LIQUEFACTION SUSCEPTIBILITY OF SILTY SOILS

[1]DILPREET SINGH, [2]ARSHDEEP SINGH, [3]GURWINDER SINGH, [4]ARSHVEER SINGH, [5]JASPREET SINGH

[1, 2,3,4,5]Guru Nanak Dev Engineering College, Ludhiana
E-mail: [1]dilpreetsingh2696@gmail.com, [2]arshgrewal62@gmail.com, [3]grewalguri88@gmail.com, [4]chahalarshveer@gmail.com, [5]jasbhuller05@gmail.com

Abstract— The phenomenon of liquefaction which has done considerable loss over the years is often associated with sandy soils whereas same level of emphasis is not given to silt. To determine the extent of remedial measures required for a soil against liquefaction, susceptibility to liquefaction of the same must be checked. This paper advocates a simple criterion based on two key soil parameters that differentiate liquefiable and non-liquefiable silts. Firstly, some imperative physical characteristics of silts are briefly discussed to clarify the misconceptions about silts. Following that, clay content and liquid limit are taken as two key parameters that help partition liquefiable and non-liquefiable silts. Analogy between liquid limit and the shear strength of silts is used to show that liquid limit can be regarded as a key soil parameter to measure liquefaction susceptibility. Need of using clay content as another factor is also discussed, while explaining the inadequacies of basing criterion for liquefaction of silts on just one key parameter. The applicability of using clay content as a key soil parameter is also illustrated using several case histories. Lastly, this research paper leads to the promotion off simple criteria for liquefaction of silts, utilizing together both the clay content and the liquid limit soil parameters.

Index Terms— Susceptibility, liquefaction, liquid limit, strength.

I. INTRODUCTION

Recent experience with earth failure in low plasticity silts and clay's, during vibrant earthquakes, have pointed up the fact that seismic forces can spark the development of substantial strain and strength loss over a wide range of saturated soil from clay's to sand.
However, the earthquakes which induced ground failure are less frequent in silts, but a number of cases have expressed the need for a better understanding of seismic behavior of fine grained soils and for an engineering procedure that are most suitable for differential liquefiable and non-liquefiable and non-liquefiable silts.
There is insufficient guidance on engineering procedure that is most suitable for evaluating potential strains and strength loss, particularly for silts. Hence, it is common to compare the results of current susceptibility criteria that exist, which were developed for sands.
This paper present liquefaction susceptibility criteria based on two 'Key' soil parameters, clay content and liquid limit.

II. SUSCEPTIBILITY OF SILTS TO LIQUEFACTION

There is a lot of confusion in geotechnical engineering about liquefaction susceptibility of silty soils. It is noticed that liquefaction susceptibility of silts must fall somewhere between high susceptibility of sand and the non-susceptibility of clays, as the grain size of silt particles lies in between the sand and clay. In addition to it, liquefaction susceptibility of silt is further exasperated where silts and clay are categorized under one leading finest.
Silt, indeed are very fine sand and have grain size less than 0.074m. Silt grains cannot be seen by naked eyes, but this fact does not significantly veer physical characteristics of silt grains to that of sand grain.
For example, silt grains and sand grains are generally of same shape and comprise of rock forming mineral. Alike, sand grains, attraction force such as hydrogen bond and van-der waals bond are negligible between silt grains.
The soil of grain finer than 0.02mm is regarded as clay and they bear very less similarity to sand and silts. Since, clay particles are comprised of clay minerals; they have high plasticity and tend to be platey shape. Moreover, hydrogen and van-der waals forces of attraction exist between the particles due to which clays exhibit plastic nature. Based on the comparison of silts and clay, silts are more similar to sand.
Now, the doubt arises, at what clay content susceptibility of silt changes from liquefaction susceptibility of sands to that of clay?

III. KEY SOIL PARAMETERS THAT DIFFERENTIATE LIQUEFIABLE AND NON-LIQUEFIABLE SILTS

The clayey soil prone to potential strain and severe strength loss, as outlined by Seed etal. (1983), from case history of china's earthquake, by which Wang (1979) expected to have following characteristics;

Clay Content	<15%
Liquid Limit	>35%
And Water Content	>0.9(L.L)

To fortify the criteria outlined by seed et al. and promote their application to silts, further case histories are used in this paper. However, it is worth noting that water content is not considered as key Parameter, as its value changes remarkably according to environmental conditions.

IV. CLAY CONTENT

A plethora of case histories evidence that silt having low clay content is highly sensitive to liquefaction. A brief discussion of case histories is as under:

Kishida (1970) inspected the grain size distribution of soils generated at Nanechama Beach, Japan during Tokachioki earthquake of 1968. The figure indicates that the soil which liquefied was very silty and had clay content less than 10%.

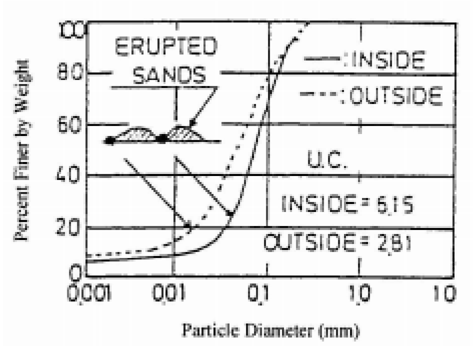

Figure 1: Soil Boils (GRAIN DISTRIBUTION CURVE)

Kishida points out that grain size distribution of boils showed resemblance with grain size distribution of soil located at a depth 1m to 12m. However, the grain size distribution of the boils did not match those soils at depth 12m to 17m. These soils had clay content more than 10% and did not liquefy.

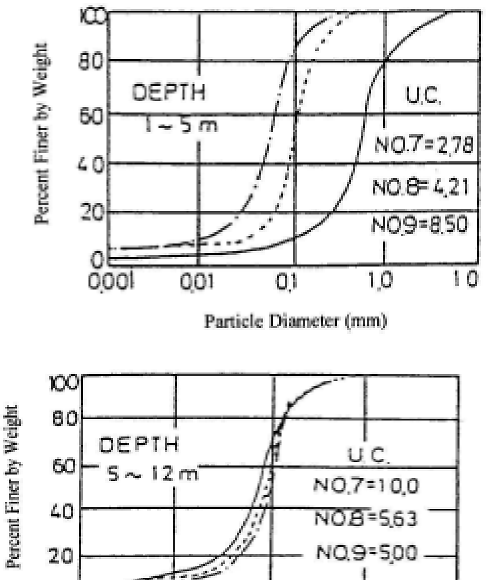

Figure 2: Grain Size Distribution of Soils

Figueroa et al. (1995) determine this grain size distribution of soil samples called from sand boils formed at the lower San Fernando Dam, California during north bridge earthquake of 1994. The curve is shown in Fig. 1. The soil formed to be very silt with clay content less than 10%.

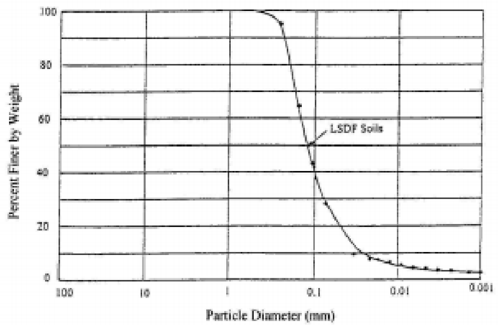

Figure 3: LSFD Soils

Tokimatsu and Yoshimi (1983), after an intensive research collected, 90 case histories of liquefaction (70 inside Japan from 10 earthquake and 20 outside Japan). They proposed a triangular classification chart representing the grain sizes of silty sand to slightly sand silt soils.

By defining clay as grains finer than 0.005mm, they depicts a cut off for liquefaction susceptibility at clay content 20%, however, a cut off at clay content may be more accurate. On the other hand, if clay is defined as grains finer than 0.002mm, a final cut off at clay content of about 10% would be appropriate.

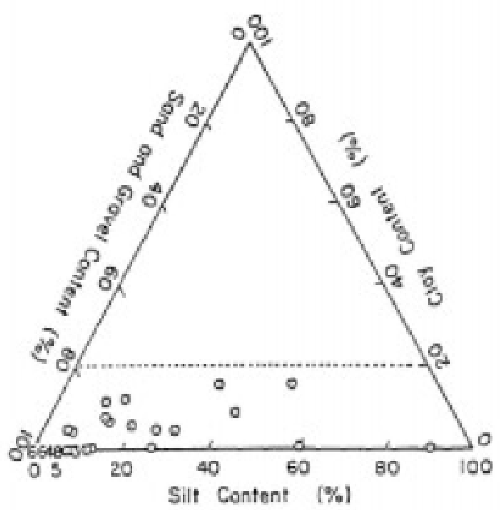

Figure 4: Grain Size of Liquefied Soils

Tuttle et. al (1990) published liquefaction failures occurred during saguenay earthquake of 1998 at Ferland, Canada. As indicated by grain size distribution curve of the sand boils erupted, the soil liquefying was a very silty sand to slightly silt having clay content less than 10%. Soil laid at depth 1.5m to 9m advocates strength loss. Clayey silts at depth of about 9m to 11m were not erupted in boils and seem to have not liquefied.

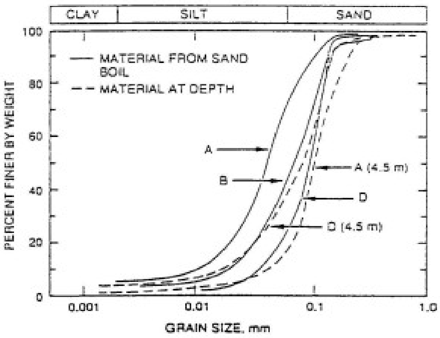

Figure 5: Grain Size Distribution of Soils

Zhou(1981) examined the liquefaction that arose in Tangshan, China during Tangshan earthquake of 1976. Lutai, southwest of Tangshan, was the most affected area. Across section of several soil layers are shown in Fig. 33333. Similar patterns of grain size distribution curve were also seen and clay content of the soil erupted in soil boils was found to be less than 10%.

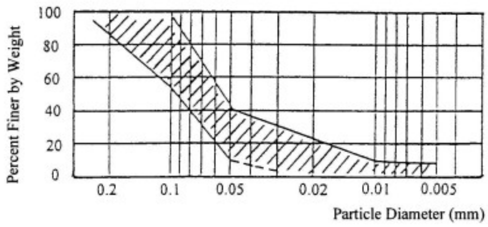

Figure 6: Ejecta Grain Size distribution Curve

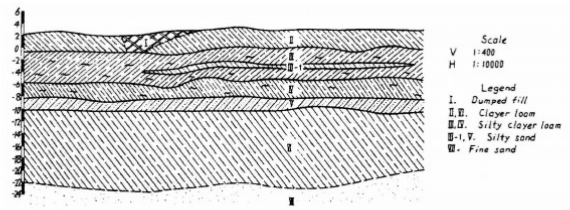

Figure7: Lutai Area stratigraphy

Zhou (1981) illustrated the grain size distribution of layer 3 and layer 2 of Lutai area. According to Zhou, layer 3 exist only in some parts of Lutai area, and consists of a less deposit 0.5 to 1.0 thick, located at a depth of 6m. For layer 5 soilswere found to be sandy to slightly sandy silt with clay content 19% (for clay finer than 0.005mm). For clay finer than 0.002mm, it could be supposed that the clay content is up to say 15%.

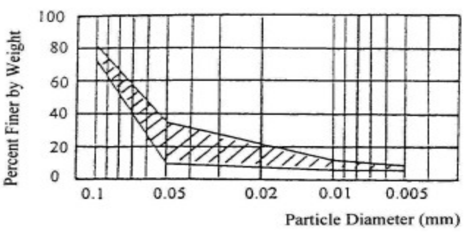

Figure 8: Layer III-1 Curve

According to Zhou, layer 5, which is presented all over the Lutai, about 2.5m thick and positioned at a depth of about 10m. Considerably, in a macro-survey it was found that in areas where both lenses layer 3 and 5 were present, severe eruption occurred. However, no significant eruption occurred where only high clay content layer 5 was present.

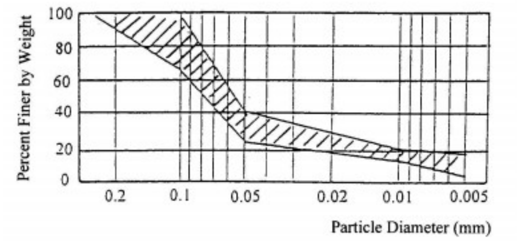

Figure 9: Layer V Distribution Curve

The aforementioned case histories illuminate liquefaction of silty soils and further relevancy of using

Clay content is a 'Key' soil parameter that differentiates liquefiable and non-liquefiable silts. In addition to this, the clay content is criterion highlighted by Seed at. el (1983) is strengthen by these case histories. The criteria developed is also reinforced by seed et al. (1964) where it was depicted that at about 10% natural clay content, Skelton voids in a sand would be filled with clay. Hence for clay contents greater than 10%, soil is termed as non-liquefiable.

V. LIQUID LIMIT

The liquid limit of a soil is defined as the water content at which the soil has a shear strength of approximately 25 gm/cm^2 seed et al (1964) or simply the minimum water content at which soil changes from liquid state to plastic state.

Seed et al (1983) also described liquid limit criterion among the three criteria for estimating potential strain and strength loss during severe earthquakes. Intergranular attraction forces reward shear strength to plastic soils. As the water content, void ratio and inter grain spacing are interconnected liquid limit can be visualized as a measure of grain spacing at which attraction forces provides a shear strength of 25 gm/cm^2. Consequently, a silty sand with high liquid limit will have a high net attractive force between any clay particles present and on the other hand, a silty soil with low liquid will possess less net attractive forces. Attractive forces tend to resist liquefaction, bestowing on silty soil a relatively low vulnerability to liquefaction. This fact defines the liquid limit as a key soil parameter that differentiate liquefiable and non-liquefiable silts.

Moreover, liquid limit is also proportional to clay content seed et al (1964) and maximum liquid limit of naturally occurring clays is 300. For a liquefiable soil, an upper limit of about 30 consistent with 10% clay criterion explained above.

VI. REFINEMENT OF CRITERIA FOR LIQUEFACTION OF SILTY SOILS

A criterion solely based on clay content does not hold good for all the conditions, where at one extreme, clay sized grains are non-plastic and at other extreme, non-clay sized grains shows plastic nature. A fine illustration of first case is mining and quarry tailings. These tailings often have clay sized non-plastic crushed stone grains. On the other hand, Mica is the perfect example of latter case. Mica rock forming minerals are completely opposite to clay minerals, illite and montmorillonite. Mica have grains similar to silt possess plasticity. Using liquid limit along with clay content criteria can eradicate errors during these extremities.

Seed et al (1983) liquid limit criteria was based on Chinese PRC data which uses PRC fall cone penetration apparatus to find liquid limit. Koester compared the liquid limit results given by Casagrande's type percussion apparatus and PRC fall cone penetration apparatus and observed that PRC method gave a higher value of liquid limit. As per Koester, a liquid limit value of 35 determined by PRC fall cone penetration is equivalent to a liquid limit of about 32 determined by Casangrande's type percussion apparatus.

CONCLUSION

The following concluding statements can be made:

1. There is an ample data showing that silts are vulnerable to strength loss and potential strains.
2. Clay Content can be regarded as a 'Key' soil parameter that differentiate liquefiable and non-liquefiable silts.
3. Liquid limit can be regarded as a 'Key' soil parameter that differentiate liquefiable and non-liquefiable silts.
4. Use of liquid limit criteria along with clay content criterion helps explore cases where clay sized particles are non-plastic and non-clay sized particles are plastic.

Based on the case histories and theory presented above, a fortified version of Seed et al (1983) criteria is given in following table.

	Liquid Limit < 32	**Liquid Limit > 32**
Clay Content < 10%	**Susceptible**	**Further Studies Required (Examining plastic non clay size grains such as Mica)**
Clay Content > 10%	**Further Studies Required (Examining non-plastic clay sized particles such as mining tailings)**	**Not Susceptible**

Notes:
1)Liquid limit determined by Casagrande's apparatus.
2)Clay defined as grains finer than .002mm.

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