

## Liquefaction Mechanisms and Mitigation-A Review

Nurmunira Binti Muhammad, Abdoullah Namdar and Ideris Bin Zakaria  
Department of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, Malaysia

**Abstract:** It is aimed to review a series of the research investigation on liquefaction mechanism for mitigation. A number of theoretical and computational studies have been performed by various researchers to determine the different types of liquefaction mechanism and evaluating ultimate bearing capacity of foundations in the presence of the static, dynamic and blast pore water pressure. But never these mechanisms have been compared base on latest scientific achievement. The liquefaction mechanisms of soil foundation under different condition have been reviewed by comparing experimental and numerical modeling for better interpretation. The result has been highlighted that the water pressure function could be controlled without reducing pore water pressure magnitude. This guideline could be used for liquefaction mitigation. The research requirement is also recommended.

**Keywords:** Foundation stability, new achievement, liquefaction, pore water pressure

### INTRODUCTION

The liquefaction has appeared inform of static liquefaction, dynamic liquefaction and blast liquefaction. The mechanism of liquefaction governs by several factors. In comparing all liquefactions, the static liquefaction creates due to structure and subsoil self-weight and other liquefaction occurred due to combination of structure and subsoil self-weight, shaking and blasting. The soil fabric due to excising pore water pressure in all types of liquefaction has been observed but the excess pore water characteristics are different.

The effect of initial static shear stresses and stress-strain relationship to analysis for a new nonlinear model with initial static shear stresses has been reported Akira and Hidetoshi (1986). There is also an explanation on soil mechanical properties investigation for definition static pre-shearing of medium dense granular soils and releasing static liquefaction resistance (Rahhal and Lefebvre, 2000). Static liquefaction in saturated loose sand has been discussed throughout the numerically modeling analysis based on alsoto-viscoplastic and non-local viscoplastic for evaluation of subsoil instability (Claudio and Silvia, 2002). The undrained triaxial test has been conducted to study sand static liquefaction behavior under two different types of specimen have been prepared the first one was the dry funnel eluviations and the second one was wet deposition for understanding effect of the method of preparation of sample on the liquefaction resistance (Della *et al.*, 2009). In a research work under laboratory condition different loose reinforced sand by short flexible fibers

have been tested to mitigate static liquefaction potential (Ibraim *et al.*, 2010). The static liquefaction mitigation of sandy subsoil has been made by several techniques, another example is sand reinforced with randomly distributing short polypropylene fiber (12 mm long) and experimental have been conducted using a ring-shear apparatus (DPRI-Ver.5) for assessing fiber effect on static liquefaction mitigation (Liu *et al.*, 2011). These are several attempts (Akira and Hidetoshi, 1986; Rahhal and Lefebvre, 2000; Claudio and Silvia, 2002; Della *et al.*, 2009; Ibraim *et al.*, 2010; Liu *et al.*, 2011) for liquefaction mitigation. But still many interpretations on liquefaction mitigation concept have been left.

Centrifuge validation of a numerical model for dynamic soil liquefaction has been reported the all required parameters for modeling derived using conventional laboratory soil experiments (Radupopescu and Prevost, 1993). In parallel to the research work some valuable review papers are published among those review on seismic safety of embankments and earth and rock-fill dams, briefly summarized the important development achieved on liquefaction (Yenerozkan, 1998). The liquefaction triggering modeling on several sands and silty sands with mechanical properties have been reported using cyclic triaxial, torsional and simple shear test. The proposed model had correlation with strain energy. This concept used for interpreting triggering dynamic liquefaction assessment of sand-silt deposits (Baziar and Jafarian, 2007). In continuing on dynamic liquefaction assessment the characteristics of the time-varying dynamic responses of a quay wall and grounds far from the quay wall based on PIF, with the aid of the HHT data-processing technique (EMD and HSA)

investigated. The HHT method represents a new tool in tracking changes in the seismic behavior of liquefaction soil and quay walls and then recognizing, understanding and interpreting their responses in greater detail throughout the shaking period (Yu-Chen *et al.*, 2010). The investigation on soil liquefaction in Taiwan two days after earthquake performed for present the preliminary geotechnical reconnaissance results with a focus on the engineering properties related to soil liquefaction. And also empirical correlation and laboratory testing results have been analyzed to assess the liquefaction resistance on high fines content soil (Wen-Jong *et al.*, 2011). An approach is introduced based on evolutionary polynomial regression for assessment of the liquefaction potential and lateral spreading due to earthquakes. For this investigation data are collected from different sources including 42 field cases includes 484 case histories from 11 earthquakes. The results of the developed models for evaluation of liquefaction and lateral spreading are compared with those obtained from the most commonly used technique in each case (Rezania *et al.*, 2011). There is a numerical simulation of the effect of soil liquefaction on surface structures and also a full model configuration for a generic charge-soil-structure system is described (Zhongqi *et al.*, 2011). The liquefied soil and pile foundation stability has been investigated in three different steps: field observation, laboratory testing and numerical simulation in order to provide better insights into the dynamic behavior of pile foundation in liquefied soils (Amin and Ali, 2012). And also permeability has been considered for understanding liquefaction behavior (Shahir *et al.*, 2012). The homogeneous and heterogeneous soils are important factor for dynamic liquefaction mechanism which is explained perfectly (Chakraborty and Popescu, 2012). In all cases the pore water pressure, effective stress and soil mass are considered and mitigation as well as theorization of liquefaction concept evaluated.

It is an attempt to study liquefaction-mechanisms for improving foundation stability and design based on comparing several scientific achievements. And aimed to provide acceptable guideline in considering limitation of this review study and propose requirement research to understanding liquefaction mechanism.

### LIQUEFACTION MECHANISMS

The static external loading and gravity force induced static liquefaction in loose or medium dense sand when the pore water pressure is increased and the effective pressure reached to the zero. The factors like granular permeability coefficient, eccentricity static gravity force and lateral pressure due to differential

settlement, soil fabrication and morphology are important in liquefaction resistance. In Rollins and Seed (1990) identified effect of density and static shear stress on liquefaction resistance of sandy subsoil.

The sand from one side has high level of permeability coefficient under ordinary condition like laboratory and from other side if is subjected to the external force faced non-permeability and reducing shear strength, volumetric instability and liquefaction due to its morphology and particle movement.

The liquefaction started from hydraulic characteristics of water and in correlation with mechanical characteristics of soil is effected to the subsoil and structures stability based on loads and displacements. In the static liquefaction, static self-weight of structure and surcharge govern liquefaction function. And in the dynamic liquefaction the seismic or dynamic force are play main role in liquefaction ability. And in the both case the shear-stress and shear-strain have unique value especially in initial triggering and it can be more destructive. There are many unknown factor on liquefaction behave, it is hope of after realizing liquefaction mechanism the numerical simulation be close to precision.

The static liquefaction resulted in increasing large strain and reducing shear strength (Poulos, 1981) and it may end with subsoil and structure instability.

**Liquefaction mitigation:** It has been finding that the sand polypropylene fiber reinforced reduced static liquefaction and lateral spreading of specimen (Ibrahim *et al.*, 2010), the fiber not increased sand compression and tensile strengths but reduced re-fabrication of sand particle and mass soil shown more geometrical stability in presence of fibers even if pore water pressure has not been reduced.

An investigation on mitigation static liquefaction shown that application of fiber-reinforcement in loose sand not greatly influenced on sand shear behavior, but for medium dense and dense samples are affected (Liu *et al.*, 2011), if the fiber is deformed instate of smooth, may be shear behavior improved in loose sand, even in this case still in medium dense and dense shear behavior will be better due to fiber-sand healthier bending.

The effectiveness of the reinforcement in soil influenced under factors like fiber type, volume fraction, length, aspect ratio, modulus of elasticity and orientation and also soil morphology and gradation, as well as stress level and density (Jewell and Wroth, 1987; Palmeria and Milligan, 1989; Michalowski and Cermak, 2002). However, he most common procedure

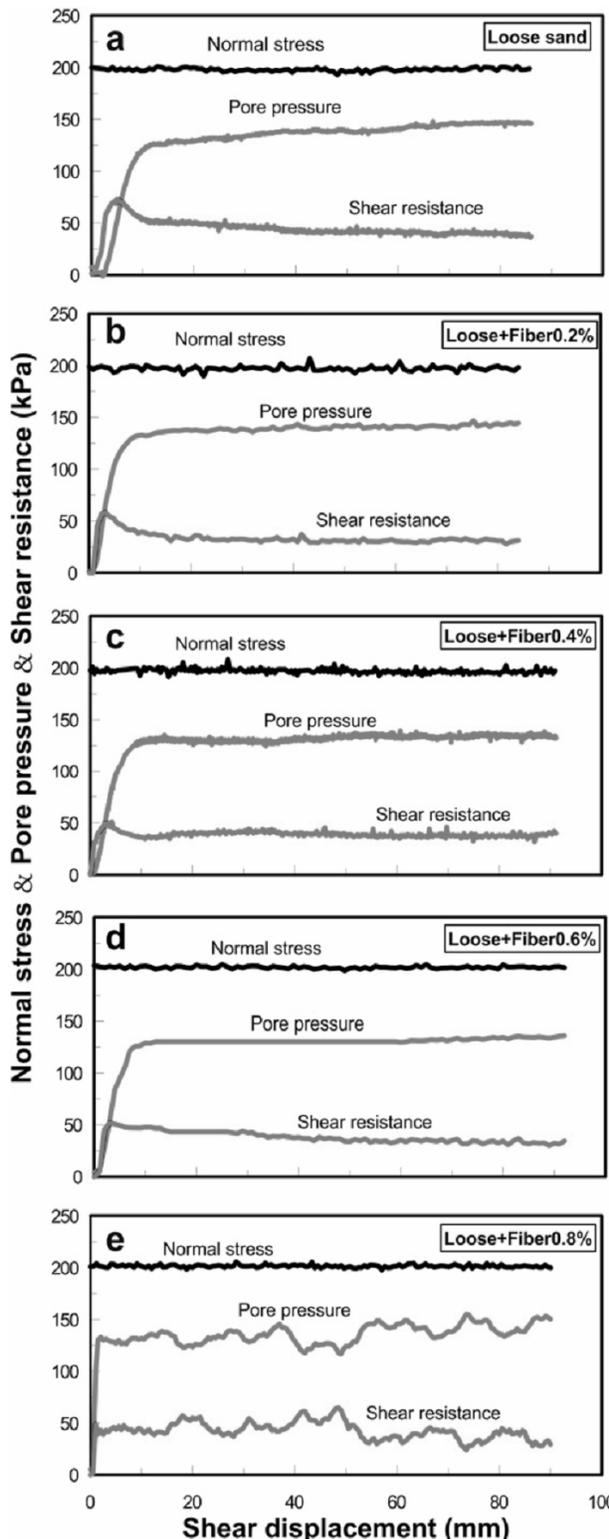


Fig. 1: Normal stress, pore pressure and shear resistance against shear displacement for loose samples with different fiber contents (Liu *et al.*, 2011)

for preparing reinforced specimens, moist tamping and leading to preferred sub-horizontal orientation of fibers (Diambra *et al.*, 2008). When the fiber is increased to 0.8% in the soil reinforced in Fig. 1, due to reducing density and allowing soil particles to refabricate the pore water pressure shown non-linear behavior. It is required having a fiber with appropriate density and bending with soil in order to have more linear excessing pore water pressure to control liquefaction. Fiber with surface roughness is acceptable fiber. And regarding to fiber density may be chemical modification process on fiber is required and or sometimes increasing degree of saturation in fiber resulted in increasing density and tensile strength of fiber. As long as no tensile fiber failure has been observed in soil fiber reinforcement, the fiber density is more important in liquefaction mitigation.

The whole specimen mass characteristic has resistance against lateral pressure. There is not destructive pore water pressure. The fiber changed whole soil mass morphology. It means that there is sand without drainage and cohesion. But the fibers act as small bracing controlled sand particles to not refabricate. It is a micro system for liquefaction mitigation.

**Pore water pressure mechanism:** The pore water pressure mechanism has been reported under seismically condition (Chakraborty *et al.*, 2008, 2010; Popescu *et al.*, 2006; Chakraborty, 2008). It is important to consider that the mechanism of liquefaction always not same. In the several literatures static liquefaction, earthquake liquefaction and blasting liquefaction have been reported and explained clearly with practical examples.

The earthquake liquefaction loading on the soil mass arises from oscillatory shear waves, of which predominant motion is in the horizontal plane. And the amplitude of motion is generally small and the large cycles of deformation with predominant period on the order of one second is observed. And in the blast loading has big amplitude and propagated rapidly outward and it is decreased from the source. And the blast predominant of frequency is higher than earthquake (Liyanapathirana and Poulos, 2002; Zeghaland and EiShamy, 2008; Arya *et al.*, 1978; Melzer, 1978). But in all liquefaction mechanisms, soil is transferred from the solid state to the liquefied state and subsequently pore water pressure increases and effective stress decreases. However, it is essential in numerical simulation studying pore water pressure-soil interaction mechanisms. Figure 2 is indicated increasing pore water pressure in the outside and inside liquefied soils, and figure one in 0.8% fiber-sand

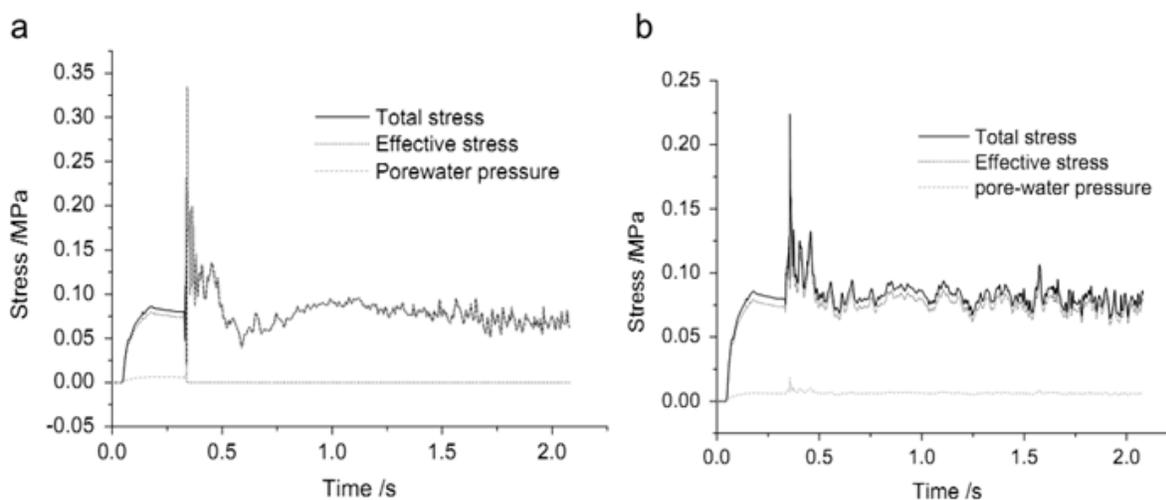


Fig. 2: Stress history curves at two representative locations (a) 8.5 m-inside liquefaction zone and (b) 9.5 m-outside liquefaction zone (Zhongqi *et al.*, 2011)

mixture shown non-linear pore water pressures. This kind of differential pore water pressure could help in creating differential settlement. It is important to keep in mind that in liquefaction mitigation planning any mitigation may not be safe for structure and it may causes other problem for structure or subsoil.

**Research limitation:** The limitation of this research work is the solid physics concept has been not correlated with theory of elasticity and plasticity for analyzing effect of Nano particle on liquefaction mechanism.

**Research requirement:** The research requirement is in case the static, dynamic and blast liquefaction is occurred simultaneously how will be liquefaction mechanism.

The effects of fiber roughness and morphology on pore water pressure and liquefaction behavior require to be investigated. And it is essential analyzing effect of Nano particle on liquefaction mechanisms.

### CONCLUSION

- The effect of fiber surface on the controlling liquefaction and excess pore water pressure has been finding an important factor for further investigation.
- The fiber improve sand liquefaction resistance, drainage and sand mass lateral deformation but no effected on pore water pressure mitigation.
- The sand-fiber reinforcement improved specimen lateral pressure resistance. There is not destructive

pore water pressure. The fibers act as small bracing controlled sand particles to not refabricate. It is a micro system for liquefaction mitigation

- The non-linear pore water pressure can cause structure or subsoil differential settlement. And liquefaction mitigation planning should not cause other problem for structure or subsoil.
- The research requirement and limitation have been reviewed and it can help for future research.

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