A

Seminar report

On

# Soil Liquefaction

Submitted in partial fulfillment of the requirement for the award of degree
of Bachelor of Technology in Civil

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# Acknowledgement

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# Preface

I have made this report file on the topic **Soil Liquefaction;** I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to …………..who assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

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## ABSTRACT

The presence of silt and clay particles has long been thought to affect the behavior of a sand under cyclic loading. Unfortunately, a review of studies published in the literature reveals that no clear conclusions can be drawn as to how altering fines content and plasticity actually affects the liquefaction resistance of a sand. In fact, the literature contains what appears to be contradictory evidence. There is a need to clarify the effects of fines content and plasticity on the liquefaction resistance of sandy soils, and to determine methods for accounting for these effects in engineering practice.

In order to help answer these questions, a program of research in the form of a laboratory parametric study intended to clarify the effects which varying fines content and plasticity have upon the liquefaction resistance of sandy sands was undertaken. The program of research consisted of a large number of cyclic triaxial tests performed on two sands with varying quantities of plastic and non-plastic fines. The program of research also examined the applicability of plasticity based liquefaction criteria and the effects of fines content and plasticity on pore pressure generation. Lastly, a review of how the findings of this study may affect the manner in which simplified analyses are performed in engineering practice was made. The results of the study performed are used to clarify the effects of non-plastic fines content and resolve the majority of the inconsistencies in the literature. The effects of plastic fines content and fines plasticity are shown to be different than has been previously reported. The validity of plasticity based liquefaction criteria is established, the mechanism responsible for their validity is explained, and a new simplified criteria proposed. The effects of fines content and plasticity on pore pressure generation are discussed, and several recommendations are made for implementing the findings of this study into engineering practice.

# CHAPTER 1

## 1.1 INTRODUCTION

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, 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 neighboring soil. The contact forces produced by the weight of the overlying particles holds individual soil particle in its place and provide strength.



## 1.2 DEFINITION

*"A Phenomenon where by a saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress, usually earthquake*

*Shaking or other sudden change in stress condition, causing it to behave like a liquid" is called Soil Liquefaction.*

## 1.3 WHAT IS LIQUEFACTION & WHY DOES IT OCCUR ?

Liquefaction is the process that leads to a soil suddenly losing strength, most commonly as a result of ground shaking during a large earthquake. Not all soils however, will liquefy in an earthquake.

The following are particular features of soils that potentially can liquefy:

- They are sands and silts and quite loose in the ground. Such soils do not stick together the way clay soils do.
- They are below the watertable, so all the space between the grains of sand and silt are filled with water. Dry soils above the watertable won't liquefy.

When an earthquake occurs the shaking is so rapid and violent that the sand and silt grains try to compress the spaces filled with water, but the water pushes back and pressure builds up until the grains 'float' in the water. Once that happens the soil loses its strength – it has liquefied. Soil that was once solid now behaves like a fluid.

Fig (1.30 & 1.31) Some examples of Soil Liquefaction.

## WHAT HAPPENS NEXT ?

Liquefied soil, like water, cannot support the weight of whatever is lying above it – be it the surface layers of dry soil or the concrete floors of buildings.

The liquefied soil under that weight is forced into any cracks and crevasses it can find, including those in the dry soil above, or the cracks between concrete slabs. It flows out onto the surface as boils, sand volcanoes and rivers of silt. In some cases the liquefied soil flowing up a crack can erode and widen the crack to a size big enough to accommodate a car.

Some other consequences of the soil liquefying are:

- Settlement of the ground surface due to the loss of soil from underground.
- Loss of support to building foundations.
- Floating of manholes, buried tanks and pipes in the liquefied soil - but only if the tanks and pipes are mostly empty.
- Near streams and rivers, the dry surface soil layers can slide sideways on the liquefied soil towards the streams. This is called lateral spreading and can severely damage a building.

It typically results in long tears and rips in the ground surface that look like a classic fault line.

Not all of a building's foundations might be affected by liquefaction.

The affected part may subside (settle) or be pulled sideways by lateral spreading, which can severely damage the building. Buried services such as sewer pipes can be damaged as they are warped by lateral spreading, ground settlement or flotation.

Fig (1.32 & 1.33) Some examples of Soil Liquefaction.

## AFTER THE EARTHQUAKE

After the earthquake shaking has ceased, and liquefaction effects have diminished (which may take several hours).

The permanent effects include:

• Lowering of ground levels where liquefaction and soil ejection has occurred. Ground lowering may be sufficient to make the surface close to or below the watertable, creating ponds.

• Disruption of ground due to lateral spreading.

The liquefied soil that is not ejected onto the ground surface re-densifies and regains strength, in some cases re-densified soil is stronger than before the earthquake.

Careful engineering evaluation is required to determine whether ground that has suffered liquefaction can be redeveloped.

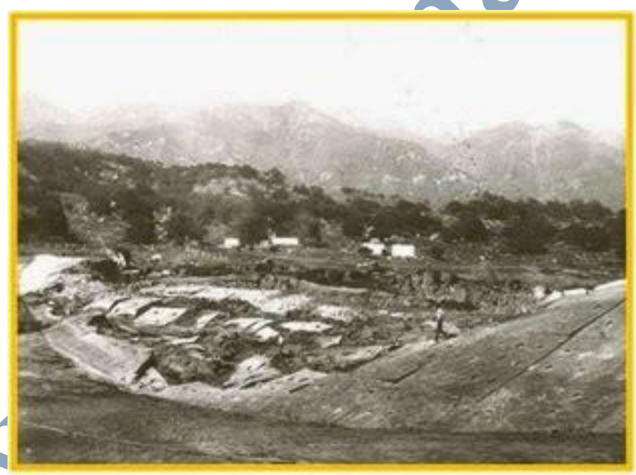
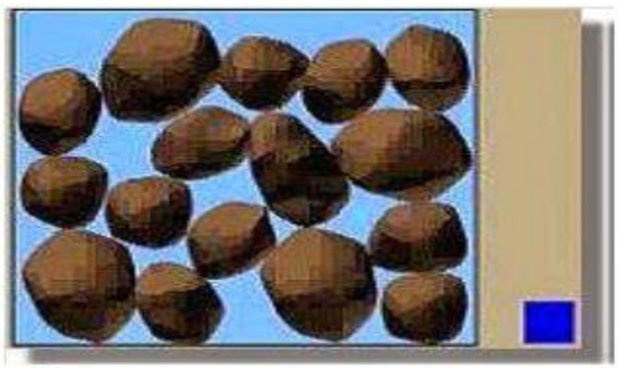
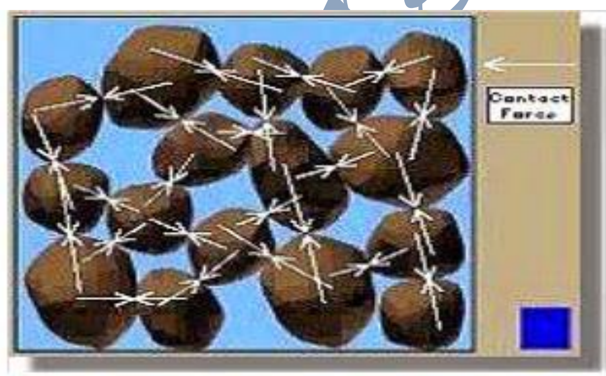


Fig (1.34 & 1.35) some examples of Soil Liquefaction.

## 1.4 CAUSE BEHIND LIQUEFACTION

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 neighboring soil. The contact forces produced by the weight of the overlying particles holds individual soil particle in its place and provide strength.






Soil grains in a soil deposit. The height of the blue column to the right represents the level of pore-water pressure in the soil.

The length of the arrows represents the size of the contact forces between individual soil grains. The contact forces are large when the pore-water pressure is low.

Occurrence of liquefaction is the result of rapid load application and break down of the loose and saturated sand and the loosely-packed individual soil particles tries to move into a denser configuration. However, there is not enough time for the pore-water of the soil to be squeezed out in case of earthquake. Instead, the water is trapped and prevents the soil particles from moving closer together. Thus, there is an increase in water pressure which reduces the contact forces between the individual soil particles causing softening and weakening of soil deposit. In extreme conditions, the soil particles may lose contact with each other due to the increased pore-water pressure. In such cases, the soil will have very little strength, and will behave more like a liquid than a solid - hence, the name "liquefaction".

Fig (1.40) Nishinomia Bridge 1995 Kobe earthquake, Japan.

# CHAPTER 2

## LITERATURE REVIEW

**Carmine Paul Polito (10 Dec 1999)**
The published results of geotechnical studies were examined in order to determine the state of knowledge on the effects of fines content and plasticity on the liquefaction resistance and pore pressure generation characteristics of sandy soils.

### 2.1 The Effects of Fine Content and Plasticity on Liquefaction Resistance

Both clean sands and sands containing fines have been shown to be liquefiable in the field (Mogami and Kubo (1953); Robertson and Campenella (1985); and Holzer et al. (1989)) and in the laboratory (Lee and Seed (1967a); Chang et al. (1982); and Koester (1994)). Additionally, non-plastic silts, most notably mine tailings, have also been found to be susceptible to liquefaction (Dobry and Alvarez (1967); Okusa et al. (1980); and Garga and McKay (1984)). A review of the literature, however, shows conflicting evidence as to the effect which fines have on the liquefaction resistance or cyclic strength of a sand. The main factors that are reviewed here are the effects of non-plastic fines content and the effects of plastic fines content and plasticity on the liquefaction resistance of sandy soils.

### 2.2 The Effects Of Non-Plastic Fine Content

There is no clear consensus in the literature as to the effect which increasing non-plastic fines content has upon the liquefaction resistance of a sand. Both field and laboratory studies have been performed, and the results of these studies indicate that increasing the non-plastic fines content in a sand will either increase the liquefaction resistance of the sand, decrease the liquefaction resistance of the sand, or decreases the liquefaction resistance until some limiting fines content is reached, and then increases its resistance. To further complicate issues, some researchers have shown that the liquefaction resistance of silty sands is not a function of the silt content of the soil so much as it is a function of the soil's sand skeleton void ratio.

### 2.3 The Effects of Plastic Fines Content and Plasticity And Plasticity Based
### Liquefaction Criteria

There is general agreement in the literature as to the effect which the quantity and plasticity of the fine-grained material has on the liquefaction resistance of a sandy soil. There is agreement that whether the fine grained material is silt or clay, or more importantly, whether it behaves plastically or non-plastically, tends to make an important, consistent difference in the cyclic strength of the soil. The majority of studies have shown that the presence of plastic fines tend to increase the liquefaction resistance of a soil.

## 2.4 Plasticity Based Liquefaction Criteria

Jennings (1980) presents a listing of the “thresholds to liquefaction” used by engineers in the People’s Republic of China to separate soils which are considered liquefiable from those considered non-liquefiable. Soils meeting these criteria are considered to be nonliquefiable and include those with plasticity indexes greater than 10, clay contents greater than 10 percent, relative densities greater than 75 percent, and void ratios less than 0.80.

Other criteria presented are related to epicentral distance, intensity, grain size and gradation, the depth of the sand layer, and the depth of the water table.

Seed et al. (1973) in their review of the slides that occurred in the Lower San Fernando Dam during the February 1971 San Fernando earthquake presented a modified form of the Chinese criteria. As reported by Marcuson et al. (1990), soils with greater than 15 percent material finer than 0.005 mm, liquid limits greater than 35 percent, and water contents less than 90 percent of the liquid limit should be safe from liquefaction.

## 2.5 The Effects Of Fines Content And Plasticity On Pore Pressure Generation

The rate and magnitude of pore pressure generation may have important effects on the shear strength, stability, and settlement characteristics of a soil mass, even if the soil does not liquefy. Similarly, the peak pore pressure generated may affect the stability of structure founded on, or in the soil mass.

## 2.6 Rate And Magnitude Of Pore Pressure Generation

There are two methods of examining the rate and magnitude of pore pressure generation during cyclic loading which have been reported in the literature. The first is to examine the pore pressures generated in relation to the ratio of the number of cycles of loading applied to the number of cycles required to cause liquefaction. This is the method used by Lee and Albaisa (1974). Pore pressures may also be measured in terms of the strain required to generate them. This is the approached taken by Dobry et al (1982).

# CHAPTER 3

## 3.1 SOIL PROPERTIES DURING LIQUEFACTION

### SHRINKAGE LIMIT

The shrinkage limit (SL) is the water content where further loss of moisture will not result in any more volume reduction.

### PLASTIC LIMIT

The plastic limit (PL) is determined by rolling out a thread of the fine portion of a soil on a flat, non-porous surface.

### LIQUID LIMIT

The liquid limit (LL) is often conceptually defined as the water content at which the behavior of a clayey soil changes from plastic to liquid . Actually, clayey soil does have a very small shear strength at the liquid limit and the strength decreases as water content increases; the transition from plastic to liquid behavior occurs over a range of water contents.

### THE ATTERBERG LIMITS

The Atterberg Limits are a basic measure of the critical water contents of a fine-grained soil, such as its shrinkage limit, plastic limit, and liquid limit. As a dry, clayey soil takes on increasing amounts of water, it undergoes dramatic and distinct changes in behavior and consistency. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. In each state, the consistency and behavior of a soil is different and consequently so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behavior. The Atterberg limits can be used to distinguish between silt and clay, and it can distinguish between different types of silts and clays. These limits were created by Albert Atterberg, a Swedish chemist. They were later refined by Arthur Casagrande. These distinctions in soil are used in assessing the soils that are to have structures built on. Soils when wet retain water and some expand in volume. The amount of expansion is related to the ability of the soil to take in water and its structural make-up (the type of atoms present). These tests are mainly used on clayey or silty soils since these are the soils that expand and shrink due to moisture content. Clays and silts react with the water and thus change sizes and have varying shear strengths. Thus these tests are used widely in the preliminary stages of designing any structure to ensure that the soil will have the correct amount of shear strength and not too much change in volume as it expands and shrinks with different moisture contents.

As a hard, rigid solid in the dry state, soil becomes a crumbly (friable) semisolid when a certain moisture content, termed the shrinkage limit, is reached. If it is an expansive soil, this soil will also begin to swell in volume as this moisture content is exceeded. Increasing the water content beyond the soil's plastic limit will transform it into a malleable, plastic mass, which causes additional swelling. The soil will remain in this plastic state until its liquid limit is exceeded, which causes it to transform into a viscous liquid that flows when jarred.

## 3.2 POREWATER PRESSURE DURING LIQUEFACTION

A state of 'soil liquefaction' occurs when the effective stress of soil is reduced to essentially zero, which corresponds to a complete loss of shear strength. This may be initiated by either monotonic loading (e.g. single sudden occurrence of a change in stress – examples include an increase in load on an embankment or sudden loss of toe support) or cyclic loading (e.g. repeated change in stress condition – examples include wave loading or earthquake shaking)

. In both cases a soil in a saturated loose state, and one which may generate significant pore water pressure on a change in load are the most likely to liquefy.

This is because a loose soil has the tendency to compress when sheared, generating large excess Porewater Pressure as load is transferred from the soil skeleton to adjacent pore water during undrained loading. As pore water pressure rises a progressive loss of strength of the soil occurs as effective stress is reduced. It is more likely to occur in sandy or non-plastic silty soils, but may in rare cases occur in gravels and clays.

## OCCURRENCE OF SOIL LIQUEFACTION

- Liquefaction is more likely to occur in loose to moderately saturated granular soils with poor drainage, such as silty sands or sands and gravels capped or containing seams of impermeable sediments.
- During wave loading, usually cyclic undrained loading, e.g. seismic loading, loose sands tend to decrease in volume, which produces an increase in their pore water pressures and consequently a decrease in shear strength, i.e. reduction in effective stress
- The resistance of the cohesionless soil to liquefaction will depend on the density of the soil, confining stresses, soil structure. The magnitude and duration of the cyclic loading, and the extent to which shear stress reversal occurs.
- Depending on the initial void ratio, the soil material can respond to loading either strain-softening or strain-hardening. Strain-softened soils, e.g. loose sands, can be triggered to collapse, either monotonically or cyclically, if the static shear stress is greater than the ultimate or steady-state shear strength of the soil. In this case flow liquefaction occurs.

## 3.3 EARTHQUAKE LIQUEFACTION

Fig (3.30) Sand boils that erupted during the 2011 Christchurch earthquake.

The pressures generated during large earthquakes with many cycles of shaking can cause the liquefied sand and excess water to force its way to the ground surface from several metres below the ground. This is often observed as "sand boils" also called "sand blows" or "sand volcanoes" (as they appear to form small volcanic craters) at the ground surface. The phenomenon may incorporate both flow of already liquefied sand from a layer below ground, and a quicksand effect whereby upward flow of water initiates liquefaction in overlying non-liquefied sandy deposits due to buoyancy.

One positive aspect of soil liquefaction is the tendency for the effects of earthquake shaking to be significantly damped (reduced) for the remainder of the earthquake. This is because liquids do not support a shear stress and so once the soil liquefies due to shaking, subsequent earthquake shaking (transferred through ground by shear waves) is not transferred to buildings at the ground surface.

Studies of liquefaction features left by prehistoric earthquakes, called Paleoliquefaction or Paleoseismology, can reveal a great deal of information about earthquakes that occurred before records were kept or accurate measurements could be taken. Soil liquefaction induced by earthquake shaking is also a major contributor to urban seismic risk.

## TECHNICAL DEFINITION

A state of Soil Liquefaction occurs when the effective stress of soil is reduced to essentially zero, which corresponds to a complete loss of shear strength. This may be initiated by either monotonic loading or cyclic loading .

## TYPES OF FAILURES

1. Cyclic Mobility
2. Over Turning
3. Sand Boiling

These are some of failures.

## 3.4 FACTORS AFFECTING SOIL LIQUEFACTION

1. Soil Type
2. Grain size and its distribution
3. Initial relative density
4. Vibration characterstics
5. Location of drainage and dimension of deposit
6. Surcharge load
7. Method of soil formation
8. Period under sustained load
9. Previous strain history
10. Trapped Air

These are some factors affecting Soil Liquefaction.

## 3.5 CONSEQUENCE OF LIQUEFACTION

ü Settlements

ü Lateral spreads

ü Lateral flows

ü Loss of lateral support

ü Loss of bearing support

ü Flotation of bearing supports

These are some consequences of Soil Liquefaction.

# CHAPTER 4

## 4.1 SAND PHENOMENONS

- **QUICK SAND**

QuickSand forms when water saturates an area of loose sand and the ordinary sand is agitated. When the water trapped in the batch of sand cannot escape, it creates liquefied soil that can no longer support weight. Quicksand can be formed by standing or (upwards) flowing underground water (as from an underground spring), or by earthquakes. In the case of flowing underground water, the force of the water flow opposes the force of gravity, causing the granules of sand to be more buoyant. In the case of earthquakes, the shaking force can increase the pressure of shallow groundwater, liquefying sand and silt deposits. In both cases, the liquefied surface loses strength, causing buildings or other objects on that surface to sink or fall over.

The saturated sediment may appear quite solid until a change in pressure or shock initiates the liquefaction, causing the sand to form a suspension with each grain surrounded by a thin film of water. This cushioning gives quicksand, and other liquefied sediments, a spongy, fluidlike texture. Objects in the liquefied sand sink to the level at which the weight of the object is equal to the weight of the displaced sand/water mix and the object *floats* due to its buoyancy.

Fig (4.10 & 4.11) Some examples for QuickSand Phenomenon.

- **QUICK CLAY**

Quick clay, also known as Leda Clay in Canada, is a water-saturated gel, which in its solid form resemble a unique form of highly sensitive clay. This clay has a tendency to change from a relatively stiff condition to a liquid mass when it is disturbed. This gradual change in appearance from solid to liquid is a process known as spontaneous liquefaction. The clay retains a solid structure despite the high water content (up to 80 volume-%), because surface tension holds water-coated flakes of clay together in a delicate structure. When the structure is broken by a shock or sufficient shear, it turns to a fluid state.Quick clay is only found in the northern countries such as Russia, Canada, Alaska in the U.S., Norway, Sweden, and Finland, which were glaciated during the Pleistocene epoch.

Quick clay has been the underlying cause of many deadly landslides. In Canada alone, it has been associated with more than 250 mapped landslides.

Fig (4.12 & 4.13) Some examples for Quick Clay Phenomenon.

# CHAPTER 5

## 5.1 SOIL LIQUEFACTION TRAGEDIES

Fig (5.10) 1964 Niigata earthquake.

Fig (5.11) 1964 Alaska earthquake.

Fig (5.12) 1989 Loma Prieta earthquake.

Fig (5.13) 2010 Canterbury earthquake.

Fig (5.14) Liquefied soil exerts higher pressure on retaining walls,which can cause them to tilt or slide.

Fig (5.15) Foundation failure in Kerala during Tsunami (December 26th, 2004)

## 5.2 EFFECTS

The effects of lateral spreading (River Road in 2011 Christchurch earthquake)

Damage in Brooklands from the 2010 Canterbury earthquake, where buoyancy caused by soil liquefaction pushed up an underground service including this manhole

The effects of soil liquefaction on the built environment can be extremely damaging. Buildings whose foundations bear directly on sand which liquefies will experience a sudden loss of support, which will result in drastic and irregular settlement of the building causing structural damage, including cracking of foundations and damage to the building structure itself, or may leave the structure unserviceable afterwards, even without structural damage. Where a thin crust of non-liquefied soil exists between building foundation and liquefied soil, a 'punching shear' type foundation failure may occur. The irregular settlement of ground may also break underground utility lines. The upward pressure applied by the movement of liquefied soil through the crust layer can crack weak foundation slabs and enter buildings through service ducts, and may allow water to damage the building contents and electrical services.

Bridges and large buildings constructed on pile foundations may lose support from the adjacent soil and buckle, or come to rest at a tilt after shaking.

Sloping ground and ground next to rivers and lakes may slide on a liquefied soil layer (termed 'lateral spreading'), opening large cracks or fissures in the ground, and can cause significant damage to buildings, bridges, roads and services such as water, natural gas, sewerage, power and telecommunications installed in the affected ground. Buried tanks and manholes may float in the liquefied soil due to buoyancy. Earth embankments such as flood levees and earth dams may lose stability or collapse if the material comprising the embankment or its foundation liquefies.

## 5.3 MITIGATION METHODS

Methods to mitigate the effects of soil liquefaction have been devised by earthquake engineers and include various soil compaction techniques such as :

- Vibro Compaction (Compaction of the soil by depth vibrators)
- Dynamic Compaction &
- Vibro Stone Columns

These methods result in the densification of soil and enable buildings to withstand soil liquefaction.

Existing buildings can be mitigated by injecting grout into the soil to stabilize the layer of soil that is subject to liquefaction.

1. **Vibro Compaction.**

2. **Dynamic Compaction.**

**3. Vibro Stone Columns.**

These are some methods to mitigate the effects of Soil Liquefaction.

# CHAPTER 6

## 6.1 SUMMARY

This Promotes simple criterion based on “key” soil parameters that help partition liquefiable and non-liquefiable silty soils. A brief review of the physical characteristics of silts and clays is first given to help clarify some misconceptions about silty soils. Clay content and liquid limit are then considered as two “key” soil parameters that help partition liquefiable and non-liquefiable silty soils. Several case histories are presented that illustrate the applicability of using clay content as a “key” soil parameter. Attention is drawn to an analogy between the liquid limit and the shear strength of a soil.
This analogy is expanded to show that the liquid limit can be regarded as a “key” soil parameter that gives a relative measure of liquefaction susceptibility. Inadequacies of basing criteria for liquefaction of silty soils on just one “key” parameter are finally discussed, leading to the promotion of simple criteria for liquefaction of silty soils, utilising together both the clay content and the liquid limit soil parameters.

**DISCUSSION**

- The effects of the following parameters on the durability of concrete were investigated:
- Bacteria suspended in water (BW).
- Bacteria suspended in urea-CaCl2 (BU).
- Bacteria suspended in phosphate buffer (BP) and
- Different concentrations of bacteria.

All the test results were compared with that of the control concrete. It was found that all the beams made with bacteria performed better when compared to the control concrete with one exception (BW).

- The compressive strength of concretes made with BW, BU and BP were determined. It was found that concretes made with BU and BP had marginal (5 to 10%) increase in the strength whereas the concrete made with BW had marginal decrease in strength (10%) when compared to control concrete. This increase in the matrix strength (for concrete made with BU & BP) would have resulted in lesser mean expansion and would have eventually increased the overall durability performance of the concrete.
- The higher the bacterial dosage, the better was the durability performance. Further tests are planned for determining the optimum concentration of bacteria in increasing the durability

- The beams made with bacteria suspended in water (BW) performed as bad as the control concrete. Because of a difference in osmotic pressure, bacteria cannot survive in water and they will eventually lyse.

The following major reasons are attributed to the better performance of the bacterial concrete:

- Formation of a new additional layer on the surface of the already existing concrete layer.
- This new additional calcite layer formed by bacteria is highly insoluble and increases the impermeability of the specimen. Thus it resists the penetration of harmful solutions into the concrete (alkali, sulphate etc….) thereby decreasing the deleterious effects they may cause.
- The compressive strength of concretes made with BW, BU and BP were determined. It was found that concretes made with BU and BP had marginal (5 to 10%) increase in the strength whereas the concrete made with BW had marginal decrease in strength (10%) when compared to control concrete. This increase in the matrix strength (for concrete made with BU & BP) would have resulted in lesser mean expansion and would have eventually increased the overall durability performance of the concrete.
- The higher the bacterial dosage, the better was the durability performance. Further tests are planned for determining the optimum concentration of bacteria in increasing the durability performance of concrete.

**CONCLUSION**

The presence of bacteria in different mediums (water, phosphate-buffer and urea-CaCl2) increased the resistance of concrete towards alkali, sulfate, freeze-thaw attack and drying shrinkage. Phosphate-buffer proved to be an effective medium for bacteria than the other two mediums (water and urea-CaCl2).

Concrete made with bacteria suspended in water did not perform well as expected, because bacteria cannot survive in water. The durability of bacterial concrete increased with the increase in the concentration of bacteria.

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