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STUDY ON CHARACTERISTICS OF KOLKATA SOIL ON THE BASIS OF LIQUEFACTION SUSCEPTIBILITY

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Abstract

The present study describes liquefaction of soil due to loss of strength of cohesion less soils in saturated condition due to sudden increase of pore water pressure during earthquake in untrained condition. Many failures of various structures such as seismic dams, retaining structures, and harbours have been attributed to liquefaction of saturated soils. There have been very limited studies regarding the behaviour of soil liquefaction at large depths, yet this situation commonly occurs at foundations of some structures such as large earth dams. This paper describes effects, mechanism, susceptibility, evaluation and prevention of liquefaction and it concludes by proposing that dynamic consolidation is the best suitable method of soil improvement which can be adopted before constructing any structures in Kolkata in those places are highly prone to liquefaction.

Keywords: *Liquefaction, Kolkata soil character, Anti-liquefaction Measures, Dynamic Compaction, Pile Driving Method*

1. INTRODUCTION

Liquefaction of sand can be defined as the loss of shear strength of sand due to oscillatory motion. It may lead to the failures such as bearing capacity failures, sinking, landslides, and flotation of underground structure. For liquefaction cohensionless, loose and saturated soil must be present. There is shaking of ground of required intensity and undrained condition develops in the soil during liquefaction. Liquefaction occurs normally when SPT number N is less than 15 (Whitman, 1971) . The loose sand is more compressible thus better for the observation of this phenomenon. If the soil is below the ground water table the voids of the soil get filled by water. In response of sudden soil compression water increases pressure and flows out. In low pressure zone if the loading is rapidly applied the flow out of water is not possible and pressure builds up to a large extent exceeding the contact stresses between the grains of soil in contact in that case liquefaction will occur. Soil liquefaction occurs due to large earthquakes and it is also termed as ground failure (for flow liquefaction) and sometime it is termed as lateral spreading (cyclic mobility) (Seed, 1979). Generally soil liquefaction occurs due to less strength of soil. In saturated cohesionless soil due to build-up of pore water pressure and due to application of sudden earthquake load, the strength of soil gets decreased and soil liquefaction is occurred (Seed and Lee, 1966) [18]. Several case histories, field and laboratory studies revealed that silty sands (also present in Kolkata sub soil strata) are also prone to liquefaction (Seed et al., 1983; Yamamuro and Lade, 1998) [17, 26]. So on the basis of seismological and geotechnical characteristics; it is necessary to assess liquefaction susceptibility at Kolkata city and also the most suitable ground improvement technique has been proposed to mitigate soil liquefaction.

2. LIQUEFACTION PHENOMENON

The main cause of destruction during earthquake is the failure of ground structure. Under earthquake loading some soils may compact, increasing the pore water pressure and causing a loss of shear strength, and behave like liquid mud. This phenomenon is generally referred to as liquefaction. Liquefaction can occur at some depth causing an upward flow of water. Although the flow may not cause liquefaction of the upper layers, it is possible that hydrodynamic pressure may reduce the allowable bearing pressure at the surface.

2.1. Effects of liquefaction: Soil liquefaction causes enormously damage to the environment condition. Due to liquefaction the building foundation may face loss of support which result in virulent and irregular settlement of building causes structural damage and cracking of the building structure. The uplift force due to movement of earth plates and shaking of earth can crack weak foundation, slab, beam and columns. The entire building may fall down and electrical services may also be hampered and there can be possibility of human death. Bridges, dams and buildings constructed on pile foundation may lose support and it may buckle. It is very danger for the society that because of earthquake and soil liquefaction there may be an increase of human death and also destruction of the native peace of the environment.

2.2. Causes behind Liquefaction: Soil is basically concentration of many soil particles which stay in contact with due to its cohesion and friction property (c and υ). The force exerted by the weight of the particles holds individual soil particle in its place and provides shear strength. When an unexpected movement occurs in the earth, liquefaction occurs. The pore water pressure of the soil prevents the soil particles from moving close together. So due to increase of pore water pressure the contact forces between soil particles may get reduced. At last when the particles lose contact with each other due to increase of water pressure the strength of the soil gets reduced and it will behave like a liquid rather than a solid (Sitharam, 2012) .

3.MECHANISM OF LIQUEFACTION

Fig 1 represents a section of ground having sand layer of depth z from ground level (GL) where ground water table (GWT) lies at a depth hw from ground level where unit weight of sand is γ and γsub is saturated unit weight of sand. The shear strength of sand is primarily due to internal friction (cohesion, c = 0). In saturated state it may be expressed as: (Fig 1).

$\tau = (\sigma n - u) \tan\phi$

Where τ is the shear strength, σn is the normal stress acting on any plane at depth z, u is the pore pressure and $u = \gamma wz$, where $\gamma w$is the unit weight of water, and ϕ is the angle of internal friction. The equation can be expressed as

$\tau = \sigma n' . \tan \phi$ Or $\tau = \gamma b.z. \tan\phi$

Where σn' is the effective normal stress, γsat is the unit weight of saturated soil and γb is the submerged unit weight of soil. If there is an increase in the pore pressure $+\Delta u = \gamma w h w'$ due to vibration of the ground, the strength may be expressed as

$\tau = (\gamma bz - \Delta u) \tan\phi = (\gamma bz - \gamma w h'' w) \tan\phi = \sigma dyn' . \tan\phi$

Where σdyn' is the effective dynamic stress and hw' is the height of water rise in stand pipe.

Therefore with the development of additional positive pore pressure, the strength of the sand reduces. For a complete loss of soil strength:

$\gamma bz = \gamma w h'' w$ Or $hw'/z = \gamma b/\gamma w = (Gs-1) / (1+e) = icr$

Where Gs is specific gravity of soil solids, e is the void ratio, and icr is the critical hydraulic gradient.

f Fig:1 Section of ground showing the Position of Water Table

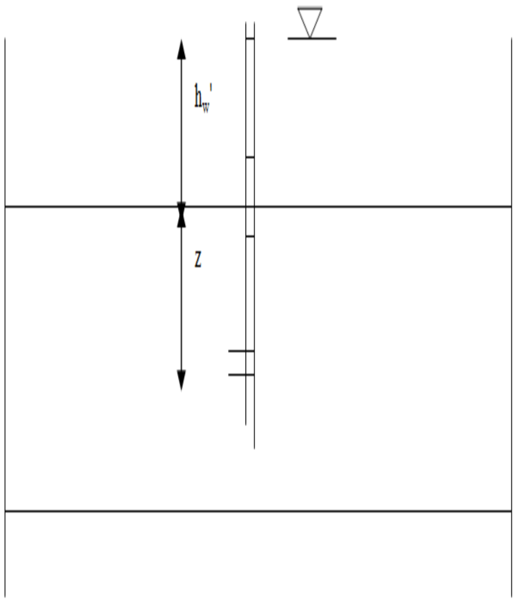

Fig:1 Section of ground showing the Position of Water Table

4. PREVIOUS HISTORY OF LIQUEFACTION DURING EARTHQUAKE

Niigata earthquake (1964): The Nigata earthquake struck at 13:01 local time on 16 June with a magnitude of 7.5.the epicentre was on the continental shelf off the northwest coast of Honshu, Japan in Nigata prefecture, about 50 kilometres north of the city of Nigata. Date: 16th June 1964, Magnitude: 7.6Mw, Depth: 34km, Epicentre: 38. 37 N 139.22 E, Tsunami: yes, Casualties: 36 dead or missing.(385 injured) Alaska earthquake(1964): The 1964 Alaskan earthquake also known as Great Alaskan earthquake and Good Friday earthquake occurred at 5.36 pm lasting for 4 minutes and thirty eight seconds, it was the most powerful recorded North American history and world history. Date: 27th March 1964, Magnitude: 9.2Mw, Depth: 14 miles, Epicentre: 61 3'0"N 147 28'48"w, Type: Mega thrust, Areas affected: United States, Canada, Total damage: 11 million, Casualties: 139 killed Nepal earthquake (2015): The Nepal earthquake is known as Gorkha earthquake killed over 8000 people and injured more than 21000. Its epicentre was east of Lamjung district, and its hypocentre was at a depth of 8.2 km. the earthquake triggered an avalanche on Mount Everest. Date: 25th April 2015, Origin time: 11: 56:26 NST, Magnitude: 7.8Mw, Epicentre: 28.147˚N 84.708˚E, Type: Thrust, Total damage: 10 billion, Casualties: 8857 dead in Nepal and 21, 952 injured. Loma Prieta earthquake (1989): The Loma Prieta earthquake occurred in northern California on October 17. Loma Prieta is a 3790 feet northern California mountain in the Santacruz Mountains range. The peak is on about 11miles west of Morgan Hill in Santaclara country. Date: October 17, 1989, Origin time: 5:04:15 PDT, Duration: 8-15 seconds, Magnitude: 6.9Mw, Epicentre: 37.04˚N 121.88˚W, Type: Oblique-slip, Tsunami: yes, Casualties: 63 killed, 3757 injured. Christchurch earthquake (2011): The earthquake located in New Zealand. A 4.4 magnitude quake rattled southerners near Christchurch late on Saturday. Date: 22

February 2011, Magnitude: 6.3 M_L, Depth: 5km, Epicentre: 43.584˚S 172.701˚E, Areas affected: New Zealand, Tsunami: 3.5m tsunami waves in Tasman Lake, following triggered glacier calving from Tasman Glacier, Casualties: 185 deaths, 1500-2000 injuries. Valdivia earthquake (1960): Valdivia earthquake or Great Chilean earthquake occurred on Sunday, 22nd May 1960 was the most powerful earthquake ever recorded, rating a 9.5 on the moment magnitude scale. Kangra earthquake (1905): Kangra earthquake occurred in the kangra valley and the kangra region of the Punjab province in India on 4 April. The earthquake measured 7.8 on Richter scale. San Fernando earthquake (1971): It occurred in the early morning of February 9. The magnitude of earthquake was 6.5 or 6.9

5. DETERMINATION OF LIQUIFACTION SUSCEPTIBILITY OF SOIL

Evaluation of liquefaction resistance of soils is an important step in many geotechnical investigations in earthquake-liable region. The most common procedure around the world for evaluating liquefaction resistance is "simplified procedure" which was developed by Seed and Idriss (1971) using blow count from standard penetration. It is important to identify whether the soil at the site is susceptible to liquefaction or not, so that suitable measures may be adopted, if required. Recent research has been directed in this direction. Various methods have been proposed by different investigators. The cyclic stress approach is generally used in most of the methods. A detailed understanding of site conditions, the soil stratification, dynamic soil properties, their variability, and the areal extension of potential critical layers should be developed. Simplified field tests like CPT, shear wave velocity test, SPT etc. are widely used in practice to characterize the soil stratum to obtain cyclic resistance ratio (CRR). Corrections of the data should be applied as necessary, e.g. the normalized SPT blow count [$(N1)_{60}$] or the normalized CPT value.

Designed earthquake should be calculated by multiplying CRR value with earthquake magnitude scaling factor (MSF). Calculation of the stress for the liquefaction of critical zones is necessary, depending on the characteristics of the critical zone(s) (e.g., normalized standardized blow count, fine content, overburden stresses, level of saturation). Mainly to cyclic stress ratio (CSR) or τ_{av} / σ_{v0}' where τ_{av} means developed shear stress during earthquake and τ_h, shear stress required to cause liquefaction.

The average cyclic shear stress imparted by the earthquake in the top 12 m of a soil deposit can be estimated as (Seed et al., 1983) .

$CSR = 0.65\ (\alpha_{max}/\ g)\ (\sigma_{\circ}/\sigma_{\circ}')\ rd$

Where, α_{max} = maximum horizontal acceleration (MHA) at the ground surface

g = acceleration due to gravity (= 9.81 m/s^2)

$\sigma_{\circ}$ = total vertical stress at the point of interest

$\sigma_{\circ}'$ = effective vertical stress at the same point

CSR = cyclic stress ratio produced by the design earthquake.

r_d = stress reduction factor

The stress reduction factor (rd) depends upon the depth of the point of interest below the ground surface. The average curve is generally used in practice (Seed and Idriss, 1971).

The relationship can be approximate as $r_d = 1 - 0.008 *$ depth in metres For each liquefaction susceptible critical layer, computation of the factor of safety against liquefaction is to be done.

Factor of safety (FOS) = CRR / CSR

If FOS is < 1 then the soil is highly susceptible to liquefaction.

According to IS: 1893-2002 (part I): the basic zone factors are responsible to estimate the effective peak ground acceleration in different seismic zones in India.

6. FACTORS AFFECTING LIQUEFACTION

Soil type: Liquefaction usually occurs in cohensionless soil; on the other hand liquefaction does not occur in fine grained, cohesive soil. However, highly sensitive clays may liquefy. Particle size and gradation: Fine, uniform sands are more prone to liquefaction than coarse well graded sands. Since the permeability of coarse sands is greater than the fine sand, the pore water pressure is dissipated in such sands and liquefaction normally does not occur. Liquefaction potential of sands depends on percentage of fines (size < 0.075mm) present in it. For a sand of a relative density, as the percentage of fine increases, liquefaction potential is decreased.

Initial relative density: Liquefaction of sand depends to a large extent on the relative density. In dense sands, both pore water pressure and settlements are considerably less than that in loose sands. Hence the proneness of sand to liquefaction is reduced with an increase in relative density. Length of drainage path: If length of drainage path is large, a sand deposit behave as undrained when the pore water pressure is suddenly increased due to earthquake and the liquefaction may occur. Characteristics of vibration: The main characteristics of vibration are its acceleration, frequency, amplitude and velocity. For liquefaction of soils, acceleration, and frequency are more dominant. Acceleration during vibration is the most important characteristics affecting liquefaction of soils, in general the greater the acceleration, the greater the chances of liquefaction. Liquefaction usually occurs only after a few number of vibration cycles are repeated.

Age of soil deposit: If the soil deposit is very old, its proneness to liquefaction is relatively low as compared to that of a recent soil deposit. In old deposit some form of cementation occurs at the contact points of sand particles and the transfer of interparticle stresses to pore water is delayed. Loss of bearing capacity: Large deformation can occur due to liquefaction which may lead to large settlements or tilting of structures. Liquefaction initially develops in sand layer at a few meters below a footing. It propagates upward through overlying sand layers and subsequently weakens the soil supporting the structure. Degree of saturation: In dry soils liquefaction does not occur. There is very little susceptibility of liquefaction in partial saturated sands. Liquefaction resistance for soil increases with decreasing degree of saturation.

7. CHARACTERISTICS OF KOLKATASA SOIL

Kolkata is situated in the eastern part of India. It has located linearly along the banks of the Hooghly River. The Kolkata municipal corporation has an area of 185 sq km. The city is lying near the sea level with average elevation 17 feet. The whole area is Ganga Delta and it is flat enough. The Bay of Bengal land fall is about 60 miles to the south. The Sundarbans National park starts within 100 km south to the city. Most of the city was marshy wetlands and remaining wetland parts which are towards the eastern parts of the city have been converted to fish farming centre. As most of the indogangetic plain which is also known as Indus Ganga and the north Indian River plain which is 255 million hectare consists of highly alluvial soil. Kolkata is situated over a basin that is formed at the boundary of continental crust and oceanic crust with large thickness of alluvial sediments. The basin can be divided into 3 parts: western most part, central hinge and deep basin part (Roy and Chattopadhyay, 1997). Subsoil condition of Kolkata municipal area: Since KMC area has been developed geologically by deposition of sediments carried by big river system, the soil below the ground is basically erratic in nature.

The area can be divided into fluvial plain, tidal flat, natural levee and aggravated channels (Nandi, 2007). It has been observed that the characteristics of the soils in different layers up to a depth of 30m are very important in modifying the earthquake shaking and liquefaction potential (Das and Chattopadhyay, 2009). Some of the sub-soil information has been published to reveal the soil profile along a particular vertical section through the KMC area in North-South direction. For construction of Kolkata Metro soil exploration were made along the metro alignment 16.6 Km from Dumdum to Tolleygaunge indicated very erratic deposition in terms of materials, thickness of layer and bedding planes. Standard Penetration Test conducted in exploratory boreholes at different locations in KMC area reveals that top soil up to a depth of 12–13 m is very much unconsolidated, where N-value varies from 0–3 (Som, 1999).

8. EFFECT OF EARTHQUAKE IN KOLKATA SOIL

- Liquefaction is not new in Kolkata. Kolkata had experienced in the Contai earthquake in 1961.Several buildings and bridges of Kolkata were damaged very badly when the earthquake was of magnitude 5.5 on the Richter scale with epi centre in Contai, East Midnapore (Nandi, 2007).
- It just struck the city. Park street flyover had faced a crack. The balcony of an old house of Kolkata has been collapsed. In Great Assam earthquake in 1897 the tower of Kolkata high court had been damaged. The spire of St Paul"s cathedral had toppled twice in earthquake first in 1897 and again in 1934. In 1906 the city had also been shaken by an earthquake.
- BBD Bag Salt lake and Newtown area are floating on a bed of slurry and it could sink in case of major earthquake strikes Kolkata (Chkrobortty et al., 2004)
- Kolkata was also shaken several times when the earthquake measuring 8.1 on the Richter scale with its epicentre somewhere near Bihar-Nepal border (Nath, 2006)
- Earlier the entire country was categorized into four earthquake zones-II, III, IV, and V where Kolkata has been categorized as a zone III according to GSI (Geological survey of India) [IS: 1893- 2002 (part 1)].

9. ANTI-LIQUEFACTION MEASURES

9.1. Compaction of soils: The liquefaction of a soil can be prevented by compaction and by increasing its relative density. Compaction is usually done by means of vibratory rollers, compaction piles, Vibro floatation, blasting, etc.

9.2. Grouting the soil: In this method the soil is stabilised by injecting chemicals or cement grout into the soil so that the voids are replaced by fine particles and shear strength of soil is increased.

9.3. Ground water pumping: The effective stress at a point increases as the water level is lowered. By restoring to extensive ground water pumping, the liquefaction can be prevented to some extent. However this method is cost effective only when the water that is pumped can be used for municipal and industrial purposes.

9.4. Drainage of soils: The liquefaction hazard can be reduced to some extent by providing course and blankets and drains in the soil deposit. The dynamic pore pressure is thus dissipated and there will be lesser chance of liquefaction.

9.5. Providing stone columns: In this method a certain number holes are bored in the soil deposit and later they are filled with gravel and stones either by inserting them into a casing or compacting them by application of external load without casing provided. The stone columns have high permeability and are quite effective for rapid drainage of pore water.

9.6. Application of surcharge: when surcharge load is applied to a soil deposit, the effective stress is increased. Thus the possibility of liquefaction is reduced as there will be higher number of cycles will be required to increase excess pore water pressure up to total overburden pressure.

10. BEST GROUND IMPROVEMENT METHOD SUITABLE FOR KOLKATA SOIL AGAINST LIQUEFACTION

10.1. Dynamic compaction: Dynamic compaction can be used as best suitable and economic applicable for constructing those structures having shallow foundation (depth of foundation less than or equal to width of foundation). Generally a huge number of constructions are going on in Kolkata mainly those places which are highly prone to liquefaction (especially Rajarhat, Newtown and Saltlake region). Except construction of high rise structures and bridges before construction of light weight structures like buildings, water tanks (except elevated service reservoir) etc. dynamic compaction must be applied. This method can be used to increase the density of soil. In this process a heavy weight dropped on the ground at regularly spaced intervals. The weight is between 8 tonne to 36 tonne depends on the degree of compaction. Degree of compaction depends on the weight of hammer and height of fall. Dynamic compaction provides an economical way of improving soil for mitigation of liquefaction hazards. From the above study it can be concluded that by the dynamic compaction method the sandy soils containing silts with hydraulic conductivities as low as 10^{-8} m/s can be improved. However, densification of soil requires specially controlled sequence of impact to inhibit pore pressure build-up at any section.

10.2. Pile driving method: For construction of heavy weight structures like high rise buildings this method is most suitable. A huge number of high rise buildings which require large length of piles, are being constructed in and around Kolkata. As a result there will be an increase in the horizontal soil stress and consequently a change of the at rest pressure coefficient. Densification of loose sand by compaction of piles can be done. Loose sand strata often need densification by artificial means to improve their relative density since they are liable to liquefaction during earthquake. The process essentially involves driving a casing that has an expandable shoe into the soil – as in the case of cast – in- situ driven piles – by repeated blows of a hammer.

11. CONCLUSION

From the above study of liquefaction phenomenon it is clear that liquefaction is a dynamic source of great economic losses. It is very important that the phenomenon and its effect should be brought to the attention of engineers, geologists and professionals involved to the planning and construction of structure. Further research is needed to make Microzonation, site investigations and precautions to prevent the impact of liquefaction. After analyzing it has been suggested that „driving of piles‟ is the best method suitable for an anti-liquefaction measure applicable to Kolkata city. Since, pile driving believed to result in an increased in the horizontal soil stress and consequently a change of soil pressure coefficient at rest. Though driven piles are most cost effective, environmentally friendly, easily available that‟s why it is best for Kolkata soil. By driving the piles into the soil strata not only increases its bearing capacity but also densify the soil by vibrating and compacting while driving onto the soil. As a result void ratio within the soil reduces substantially there will be no chance of sudden rise of excess pore water pressure. But in case of structures which will require shallow foundation in that case „dynamic compaction‟ (for cohesionless soil) would be the most suitable method applicable to Kolkata soil.

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