Construction on cohesionless soil – A review

Urvi Patel[1] Brijesh Darji[2]
[1, 2]B.Tech Student, Civil Engineering
[1,2] NSIT-Jetalpur, Ahmadabad, Gujarat, India

Abstract— In India, specifically in Gujarat region like Kutch, Bhuj, Kandla large deposits of cohesionless soil are observed. Cohesionless soil is defined asthe soil which is not containing water andthe shear strain does not exist (or is negligible)between two particles. Loose and sandy material in which there is no bond between the particles is also termed as cohesionless soil. Cohesionless soil is also known as frictional soil. Cohesionless soil have lessload bearing capacity, less shear strength, less specific surface and they do not have any plasticity. Therefore, the cohesionless soil is mostly settled during earthquake and in heavy rainy season.Owing to such properties of cohesionless soil,it is very difficult to carryout construction work on such soil in a normal way.Here, need is felt to find some problems encountered during construction on cohesionless soil and methods for preventionof these problems. This paper aims at focusing the most predominant problems encountered while doing construction on such cohesionless soil and remedial measures taken for the same.

Keyword— Cohesionless soil, Ground failure, Soil liquefaction, Structure damages, Soil washout

I. INTRODUCTION

Soil is a naturally occurring component either loose or dense depositproduced as a result of weathering or disintegration of rock formation or decay of vegetation, intermingled together. There is a variety of natural soil material found in Mother Nature's womb.

On the basis of shear strength, soil is divided intothree main types: (1) Cohesionless soil, (2) Purely cohesive soil, and (3) Cohesive-frictional soil. The soil which do not have cohesion, is known as cohesionless soil(C=0). For example, sands and gravel are cohesionless soil. The soil which exhibits cohesion but the angle of shearing resistance is zero (Φ=0) is known as purely cohesive soil. For example, saturated clay and silt under un-drained condition. Soil having composition of bothC and Φ is known as cohesive-frictional soil. These are also called as C-Φ soil. For example, clayey sand, silt, sandy clay, etc. Cohesionless soil has interesting properties which are discussed below.

Soil Texture: Soil texture is a qualitative classification tool which is used in both field and laboratory to determine classes based on physical texture.Sand is gritty, silt has a rougher texture than clay, and clay is smooth and greasy to the touch.

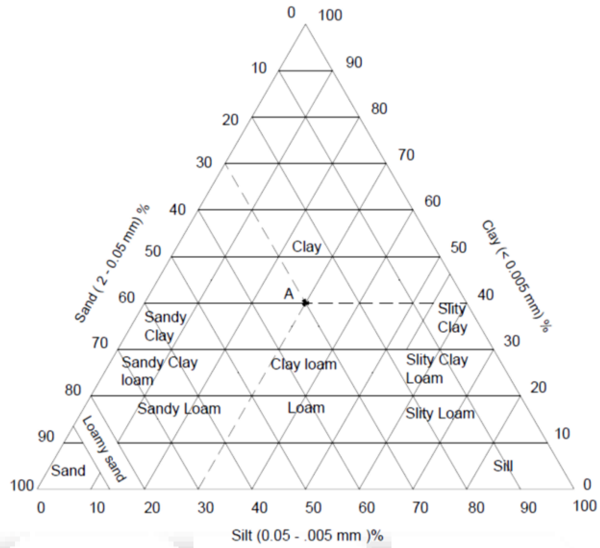

Figure. 1: Texture Classification

Strength of soil(s)--The behavior of soil under loading is very complex. The tests used to determine the strength property of soil can be divided into three broad groups. Shear tests, Bearing tests and Penetration tests.

Shear Tests-- The objective of shear tests is to determine: (a) the ultimate bearing capacity of the soil mass for the design of footings and other foundations.(b) The stability of earth slopes. (c) Estimation of earth pressure on retaining walls, footings and sheet piling etc.and (d) Design of thickness of road pavements. Understanding the shear strength of soil is one of the most complex problems in soil mechanics. There are several methods of testing the shear strength of soil in a laboratory, the most common laboratory is the Box Shear Test, Tri-axial test, Unconfined Compression test, and Vane test.

Bearing Tests--The bearing capacity of soil is determined by Unconfined Compression Test and The Vane Test.

Penetration Test-- Penetration test is used to determine strength property of soil. The most common being is the C.B.R.(California Bearing Ratio) Test, North Dakota Cone Test and Cone Penetration Test (CPT).

Shear strength of soil can easily understand by Mohr coulomb's equation explained by relation shown in figure – 2 below.

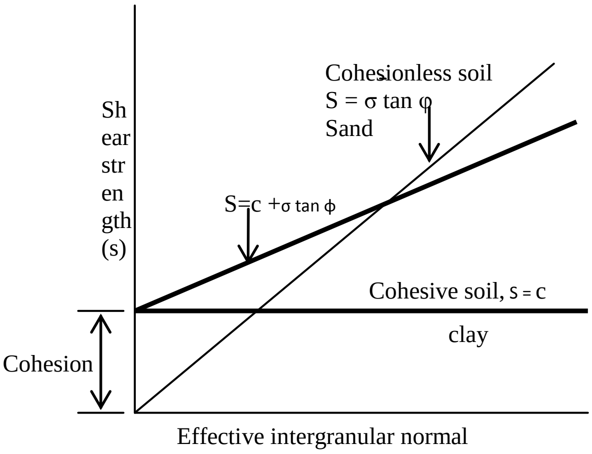

Figure. 2: Shear Strength of soil

Where,

S = Shear strength.
C = Cohesion.
σ = Effective intergranular normal (perpendicular to the Shear plane) pressure.
Ø = Angle of internal friction,
tan Ø = Coefficient of friction.

Compressibility--Gravels, sands and silts are incompressible, if a moist mass of these materials is subjected to compression; there is no significant volume change. Compressibility of sand and silt varies with density.

Density--The density or true weight of soil is equal to the specific gravity of the solid material×1000 (density of water in m^3). A soil consists of solids, pores or voids and the moisture. The overall weight of the mass (including solid particles and the effect of voids whether filled with air or water) per unit volume (i.e. total weight of soil/total volume of soil) is termed as Bulk Density. Bulk density varies with the type of soil, moisture content and its compaction. The weight of the dry solid matter contained in a unit volume of soil is termed as Dry Density.

Angle of internal friction (φ)--The resistance in sliding of grain particles of a soil mass depends upon the angle of internal friction. A measurement of the ability of the coarse grained fraction of a soil to resist shear through inter granular friction depends on size, shapedistribution of the grains, moisture content and the degree of compaction. If largeangle of internal friction the grains are angular rather than rounded,fine grained soil does not possess angle of internal friction.

II. PROBLEMS ENCOUNTERED WHEN CONSTRUCTION ON COHESIONLESS SOIL

When any structure is constructed on cohesionless soil there are four main problems encountered:

1) Earth collapsed or Ground failure
2) Soil Liquefaction
3) Structure Damages
4) Soil Washout

These four problems are briefly explained below.

1) *Earth Collapsed or Ground Failure:*

Ground failure is the term used to describe zones of ground in cracking, fissuring and localized ground displacements that can be formed by a verity of mechanisms on gently sloping grounds. Ground failure may be caused due to surface rupture along faults, secondary movement on shallow faults, shaking-induced compaction of natural deposits in sedimentary basins and river valleys, liquefaction of loose/sandy sediments, deep excavations, settlement of adjacent ground, the water content of the soil, previous disturbance of soil, ground water table etc.

Expected ground failures are fault rupture, lateral spreading, land sliding, land subsidence etc. These are briefly explained below.

Figure. 3: Earth Collapse / Ground Failure

Fault rupture- A break in the ground along the fault line during an earthquake. With a large earthquake (about magnitude 6.5 and greater) the fault rupture can reach and displace the ground surface, forming a fault scarp (steep break in slope). The resulting fault scarp may be several inches to 20 feet in height, and up to about 40 miles in length, depending on the size of the earthquake

Effects of surface fault rupture-- Hundreds of feet wide area can be affected by surface fault rupture. This is called the zone of deformation, which occurs mainly on the downthrown side of the main fault and encompasses multiple minor faults, cracks, local tilting and grabbers (down dropped blocks between faults). Buildings in the zone of deformation will be damaged, particularly building which are straddling the main fault. Anything crossing the fault, such as transportation corridors, utilities and other lifelines, both underground and above ground, can be damaged or broken. The ground can be dropped below the water table on the down dropped side, resulting in localized flooding.

Lateral sliding--Landslides are a type of slope failure, resulting in a downward and outward movement of rock, debris or soil down a slope under the force of gravity. This is usually the rapid downward movement of a mass of rock/earth or artificial fills on a slope *and* mass that moves down. They are one of the forms of erosion called mass washing, which is broadly defined as erosion involving gravity as the agent causing movement. Because gravity constantly acts on a slope, landslides only occur when the stress produced by the force of the gravity exceeds the resistance of the material. Landslides can occur naturally or be triggered by human-related activities. Naturally-occurring landslides can occur on any terrain, given the right condition of soil, moisture and the angle of slope.

They are caused by an inherent weakness or instability in the soil combined with one or more triggering events such as heavy rains, rapid snow melting, flooding, earthquakes, vibrations and other natural causes. Due to the geophysical or human factors that can induce a landslide, landslides can occur in developed areas, undeveloped areas or any areas where the terrainis altered for roads, houses, utilities, buildings and even for lawns in backyard.

Land subsidence-- Land subsidence can be defined as the sudden sinking or gradual downward settling of the earth's surface with little or no horizontal motion, owing to the subsurface movement of earth materials. Subsidence is caused by either human actions, alterations to the surface and underground hydrology or natural geologic processes and many more like collapse of underground mines, dewatering or drainage of organic soils, pumping of groundwater from limestone (sinkholes), wetting of dry, low density soil (hydro compaction), natural sediment compaction, melting of permafrost, liquefaction and crustal deformation.

Lateral spreading-- Lateral spreading is the finite, lateral movement of gently to steeply sloping, saturated soil deposits caused by earthquake-induced liquefaction.

2) *Soil Liquefaction*

Liquefaction is a phenomenon in which the strength and stiffness of soil is reduced by earthquake shaking or other rapid loading conditions. There are two types of Soil Liquefaction.

1. Residual liquefaction: Liquefaction caused by the built up of pore pressure is known as residual liquefaction.
2. Momentum liquefaction: Liquefaction caused by the upward direct pressure gradient is known as momentum liquefaction.

Reasons for liquefaction:

1. Cohesionless soil
2. Earthquake.

Liquefaction occurs in cohesion less soil which has water in pore space poorly drained when the seismic waves pass through the soil.

When liquefaction occurs the soil loses its ability to support load and due to this it cause a subsidence of building foundation, Liquefaction occur when water-laden sand or silt is subjected to vibration, the water will now escape from the sand/silt and it carries finer silt/sands, this is known in seismology circle as sand volcanoes. Liquefied soil also exerts higher pressure on retaining walls, which can cause them to tilt or slide. This movement causes settlement of soil, collapse of dams and collapse a building and infrastructure. When the seismic waves from the earthquake pass through the soil, the vibrations cause the individual grains in the soil to move around and re-adjust their positions. This ultimately results in decrease in volume of the soil mass as the grains become denser. The pore water becomes compressed. Water is relatively incompressible and as such it pushes back against the soil grains, due to this activity pore pressure becomes so high and the soil grains become almost buoyant and cause a significant drop in the shear strength of the soil to very low value. Due to liquefaction,soil loses its ability to support loads which can cause subsidence of building foundations. Increased water pressure can also trigger landslides and cause the collapse of dams.

Lower San Fernando dam suffered an underwater slide during the San Fernando earthquake, 1971. Fortunately, the dam barely avoided collapse, thereby preventing a potential disaster of flooding of the heavily populated areas below the dam. Liquefaction can lead buildings and infrastructure to collapse. Saturated soil and earthquake are two factors responsible for liquefaction.

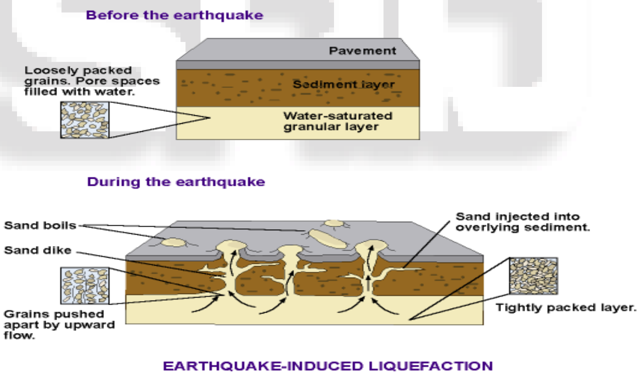

Figure. 4: Earthquake induced Liquefaction

Factors affecting Soil Liquefaction

a) Grain size distribution of sand.

Fine & uniform-size sands are believed to be more prone to Liquefaction, since the permeability of coarse sands is greater than that of fine sand.

b) Vibration characteristics.

Liquefaction and settlement depend on the nature, magnitude, and type of dynamic loading. Under dynamic loading the whole stratum may be liquefied at once, while under steady-state vibrations liquefaction may start from the top pore and precede downwards. Under steady-state vibrations, the maximum pore pressure develops only after a certain number of cycles have been imparted to the deposit. In general, it is observed that horizontal vibrations in dry sand lead to larger settlements compare to vertical vibrations. Similar behavior is anticipated in saturated sands. Multidirectional vibrations/the stress conditions created by an earthquake are more severe than one-directional loading/stress conditions. Pore water pressure builds up faster under the former conditions. The stress ratio required for a peak cyclic pore pressure ratio of 100% under multidirectional vibration conditions is about 10% less than that required under unidirectional vibration conditions.

c) Location of drainage and dimensions of deposits.

Sands are generally more pervious than fine-grained soils. However, if a pervious deposit has large dimensions than the drainage path, i.e., the drainage length of water from large soil deposits, increases and under rapid loading during an earthquake the deposit may behave as if it were undrained. Therefore, the chances of liquefaction increase in such deposits.

d) Magnitude and nature of superimposed load.

To transfer effective stress to the pore water, the intensity of vibrations or the number of particular stress cycles must be large. Hence, large initial effective stress reduces the possibility of liquefaction.

e) Method of soil formation.

Sands are generally not known to display a characteristic structure as fine-grained soil such as clays. However, recent investigation has demonstrated that the liquefaction characteristics of saturated sand under cyclic loading are significantly influenced by the method of sample preparation and the soil structure.

f) Period under sustained load.

The age of a sand deposit may influence its liquefaction characteristics. A study of the liquefaction of undisturbed sand and its freshly prepared sample indicates that the liquefaction resistance may increase by 75%. This strength increase might be due to some form of cementation or welding, which may occur at the contact points between sand particles, and might be associated with secondary compression of soil.

g) Entrapped air.

A part of the developed pore pressure might get dissipated due to the compression of air entrapped in the water; entrapped air helps to reduce the possibility of liquefaction.

3) Structure Damages

When structure is constructed on cohesionless soil without application of any ground improvement technique, then the chances of structural damages like cracks in wall, wall separation, roof collapse, multiple fractures etc. are increased.

Many silos and tanks were observed to have damage due to the earthquake. It is also observed that tanks and silos failed due to the strong ground shaking with high long period motion. There were several cases observed to have failed due to liquefied foundation conditions. Other liquefaction effects include tanks that became buoyant when the higher unit weight soil fluidized. This was observed in San Fernando Chillan, Aruaco and Lebu.

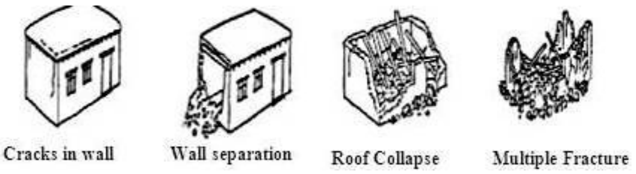

Figure. 5: Typical Structural Damages

4) Soil Washout

Wash out is the sudden erosion of soft soil due to gush of water, thunder storm, tropical cyclone or a heavy downpour of rain or other stream flooding. Severe wash out can become a landslide or cause a near then dam break.

Wash out can be prevented by vegetation whose roots hold the soil and slow the flow of water. Deforestation increases the risk of washouts. Widespread washouts can occur in mountainous areas after heavy rains, even in normally dry ravines. Retaining walls and culverts may be used, although severe washouts may even destroy these if they are not large or strong enough.

In road and rail transport, a washout is the result of a natural disaster where the roadbed is eroded away by flowing water, usually as the result of a flood. When a washout destroys a railroad's right-of-way, the track is sometimes left suspended in midair across the newly-formed gap, or it dips down into a ditch. The phenomenon is discussed in more detail under erosion. Bridges may collapse due to Bridge scour around one or more of the bridge abutments or piers.

These are the major problems which are encountered during construction of any structure on cohesionless soil.

III. CONCLUSION

After studying all the problems and reasons for their occurrence, following discussed are few methods which can be applied during construction on such soil. Hence, it becomes easy to construct any kind of structure on cohesionless soil.

1) Ground failure or Earth Collapsed

(1) Use of Vibro-compaction can be adopted as it reduces the foundation settlements and risk of liquefaction due to seismic activity and permits construction on granular fills.

(2) Vacuum consolidation replace standard pre-loading techniques eliminating the risk of failure, Combine with a water pre-loading in scare fill area. The method is used to build large developments on thick compressible soil combined with embankment pre-load using the increased stability.

(3) Pre loading reduces post-construction; settlements reduce secondary compression and densification, improving the bearing capacity.

(4) Heating groundis immobilization of radioactive or contaminated soil, densification and stabilization.

(5) Vibro replace stone column reduces foundation settlements, improves bearing capacity, reduces footing size requirements and also leads to reduction in the risk of liquefaction due to seismic activity, slope stabilization and permits construction on fills, permits shallow footing construction.

(6) Mechanical stabilized earth structure such as Reinforced Stabilized Structures are cost effective alternatives for new construction where the cost of embankment fill, right-of-way and other consideration may make a steeper slope desirable. Another use of reinforcement in engineered slopes is to improve compaction at the edges of a slope to decrease the tendency for surface sloughing.

(7) Soil nailing includes the stabilization of railroad and highway cut slopes, excavation of retaining structures in urban areas for high-rise building and underground facilities, tunnel portals in steep and unstable stratified slopes, construction and retrofitting of bridge abutments with complex boundaries involving wall support under piled foundations.

(8) For structural support and stability, foundations for new structures micro piles are used. This method can also be used for Repair / Replacement of existing foundations, Arresting / Prevention of movement, Embankment, slope and landslide stabilization.

(9) Jet grouting method is used to modify or improve ground, the soil particles in-situ to create a homogeneous mass, which turn in solidifies, providing better stability to the ground.

2) Soil Liquefaction

i. Soil compaction reduces air water and swelling.

ii. Dynamic compaction is a method that is used to increase the density of the soil which helps in the densification of the soil.

3) Structure Damages

To reduce the structural damages the following criteria are used:

- Use laws of building code
- Earthquake resistance building design
- Jolt proof joint
- Shallow excavation and use plastic sheet
- Trench box
- Bracing for shallow trench top to bottom
- Soldier piles or soldier beams are H-piling
- Soil beam and lagging or bracing on corner
- Soil nailing
- Narrow excavation bracing
- Corner bracing

4) Soil Washout

Culverts and retaining walls are two alternatives to prevent soil washout. This will lead to reduction in scouring of soil.

REFERENCES

[1] P N Khanna. “Indian practical civil engineering handbook”,

[2] K.R.ARORA” Soil Mechanics and Foundation engineering book ”

[3] B.C.PUNAMIA “Soil mechanics & foundation engineering “

[4] S.K DUGGAL Earthquake Resistant Design of Structures.

[5] V.N.S. Murthy “Text book of soil Mechanics and Foundation Engineering by.”

[6] Ronald D. Andrus & Riley M.chung.” Ground Improvement Techniques for Liquefaction Remediation near Existing Lifelines”

[7] Soil Texture, by R. B. Brown, University of Florida, Institute of Food and Agricultural Sciences. ”soil mechanics in engineering practice”