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Tsunami and Liquefaction Resistance of Subsoil

Abdoullah Namdar
Faculty of Civil Engineering & Earth Resources
Universiti Malaysia Pahang
ab_namdar@yahoo.com

ABSTRACT

To minimize destructive effect of tsunami, accurate investigation requires. It is well known that the effect of tsunami on subsoil is not always similar and depend on many parameters. The geological properties and geomorphology of region play important role in situ stress during a tsunami. In this investigation, several factors play important role in changing site geological and geomorphology properties during a tsunami have been discussed. The liquefaction resistance of site after tsunami has also been discussed. The naturally mixed soil due to tsunami changes geomorphology and mineralogical profile of site. The naturally mixed soil in laboratory helps to predict liquefaction resistance after tsunami.

KEYWORDS: Geological properties, geomorphology, stress, naturally mixed soil, mineralogical profile

INTRODUCTION

The stability of soil during a tsunami makes urban design a complicate task. It is well known that liquefaction mostly appears in loose saturated cohesionless soil where pore water pressure is reached to maximum level in very short time, and main aftermath fails subsoil. The structure of urban, shape of structures, type of foundation, along with force, direction, frequency and duration of earthquake are important factors to stability of subsoil and liquefaction resistance during a tsunami. The history of earthquake provides valuable information for tsunami forecasting.

The US Geological Survey (USGS) lists 96 significant earthquakes of magnitude 6.5 or greater in the year 2008 only (Tucker, 2004). The three phases for controlling earthquakes are (1) seismic hazard assessment and input ground motion characteristics, (2) modification of these input ground motion due to site conditions, and (3) vulnerability formulations to estimate damage distribution (Atilla, Ansal et al, 2010). The accuracy of earthquake simulation in small zonation provides unique information for earthquake damage mitigation.

The research on liquefaction at Kaiapoi based on nature of settlement has been investigated in urban area (Christensen, 2001). The investigation shown that the M6.3 shaking on 2011 at distance of 22 km in duration of 10 second of 0.21 g created liquefaction in some part of Kaiapoi (GNS, 2011). There is an investigation based on application of GIS in Japan-US collaboration for earthquake restoration and mitigation planning for Kobe of Japan based on instructing spatial analysis and graphic communication, professional experience, mediating local knowledge trough academic and professional actors. These concepts concentrated on three areas in different size, faced different strong earthquake result (Tanaka, 2009). There is a scientific work has been introduced for risk-oriented for seismic micro-zonation study of an urban to analyze acceptable settlement through local seismic response for risk mitigation measure. The work was for improving accuracy of probabilistic seismic hazard analysis (Romeo, 2006). There is a study in Metro Manila on building seismic capacity and reliability to estimating damage and comparing (Miura, 2008). It has been reported on different level of liquefaction in urban area based on field collected soil mechanical properties data and calculating soil factor of safety for liquefaction (Mhaske, 2010). Another important concept in urban seismic and tsunami analysis is effect of earthquake on particular structure if affected by tsunami simultaneously, may create big aftermath, in this regard the nuclear plant is one of that kind structures, for such urban safety one research work has been reported to evaluate safety implication of near-fault earthquake ground motion on the design nuclear plant (NUREG/CR 6728, 2001). The urban seismic analysis has important role for social, environmental and functional dimensions of housing (Akinci, 2004). There is excellent and perfect documented research work on liquefaction and no liquefaction cases with comparing potentials from 31 CPT profiles, the aim was to develop feasible guideline for prediction liquefaction based on geological similarities (Heidari, 2010). The erosion, sediment deposit, naturally mixed soil, modified subsoil mineralogy, subsoil stability and liquefaction resistance prediction after a tsunami have been assessed where the coastal area is under change in geological profile and geomorphology during a tsunami.

TSUNAMI AND LIQUEFACTION

The tsunami usually occurs in the oceans, seas and gulf (Alpar and Yaltırak, 2002; Altinok et al., 2001). The landslides generate tsunami's waves in offshore (Tinti et al., 2005). The earthquake causes landslide on the continental slope (Gutenberg, 1939), and tsunami if slope is in offshore. The liquefaction may starts during tsunami or earthquake in onshore and offshore. Well geological and construction information documented help in better realize relationship between structure earthquake resistance, seismic force, tsunami ability and liquefaction. The seismic force from any epicenter, frequency, direction and duration in respect to geological site characteristics and geomorphology can create liquefaction. But exactly result not clears when these parameters are mixing and if tsunami surcharge force adds to that. The figure 1 depicts the peak ground acceleration variation in a site. The geological site characteristic, self-weight of structures, geomorphology of site and wave of tsunami govern the liquefaction resistance of subsoil. These parameters make prediction of liquefaction a complicate task. In an reconnaissance on liquefaction behavior Chang., (2011) has shown that the pore water pressure dissipation process has been occurred on least 36 hours after the earthquake.

The vertical effective stress effects on liquefaction resistance. Drainage mitigates subsoil failure. Liquefied soil strengthens tsunami lateral pressure, and dissipation of tsunami occurs slowly.

An investigation recorded for approximately 16,000 building in the assessment seismic vulnerability of Zeytinburnu (Aydınoglu, N., and Polat, Z., 2004). The buildings are classified based on construction type, number of stories and age (Erdik, M et al., 2002 and Erdik, M et al., 2003). In the building tsunami resistance, requires to analyze building shape and place to control tsunami wave force. The city has some level of tsunami safety if urban structure planned appropriately. Two big earthquake in south Iran in around the city of Bam at 26 Dec 2003 (Mw 6.5) and second was in Zarand 2005 (Mw 6.4) (M, Mahood., 2011). The figure 2 indicates the earthquake history in south and south-east Iran. If earthquake occurs there, expects to see a strong tsunami with strong effect on most part of coastal area especially in urban area.

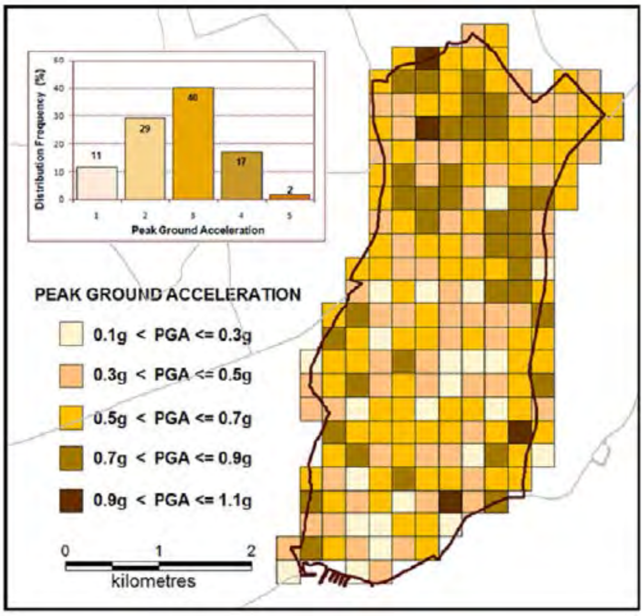

Figure 1: Variation of peak ground acceleration (PGA) from site response analyses (Atilla Ansal et al, 2010).

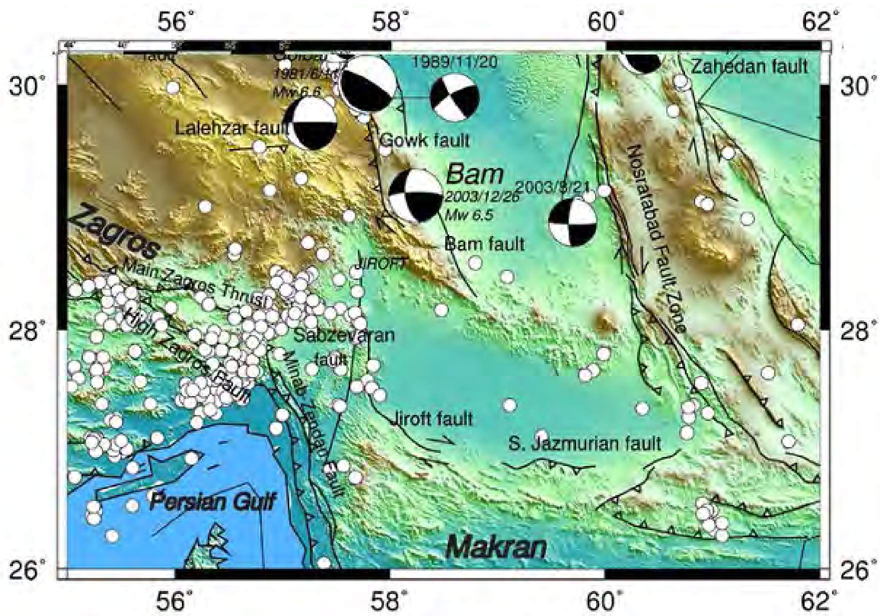

Figure 2: Destructive earthquakes of East-Central Iran are around the aseismic central Iran and Dasht-e-Lut. (Walker, 2002)

DISCUSSION

The coastal seismic hazard zone associates with tsunami. The theory of elasticity generally uses for crustal deformation modeling and, it assumes earth is homogeneous, isotropic, and elastic half space (Okada., 1985). The seismic moment calculates using

$$M_0 = \mu \sum_{j=1}^{n} S_j \, \alpha_j \quad (1)$$

When μ is subduction rigidity zone, n = number of planar fault, α = denotes the faults area, S= slip (Reiter, 1991). For collaboration between seismic moment and moment magnitude Kanamori (1977) is propose below formula.

$$M_w = \frac{2}{3} \log M_0 - 6.03 \quad (2)$$

From data presented in the figure 2 and application of equations 1 and 2, is possibility for calculating seismic moment and moment magnitude.

The M_w 9.2 rupture produces a tsunami with 15 to 20 m amplitude wave at the shore. The analytically seen that wave has been appeared in 16-m high over sand dune at Gleneden Beach and the floodwater was flows into urban area. High-speed flows associated with the tsunami waves produces extensive flooding and since outflow through the inlet channel is slow the water level keep continue rising for a few hours after the initial wave (Cheung, 2011). Up to 20 meter of a skyscraper has to be designed for tsunami resistance. To fast reduce level of water, geomorphology of site helps to minimize urban-tsunami damage. Rise up scour and sand deposit along the coastal area occurs during a tsunami. Morton et al., (2011) have been reported that the rise up to 2 m of scour and 0.76 m of sand deposits along coastlines in Chile tsunami on 2010. To stabilizing coastal area during tsunami, Namdar., (2011) suggested plantation mangrove in coastal area for increase bearing capacity of soil foundation, minimize of soil foundation deformation and settlement. This natural soil nailing, depends on coastal geological characteristics. The natural soil nailing helps to reduce or stop collapsing coastal area and deliver particles to urban region. Trifunac et al., (2002a) has been described failed materials occur due to gravity forces under mass flow or the move mass constitutes a slide process. At any of process the natural soil nailing reduces magnitude of damage. According to Booth et al., (1993) the majority of landslide (56%) have been occurred at slope equal or less than 4 º and the large landslides tend to occur on gentle the slopes of 3 to 4º. The particles quantity have been estimated by Hayir et al., (2008) for landslides are amount of debris slides (35%), the slumps (20%), the slab slides (17%) and the block slides (11%). Both debris flow and thick layer slides each have the frequency of occurrence of about 8%.

To study exact debris flow mathematical model requires, for estimate earth destruction magnitude. To develop realistic model, simplification parameter helps accurate estimation. According to the Bjerrum (1971) broken underwater cables has gravity speeds in the range 3-7 m/s. And in an experimental work Hamilton and Wigen (1987) analyzed gravity current velocities as 6 m/s along a 0.50 slope. And Terzaghi (1956) suggested 1-5 m/s for maximum underwater slide velocity. The Jiang and LeBlond (1992) presented a numerical simulation for underwater landslide with velocities of 20 - 45 m/s when inclinations interval are 2º-12º. Hayir (2006) has been used analytical method to analysis tsunami amplitudes for submarine slumps and slides. Srisutam, (2010) has been introduced a mathematical model for reconstruct tsunami run-up in beach area. The grain-size and run-up distance, sediment quantity and height has been evaluated. And the run-up velocity has been assumed in 12.78-19.21 m/s level up and is reduced approximately up to 1.93 m/s to 0 m/s.

GEOMORPHOLOGICAL AND LANDFORMS IN PERIODICAL TSUNAMI

Geomorphological investigation has been used to help in occurrence of two tsunamis and analyzing its effect on local events in the Pacific coast of Mexico (Ramírez-Herrera et al., 2012).

There is possibility of large tsunami by earthquake and subsequently arrive to the coastline in short time (Priest,1995). One of tsunami results is changing coastal morphology (Gelfenbaum and Jaffe, 2003), It is due to big quantity of the sediment in the near shore zone is transported by the tsunami (Takahashi et al., 2000). And subsequently many rivers were choked due to accumulated sediment near their mouths. Change of geomorphology of a region due to sand movement, erosion, settlement and small coastal landslides has more been imposed to city (Chester and Chester, 2010). The sediment type, quantity, velocity and direction are important in flood ability. The tsunami lateral pressure increases due to increase flow unit weight and strengthens force of tsunami and makes particle small and in long distance flow has more linear heavy unit weight due to linear distribution of particles in flow. The processes of converting geo-particles to small size depend on flow velocity, particle morphology and strength. The erosion and sediment play important role in tsunami ability and modifying subsoil engineering characteristics. In this regard Soulsby et al. (2007) have been indicated that during tsunami deposit mean size changes with distance and has a considerable effect on the settling velocity. According to Srisutam and Wagner, (2009) in sediments of tsunami the relationship between mean grain-size and distance is unclear. Marsal (1967), has been explained the particle breakage is a process and appears in form of changing stress on rockfill. In his theory particle breakage occurs even with low stress level due to dispersion of the contact force intensities. The traxial experimental results have been used to show particle breakage behavior (Figure 3) and to explain this process subsequently formula (3) has been proposed. Where W_{ki}, W_{kf} are grain size fraction before and after test respectively. And ΔW_k is particle breakage percentage by particle weight.

$$\Delta W_k = W_{ki} - W_{kf} \quad (3)$$

The majority of tsunami deposits have been formed on the sea bottom over geological times (Goto et al., 2008b), and mostly tsunami associates to the erosion and deposition (Chester and Chester, 2010) and change particles morphology. As described by Zhang (2012) from outcome of a research investigation has been indicated that in an angular grain size under force fracture occurs at an edge or apex (Figure 4) and developed from initial fissure or changing stress magnitude and it is due to rocks softness or when stress magnitude is higher than rock strength. In Figure 5 shown an isolate limestone has been subjected to the concavity due to tidal extending, this phenomenon reduces stone stability and sediment deposit reshape coastal area. In this process analyzing Microstratigraphy of the beachrock plays important role in estimate sediment.

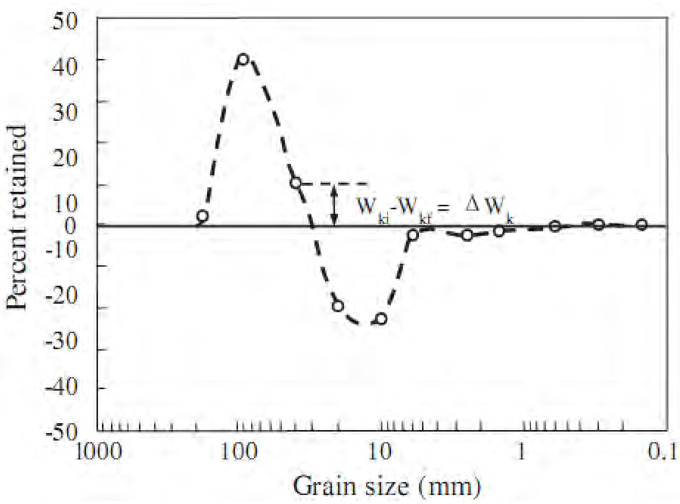

Figure 3: Variation of grain size distribution produced by particle breakage (Marsal, 1967).

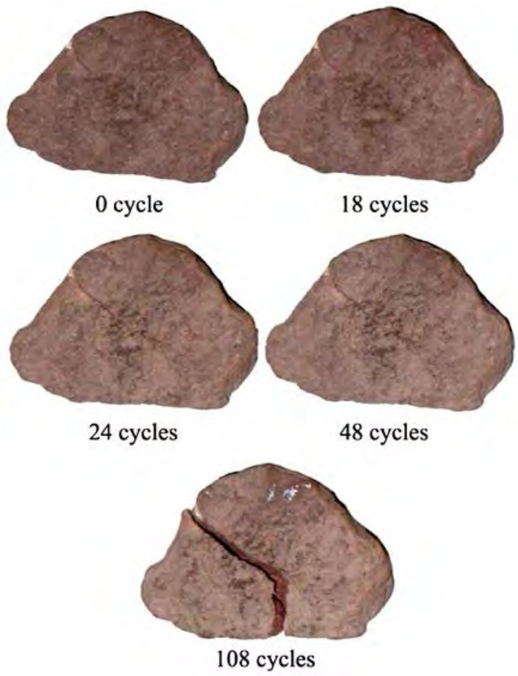

Figure 4: Particle break-up of natural irregular block subjected to baking-soaking weathering. (Zhang., 2012)

Figure 5: Tidal notch carved on isolated limestone blocks scattered on the uplifted platform in Agios Fokas 4 (M, Vacchi et al., 2012).

Araei et al., (2010) in a research work has been reported that the stress-strain and strength characteristic of rockfill has been changed based on modified grain size distribution. From scientific work of Araei et al., (2010) can be understood during tsunami due to modification and changing grain size distribution in surface, the subsoil will be affected by different stress level, coming from surcharge and it is an important factor for subsoil liquefaction resistance. The tsunami time, wave velocity, particle shape and strength are important factor in breakage of particle. The deposit quantity is not always constant and changes based on several factors like characteristics of tsunami, engineering properties of materials and geomorphology of site. In all cases, the tsunami changes coastal area and sea bottom geomorphology. Matsumoto et al., (2010) have been estimated the sediment deposit during tsunami was 83 (m^3/m) in eastern Sri Lanka. According Goto et al., (2011) most of the sediment have been deposited on the shallow sea bottom and small amount transports to coastal area. Raphaël Paris et al., (2009) have been indicated that the mean erosion rate of December 26, 2004 tsunami in Sumatra (Indonesia) beaches was ~30 m^3/m and locally exceeded 80 m^3/m, where 75% of the sediments deposited source is from offshore. The morphology of the coastal area and the local topography (dams, cliffs, buildings), have been affected by tsunami erosion. Lavigne et al., (2006) have been descripted an earthquake of 9.3 magnitude in Banda Aceh and Lhok Nga causes a tsunami consist of three main waves in few minutes.

In a tsunami, the continuous stress accelerates the erosion and geomorphology of coastal area changes considerably. A tsunami after earthquake not shakes subsoil. The new coastal area and sea bottom morphology remains under loose condition and the liquefaction resistance of subsoil reduces. The table 1 indicated erosion volume in several coastal areas. Ramírez-Herrera et al., (2012) have been identified massive erosional basal contact of the deposit occurs from high energy flow or overwash event during tsunami. According to the Raphaël Paris et al., (2009) backwash produces erosion in coastal area and submarine sediments. The factor like vegetation density covers on an area influenced degree of erosion and destruction of geomorphology.

The tsunami produces erosion, changes geomorphology of territory, and naturally mixed soil. The new geomorphology of site consists of new engineering properties. The site liquefaction resistance depends on soils mixed characteristics. Hemphill-Haley, (1995) has been mentioned that the change of environment results in possible co-seismic deformation. Recently Juan. D, (2012) has been indicated that the relative sea-level has been raised up after the occurrence of the 1979 tsunami.

Table 1: Coastal retreat by the December 26, 2004 tsunamiin Lhok Nga (Raphaël Paris et al., 2009)

	Coast length	Mean retreat	Area affected	Volume eroded
	m	m	m^2	m^3/m
Lampuuk	900	64	58,000	25–40
Lhok Nga Point	1600	86	137,400	30–80
Golf course	600	10	5300	<40
Main river	900	48	42,900	20–35
South Lhok Nga	1850	38	70,000	20–80
Harbour	110	46	5100	
Labuhan bay 1	900	16	14,250	
Labuhan bay 2	200	20	3980	
Labuhan bay 3	480	17	8360	
Leupung	1680	123	206,400	20–50
Total	9220	60	551,690	30

High in-situ stress causes failure and plastification phenomena such as squeezing or rockburst (Hoek and Marinos, 2009). The magnitude and direction of in-situ stress is important for predict subsoil stability or time of stability. Hijazo and González de Vallejo (2012) has been indicated that the stress magnitude under engineering scale maybe influenced by geological and structural anisotropies, sedimentary loads, relief effects, glacial rebound and loads produced by submarine elevations or rock composition and geomechanical behavior. The relationship between mean grain-size and distance the changing grain-size during tsunami is changed flood unit weight to more linear and it is also one of important factor for in situ stress. Change of geological characteristics of site controls direction and magnitude of stress. Zoback et al., (1989) have been indicated that the stress direction influences mainly by plate geometry and the distribution of the different plate boundaries. According to Hijazo and González de Vallejo (2012) the tectonic stress appears in hundreds or thousands of kilometers. Voight (1966b) has been mention erosion causes high horizontal stress on areas near the surface. The stress shape has to be considers in liquefaction phenomenon. The stress shape governors type of subsoil failure. The erosion thickness and mechanical properties are important factors influenced in stress shape. The morphology and mineralogy of materials paly important role in crushing particles deposit from tsunami function. The earthquake due to shaking earth increases the subsoil density but the tsunami reduces subsoil density and reduces liquefaction resistance of subsoil. M. Choowong et al., (2009) have been reported in rapid recovery of beach morphological process after tsunami event. It occurs by a sediment transport while majority of the deposition in coastal area have been derived from the offshore bottom sediments. According to P.S. Kench et al., (2008) the duration of a coastal area instability is affected by tsunami controlled by two factors of initial magnitude of change beach sediment reservoir or geomorphology and, the erosion recovery time. The multiple tsunamis govern coastal area shape and location on reef platforms. The tsunami wave geometry is important in backwash and crushing materials and produces sediment and distributes erosion, while exact predict of wave behavior is difficult. The numerical code requires for understanding tsunami results and dissipation with variable depths and local geomorphology. And numerical solutions have to use for building water lateral pressure resistance and changing soil shear strength. There are limited information on local parameters govern tsunamis response in controlling soil engineering properties. Carrier et al., (2003) performed analytical solutions to simplified tsunamis behavior. And Didenkulova et al., (2007) has shown tsunami run-up for non-breaking waves.

The volcanic causes natural hazards such as tsunamis (Perez-Torrado et al. 2006). The slide at the Ritter island volcano into the sea northeast of New Guinea in 1888 is known as largest lateral collapse of an island volcano in history (Ward and Day, 2003). The erosion studies on volcano help to evaluate short-term erosion processes (Major et al., 2000).

CONCLUSION AND SUMMARY

- The effect of new geomorphology and geological which are formed after tsunami in future tsunami destructive ability has been discussed.
- The near accurate geological and hydrological profile helps to predict liquefaction magnitude, depth and movement of liquefaction.
- The tsunami is naturally mixed soil in a sea bottom and coastal area. It is resulted in built a site with new morphology and engineering properties. The mixed material is a factor governing liquefaction resistance.
- These results are a significant contribution to the knowledge of the tsunami behavior and sediment movement in reshaping coastal area geomorphology as well as liquefaction resistance of subsoil in both sea bottom and coastal area.
- It is interesting to point out that the mixed soil technique under laboratory condition has to be used for predicting site engineering properties after tsunami for analyzing liquefaction resistance.

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