Survey of Geotechnical Aspects of Seismic Hazards

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Abstract

Observations of damages during numerous historical earthquakes have shown that Moreover the structural stability, geological factors and site conditions are also have major role in final stability of structures. Two of important types of mentioned geotechnical phenomena that causes ground failure are liquefaction and landslides, which can take a variety of forms: settlement, cracking and fissuring, sinking, surface fault displacement,…
In the frame of this paper, liquefaction and landslides definition, forming mechanism, their difference and influence of site condition on damage intensity are reviewed.

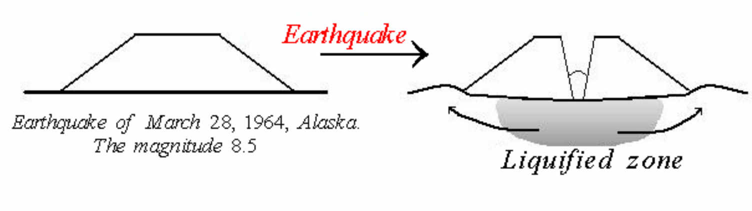
Key words: earthquake, liquefaction, landslide, damage

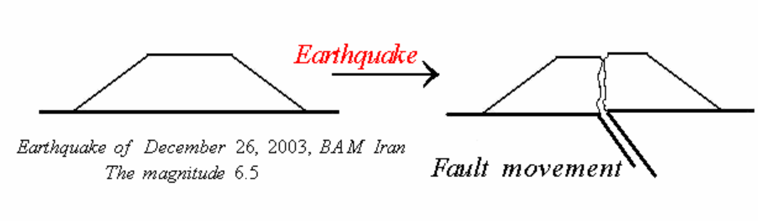
1. Introduction

Secondary effect is the usual term that describes the nontectonic surface processes directly related to earthquake shaking. Although probably the most important, direct shaking effects are not the only hazard associated with earthquakes, other effects such as landslides, liquefaction and tsunamis (as a secondary effect), have also played important part in destruction produced by earthquakes. Geotechnical hazards subdivided to a geotechnical instability and ground vibrations and impulse (site effect) which Liquefaction and landslides are two components derived from geotechnical instability and caused many damages during past earthquakes. [7]
Liquefaction and landslides processes have been commonly analysed for the evaluation of potential seismic hazard as they are well known as secondary effects and liquefaction known as a main secondary effect of earthquakes causing damage. [13][14][19]
To prevent vital loses by mentioned hazards, each country has specific standards according to its geologic positions, soil layers… . In Iranian code of seismic resistant design of buildings so called: standard NO.2800 [4], geotechnical considerations are discussed, so recommended that: construction feasibility on areas that are susceptible to liquefaction, landslides, large settlement or soil with sensitive clays, needs Special onsite and laboratory soil studies and its specially recommended for a) area where liquefaction has occurred during historical earthquake b) area with clean sands, silty sands or gravel soils and the groundwater table with level less than 10m distance from ground surface. In continue, 1) no Susceptibility to liquefaction and 2) area with average slope less than 10° , are provisions that allow construct, normally. Cause of

this provision and importance of site conditions and geologic factors are identified below in two section; liquefaction and landslides. Influence of soil types and layers, and importance of slopes steep, as a provision of site conditions are investigated and procedure of damages are shown by examples.

Variety of damage mechanisms between two Different site conditions shown by fig1-2: road damage; result from fault movement during BAM earthquake, compared with liquefaction due to ALASKA earthquake.





2. Liquefaction

Liquefaction is the transformation of granular deposits from solid to liquefied state due to water pressure increase forced by cyclic shaking. [9]

Cohesive sand and silt sediments do not have a high stress resistance that can bear important loading without any alteration in internal structure. However, natural or artificial causes of sedimentary deformation can produce loss of material resistance changing the solid stage to a viscous liquid behaviour. The mechanism that produces the transformation of solid to liquid is the liquefaction phenomena. [5]

the action in the soil which produce liquefaction due to earthquakes are as fallows: seismic waves, primarily shear waves, passing through saturated granular layers, distort the granular structure, and cause loosely packed groups of particle to progressively densify. Densification increases the porewater pressure between the grains if drainage cannot occur. If the porewater pressure rises to a level approaching the weight of the overlying soil, the granular layer temporally behaves as a viscous liquid rather than solid. Thus, liquefaction has occurred. When liquefaction occurs, the strength of the soil decreases and, the ability of a soil deposit to support foundations for buildings and bridges are reduced. [3]

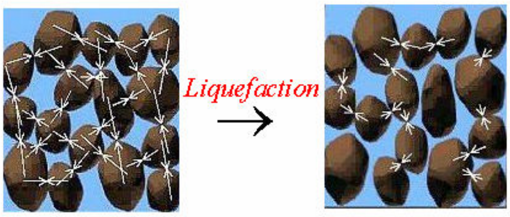


Fig.3

Liquefaction structures may vary significantly from place to place in type, geometry, and size. This can be due to the anomalous propagation, the amplification of the seismic waves at the surface and the different site conditions such as grain size, age of deposits, and ground water level position (as discussed further below).it caused major damage to waterfront facilities, structures, and buried pipelines at locations in the Bay Area, commonly occur in loose, saturated, clean to silty sands but has also been observed in gravels and nonplastic silts. Ground failures with characteristics similar to liquefaction failures have also been observed in lowplasticity silty clays [1]. In the eyes of geologist, visible effects of liquefaction are sand craters, sand volcanoes (small craters of emerging high pressure water and salinity), sand sills or dikes, sand boils and water piping, soil collapse, convolute lamination and stratification, and sub-aquatic slides. [2]

From the seismic view, Liquefaction can produce damage ranging from small slumps and lateral spreads to massive flow slides with displacements measured in tens of meters that can cause foundations and retaining structures to settle and tilt, or can tear them apart through large differential displacements like that are shown by fig4-7.

Because of variety in behavior, mechanism and effect of ground layers and earthquake waves, classification systems incorporate additional variables; for example According to Allen, the liquefaction phenomena based on earthquake intensity and ground response can be classified as: (a) static liquefaction (b) cyclic liquefaction (c) dynamic liquefaction. [10]

In the subject of this paper, described by Kramer [1], the basic mechanisms that produce liquefaction behavior can be divided into two main categories. Flow liquefaction can occur when the shear stresses required to maintain static equilibrium of a soil mass are greater than the shear strength of the soil in its liquefied state. If liquefaction is triggered by earthquake shaking, the inability of the liquefied soil to resist the required static stresses can cause large deformations, or flowslides, to develop. The second mechanism, cyclic mobility, another liquefaction-related phenomenon occurs when the initial static stresses are less than the shear strength of the liquefied soil, and occurs more frequently than flow liquefaction. Cyclic mobility can occur in dense as well as loose soils, and leads to incremental deformations that develop during earthquake shaking; the deformations may be small or quite large depending on the characteristics of the soil and the ground shaking. In the field, cyclic mobility can produce lateral spreading beneath even very gentle slopes and in the vicinity of free surfaces such as riverbeds.

In general, soils deposited in fluvial deposits, and colluvial and Aeolian deposits when saturated, are likely to be susceptible to liquefaction. Liquefaction is also observed in alluvial-fan, alluvial-plain, beach, terrace, playa and estuarine deposits, but not as consistently as in those listed previously. Younger soil deposits are generally more susceptible to liquefaction than older deposits. The physical composition of a soil deposit will play a strong role in determining its liquefaction susceptibility [2]. Uniformly graded clean sands composed of rounded particles are inherently most susceptible to liquefaction. Well-graded soils and soils with angular particles are less susceptible. The presence of fines, particularly plastic fines (PI > 10), tends to decrease liquefaction susceptibility.

Loose soils are much more susceptible to liquefaction than dense soils. Clayey soils can exhibit strain-softening behavior when subjected to earthquake shaking, which can produce failures that have many of the same characteristics as liquefaction failures. In distinguishing between strain-softening and others, Wang proposed the following four criteria [11] [13], the satisfaction of all of which would indicate the potential for strain-softening behavior:

1. Clay fraction (finer than 0.005 mm) 15%
2. Liquid limit, LL 35%
3. Natural water content, w 0.9LL
4. Liquidity index 0.75

These criteria have been the subject of considerable discussion among geotechnical engineers and this percents are not absolute.

As shown below, liquefaction caused major damage during past earthquakes:

Left - Fig.4. Earthquake Liquefaction damage, January 1996, Kobe-Japan

Right - Fig.5. Earthquake Liquefaction damage, April 1991, Costa Rica

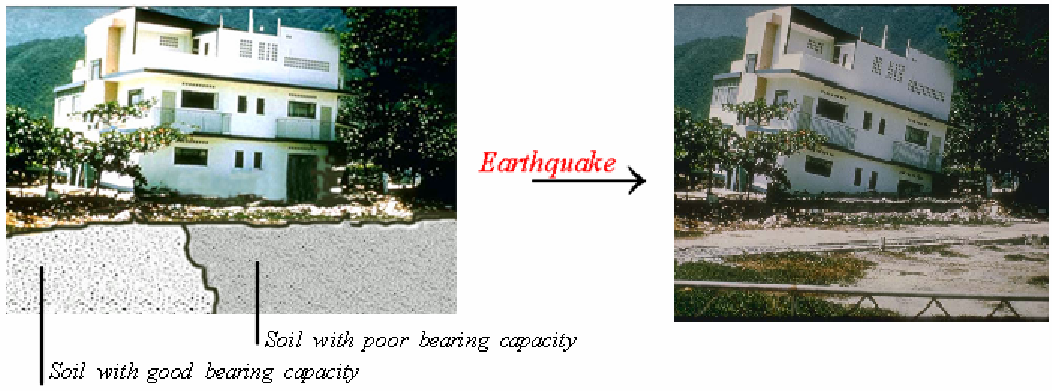


Fig.6. Differential settlement, July 1967, Caracas-Venezuela

Fig.7. Tilted buildings; bearing capacity failures, 1964, Niigata- Japan

3. Landslides

A Landslide is a geological phenomenon which includes a wide range of ground movement, such as rock falls, deep failure of slopes and shallow debris flows [1]. defined for the purpose of this discussion as seismically induced permanent shear deformations within geologic media, represent a significant source of ground failure during earthquakes. These shear deformations need to be distinguished from ground settlements associated with volumetric strains that arise from postliquefaction pore pressure dissipation or seismic compression. Earth slopes strongly shaken during earthquakes can be subject to surface displacements from both shear and volumetric strain accumulation; they can be observed in the form of landslides, and flow slides, lateral spreads… and can contribute to the failure of foundations and retaining structures [7][9][15][16]. Landslides are natural hazards that cause millions of dollars of damage each year and also cause many deaths. Large earthquakes generate thousands of landslides. [12] For example the Northridge earthquake triggered more than 11,000 landslides that have seen in different types.

So landslides can be subdivided into several generalized categories [8]:

1. Masses of disrupted slide material, such as rock falls or avalanches
2. Relatively coherent slide masses whose displacement is accommodated along well-defined slip surfaces or across relatively broad, distributed shear zones
3. Lateral spreads and flow slides associated with soil strength loss due to pore pressure increase

That a) Water and Vegetation and b) Slope and Materials are two main factors for stability of ground for mentioned categories which can affect the Driving forces and result in three types of landslides. Fig10

As described, there are different landslide mechanisms that briefly reviewed below:

Disrupted slides and falls occur in areas of high topographic relief (slopes steeper than 35°–40°) and tend to involve closely jointed or weakly cemented materials. Rock avalanches are a particularly damaging type of disrupted slide, involving slide masses that originate in steep terrain and disintegrate into streams of rock that travel large distances at high velocities.

Coherent landslides can occur in rock or soil materials and at slope angles much lower than those for disrupted slides and falls. Coherent slides in rock typically involve slip along basal surfaces weakened by weathering, jointing or prior shearing, or along bedding planes. Coherent slides in rock masses have occurred on slopes as shallow as 15° also can occur along basal slip surfaces or relatively distributed shear zones.

Lateral spreads and flows can occur in soil on very mild slopes or behind a free-face if the soil is geologically young, has a granular texture and the groundwater table occurs at shallow depths. If these postliquefaction strengths exceed static shear stresses, the problem is one of cyclic mobility, which in a slope stability context is analogous to lateral spreads. If the postliquefaction strengths are less than static shear stresses, flow slides will occur that can involve very large displacements. If the sediments are found on Slopes, even those as low as 1°, the impermeable layer, and structures built on it, can move as a lateral spread, rupturing underground utility lines. [2,15]

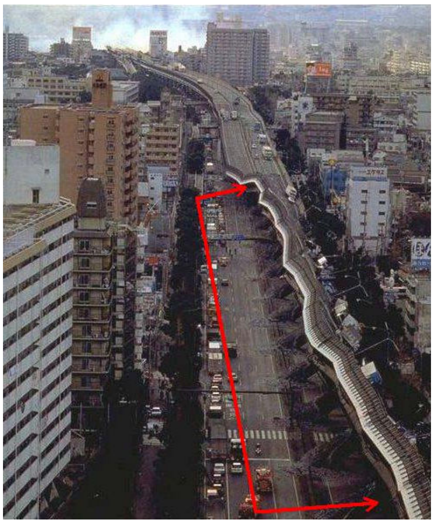


Fig.8. Landslide during the January 2001 El Salvador quake, the magnitude7.6, killed more than eight hundred people

Fig.9. Bridge's foundations moved due to lateral spreading, Kube January 1996

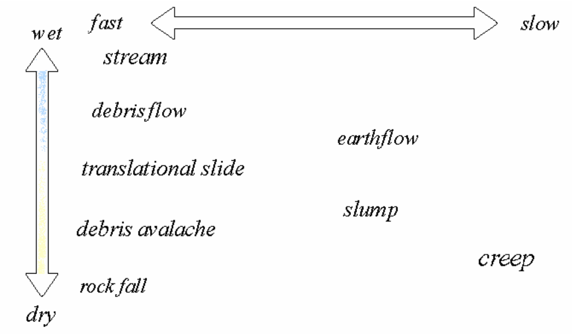


Fig.10.Water is critical in determining the rate and nature of landslide movement. This figure expresses the differences relating landslide classification to water content in the slide mass.

4. Conclusions

Observation of catastrophic experiences of past earthquakes shown that influence of site conditions in earthquake damages must be considered. In order to mitigate the seismic risk associated with areas that susceptible to liquefaction and landslides, a correct design require considering site effects and need geotechnical studies so sometimes Improving the Soil or Build Liquefaction Resistant Structures may be solution and sometime changing the site is the final choice. This paper presented a side glance of liquefaction and landslide as two main geotechnical phenomena and ground failure occurred during past earthquakes.

5.References

[1] Steven *L. Kramer & Jonathan P. Stewart*, Geotechnical Aspects of Seismic Hazards

[2] Kramer, S.L. (1996). *Geotechnical Earthquake Engineering*, Prentice Hall, Upper Saddle River, NJ, 653 pp

[3] Marshal Lew, Geoffrey R.Matin, What Structural Engineers Need to Know About Liquefaction, SEAOC CONVENTION

[4]-کمیته دائمی بازنگری آئین نامه طراحی ساختمان ها در برابر زلزله، "آیین نامه طراحی ساختمان ها در برابر زلزله استاندارد ـ ۲۸۰۰، ویرایش ۳ " ، مرکز تحقیقات ساختمان و مسکن

[5] Allen, J., 1977. The possible mechanics of convolute lamination in graded sand beds. Journal of the Geological Society of London 134, 19–31

[6] Damage Due to Liquefaction, National Information Service for Earthquake Engineering; NISEE, university of California, berkeley

[7] محمد کاظم جعفری، بررسی ناپایداری های ژئوتکنیکی، تاثیر شرایط ساختگاهی و عملکرد پی ساختمانها در زلزله ۱۷ اوت۱۹۹۹ ایزمیت ترکیه

[8] Keefer, D.K. (1984). Landslides caused by earthquakes, *Geol. Soc. Am. Bull.,* 94, 406–421.

[9] Youd, T., 1977. Discussion of ''Brief review of liquefaction during earthquake in Japan'' by E. Kuribayasi and F. Tatsuoka, 1975 Soil and Foundations 15, 81–92

[10] Allen, J., 1982. Sedimentary Structures, Their Character and Physical Basis. Developments in Sedimentology, 30B, vols. I and II. Elsevier, Amsterdam

[11] Wang, W. (1979). Some findings in soil liquefaction, Water Conservancy and Hydroelectric Power Scientific Research Institute, Beijing, China.

[12] Harp, E.L., and Jibson, R.W. (1996). Landslides triggered by the 1994 Northridge, California, earthquake. *Bull. Seism. Soc*

[13] Andrews, D.C.A. and Martin, G.R. (2000). Criteria for liquefaction of silty soils, *Proceedings, 12th World Conference on Earthquake Engineering*, Auckland, New Zealand.

[14] Bard, P-Y. (1995). Effects of surface geology on ground motion: recent results and remaining issues, *Proc.10th European Conference on Earthquake Engineering*, Duma (Ed.), Rotterdam

[15] Aerial report of damaged areas, September 1999, Taiwan earthquake, Helicopter survey of damaged areas

[16] Dr. T. Leslie Youd, Bringham Young University, Provo, Utah, LIQUEFACTION, GROUND FAILURE AND CONSEQUENT DAMAGE DURING THE 22 APRIL 1991 COSTA RICA EARTHQUAKE, (Abridged from EERI Proceedings: U.S. Costa Rica Workshop, 1993), PART 1. LIQUEFACTION AND GROUND FAILURE

[17] Initial Geotechnical Observations of the August 17, 1999, Izmit Earthquake, Atilla Ansal, Jean-Pierre Bardet, Jonathan Bray, Onder Cetin,Turan Durgunoglu, Mustafa Erdik, Abidin Kaya, Derin Ural, Tolga Yilmaz, Les Youd , A Report of the Turkey-US Geotechnical Reconnaissance Team, September 1999

[18] Professor Ramón Verdugo, Seismic response of a saturated cohesionless soil mass, Institute of Research and Testing Materials (IDIEM) Faculty of Physical Sciences and Mathematics

[19] Obermeier, S., 1994. Using liquefaction-induced features for paleoseismic analysis. Obermeier, S., Gibson, W. (Eds.), Using Ground-failure, Features for Paleoseismic Analysis Geological Survey Open-File Report