed in this article to mitigate this problem.

II. LIQUEFACTION PHENOMENON

Mogami and Kubo(1953), develops the term liquefaction, which has been associated with various phenomena regarding soil deformation of saturated cohesion less soils under undrained conditions, due to disturbances which can be caused by monotonic, cyclic or shock loading[2]. After extensive researches, geotechnical engineers found excess pore water pressure as a distinctive characteristic of entire liquefaction phenomena. The behavior of dry cohesion less soils against static and cyclic loading is long-familiar, but when it comes to saturated soils; results are not always the same. So, rapid loading under undrained condition, generates excess pore water pressure, where as effective stress decreases, owing to the tendency for densification on loading. Well, this mechanism divides the liquefaction phenomena into two parts: flow liquefaction, and cyclic mobility.

Flow liquefaction

Extensive damages which are mostly being noticed in the case of flow liquefaction, causes numerous instabilities called **flow failure**. This is mainly triggered when shear strength of soil is lower than the static shear stress, during liquefied state. Therefore, static shear stress are responsible for deformations, however, cyclic stress also creates an unstable state, which in-turn allow other stress to develop flow failure

Cyclic mobility

When subjected to vibrations, cyclic mobility produces deformations which are plastic in nature. In terms of deformation, cyclic mobility is caused not only by static stresses, as cyclic stresses also play an important role.

Lateral spreading, is the name given to these types of deformations. As compared to flow liquefaction, shear strength is generally higher than static shear stress, during liquefied state.

III. NON-STRUCTURAL REMEDIAL MEASURES AGAINST SEISMIC HAZARDS

Soil Densification

Soil densification is the most basic techniques used for both to increase strength of soil and resistance to liquefaction. However, as far as liquefaction is concerned only vibratory and dynamic techniques are employed

Vibratory Compaction, this involves soil densification by either vibroflotation or vibro probe method. Both these techniques are effective up to 30m depth.

Vibroflotation as vibratory compaction method, a vibroflot consist of a cylindrical tube, about 2m diameter fitted with water jets at top and bottom [4]. A rotating eccentric mass to develop horizontal vibratory motion is also provided in it. Vibroflot is connected to a tube of required length to increase its reach up to large depths. The vibroflot is sunk into loose soil up to desired depth using water jet. Shear strength of soil near the bottom face of vibroflot decreases as water coming out of jet creates momentary quick sand condition. Vibroflot advances into hole as its own weight and vibrations are started as the required depth is reached, which causes compaction of soil up to radius as 1.5m in horizontal direction. Water pressure is reduced and vibrations continue as vibroflot is slowly raised to surface. Rising is done in stages and at same time back filling is done to entire depth. Grid pattern is adopted, with spacing of 2m or 3m is kept between holes.

Vibro Probe as vibratory compaction method, the basic principle techniques is similar to that of vibroflotation. It is also known as terra probe, and consists of an open ended tube, about 75cm in diameter. Vibratory pile driven is the mail element which causes vertical vibrations. Sometimes, water jets are also used to boost penetration. Terra is raised in stages, while vibrator is kept on. Simultaneously back filling is done, as done in former case. Soil up to 20m depth can be effectively treated, with spacing of 1.5m

Dynamic Compaction, dynamic compaction is an economical soil densification technique used as a protective measures against liquefaction, this method involves the systematic drop of heavy weight of 6 to 35 tons from a height ranging between 12 to 40m. The maximum depth up to which dynamic compaction is effective depends upon weight and height, and is given by Lukas as [5]-[6]

$$D_{max}=n\sqrt{(wH)} \quad \ldots\ldots(1)$$

Where n [in eq. (1)], is a factor which depends upon type of soil and decline with an increase in degree of saturation.
Value of n,
For pervious soil,
n=0.5 to 0.6 (low saturation)
n=0.5 (high saturation)
For semi-pervious soil,
n=0.4to 0.5 (low saturation)
n=0.35 to 0.4 (high saturation)

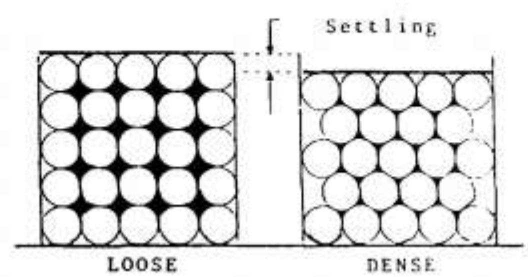

Fig. 1 Rearrangement of soil particles by soil densification method [7]

Dissipation of Pore Water Pressure

As high ground water level is the main culprit of liquefaction. So, it is must to dissipate excess pore water pressure. Proper drainage techniques are opted for lowering water table

Vertical Sand Drains or Sand wicks are operated for this purpose. A sand drain is basically a hole drill in soils of low permeability and filled with sand, in order to increase permeability of soil.

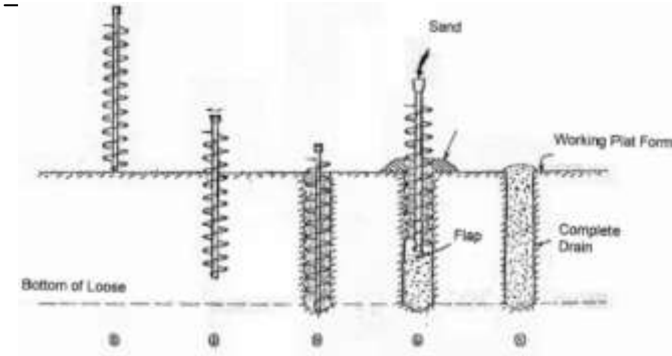

Fig. 2 Execution of sand drain process[8].

Initially in situ sand drains were popular but now due to the advancement in technology pre fabricated sand drains known as sand wicks are more common in developed countries.

In installation process, a mandrel is first hammered into the soil which is removed, thereafter, filling the hole with desired grade of sand. A sand drain is made of geosynthetic rope, 100mm wide and 5mm thick. The diameter of both types of drains varies from15 to 30cm. A spacing of generally 2.5 to 3m and simple grid pattern is adopted.

Stone columns were initially discovered to increase strength of foundation, but they are also fairly effective in boosting the consolidation process. For the installation of stone columns, bore holes are drilled into soil by any economical method, which are filled with gravel and sand in alternate layers.

It is usual practice to use both the techniques vibratory compaction to bore holes and sand drains or stone columns to make most of the both.

Shear Strain Method

This method includes the construction of diaphragm walls to increase the performance of soil during earthquake. A diaphragm wall is a in situ made reinforced concrete wall in excavation. Bentonite slurry is used to prevent the collapse of trench during excavation reinforcement and casting sometimes is used to make slurry.

Generally panels of length less than7m are used, but can vary in length, depending upon type of soil to be restraint and neighboring ground. A reinforcing cage filled with slurry is lowered into the trench to excavate for the construction of panel. Then, the trench is filled with concrete using trench pipes to cast a panel.

Following two methods can be used for joining two panels, using a CWS steel framework section with the hydro fraise; one can make direct concrete to concrete interlock.

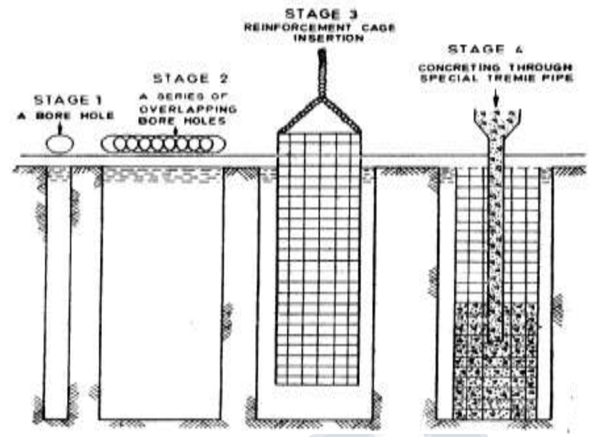

Fig. 3 Construction steps of diaphragm wall.

Diaphragm walls of width 0.50m, 0.60, 0.80m, 1.00m, 1.20, and 1.50m are commonly used.

Soil Solidification and Replacement Methods

Soil solidification means improving the properties of soil by the addition of some material to mitigate liquefaction and other failure. Soil solidification can be done by pre mixing or by deep mixing.

Cement and lime are the most preferred used for mixing as they are chemically active to react with soil. A proper procedure need to be followed during mixing. The required quantity of soil is spread on the ground and material is mixed uniformly. Curing is must after mixing.

Deep mixing is done by boring a hole using a special type of auger provided with a mixing tool at its bottom. The cement slurry is passed through drill rod to the mixing tool. Thus, vertical columns are so close to each other, such that they overlap each other. This method basically involves the liquefiable soil replacement, with a soil of desired characteristics.

If thickness of weak stratum is less, then it can be easily excavated and replaced. This method is economically justified only if good soil is available within the vicinity for replacement. Replacing the weak soil by stone column at certain intervals is another replacement method, which is highly effective and almost suitable for all kind of soils.

Lowing the Ground Water Table

As water is the principle element for liquefaction like oxygen for fire. So, to minimize the chances of liquefaction failure to negligible level, one must lower the ground water table. A lot of dewatering system are used, trenches or ditches, and deep wells are mostly adopted out of above all.

Ditches are used in coarse soil for excavation of limited depth. The depth of ditches must penetrate deeper

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than the level of work. Sump pits are installed or constructed along the ditches, at suitable locations, for the installation of pump to remove collected water.

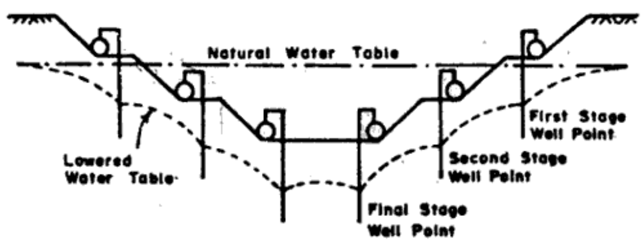

Fig. 4 Multi stage well points.

This method is not suitable for clay as sloughing or erosion can occur. Various types of walls have been developed, corresponding to different types of soils and desired results. A single stage well point is the most elementary type. It is a perforated pipe about 1mlonge and 5cm in diameter. A conical steel pipe is used to facilitate penetration, and a bail valve near lower end is provided, which permit water flow in downward direction during installation.

Multistage well point is used to lower water level to a depth greater than 6m. The installation of this well is done in stages. The first stag well points are located near the perimeter of the area, and are put into working, while second stage points are installed by excavating the earth

Special type of well points are known as vacuum well points, and are used for draining silt or fine sands with effective size less than 0.05mm. In this system, bored hole is filled with sand filter and a sealing element like clay in upper 1m. A vacuum pump is provided which cause the pressure difference and thus, lower the ground water table.

IV. STRUCTURAL ENGINEERING REMEDIAL MEASURES AGAINST SEISMIC HAZARDS

Pile Foundation

A pile is a long cylinder of material such as concrete, steel which is pushed into ground to act as a steady support for structures build on it. Pile foundation extends beyond the liquefiable soil or weak strata to provide a firm foundation.

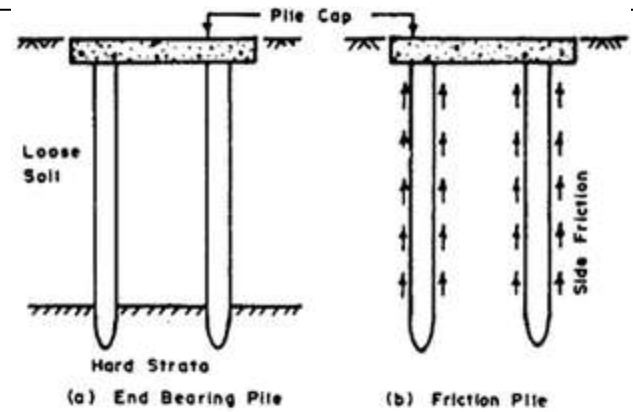

Fig. 5 (a) "end bearing pile used to transfer load at lower layers." (b) "Friction pile opted to transfer load by friction action."

Two type of pile foundations are commonly in use, End bearing pile, the lower end of pile rests on strong strata. In this case, pile acts as a column and building load is transferred through the lower end of pile to strong layer, bypassing the weak layer.

Friction pile, it works on a different mechanism. The load of building is transferred across the full high of the pile, by friction. In other words, the entire surface of pile, works to transfer the load to the soil.

Wooden, concrete or steel piles can be used. However, wooden piles are completely obsolete these days.

V. REVETMENTS

Revetments are commonly used to increase stability of river banks. This does affects the conditions favoring liquefaction, and hence can avoid liquefaction, it act as a resistance to the percolation of water from river banks and sea shores. And also, use of revetments can increase the stability of structure and improve the performance of slopes and building during earthquakes.

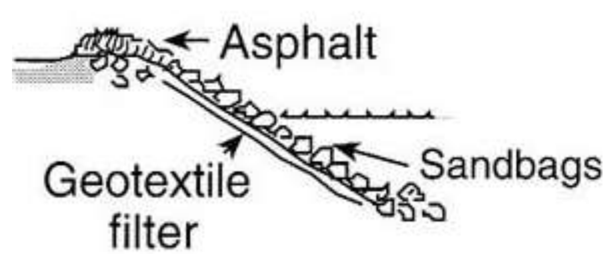

Fig. 6 shows the revetment details.

Wooden piles, loose piled boulders, concrete shapes like dykes or more solid banks can be used as revetments. For instance, Lake Ontario Riparian is provided with stone revetments to block the seepage of water to adjoining soils during floods.

Some other techniques like spread foundation can also employed to prevent failure during liquefaction, and reduce its catastrophic effects.

Lesson Learnt From Previous Earthquakes

At Kobe most of liquefaction failures takes place near the port, where, popular heavy tiled roofs and wood framed houses failed in shear, due to ground shaking.

Some recommendation are given by various agencies, which have been briefly explained below, after weighing up all considerations,

Deep Foundation, if adopted at that time, would have minimized the effect of liquefaction, provided that they are well connected and stiff. So, that load can be properly transferred to stronger ground. Pile Foundation, on the other hand, accommodate different layers of soil, undergoing liquefaction and these should be able to handle both vertical as well as horizontal loads, resulting from bending of one layer, under liquefaction , to another layer beneath it. Revetments would have also affects the destruction of area, as it controls seepage of water, particularly in coastal areas.

Non-structural protective measures should also be considered, as if these were adopted in 1964 earthquakes, results may not be the same, as it would reduce liquefaction to a much larger extent.

VI. CONCLUSION

A number of remedial measures have been introduced, since 1964 earthquake, so as to counter the liquefaction failure. Whenever, highly susceptible soil is noticed, and then these methods can be applied concurrently to avoid failures. Out of the above mentioned measures, dissipation of pore water pressure, and lowering of water table is must, as water is the principle cause of this phenomenon. As the earthquakes are unpredictable, and their number is increasing every year, therefore, careful treatment of underlying soil is compulsory.

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