LIQUEFACTION INVESTIGATION OF WENCHUAN EARTHQUAKE

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ABSTRACT :

At 14:28 May 12 2008, a catastrophic earthquake of magnitude 8.0, the epicenter of which locates at Wenchuan, struck Sichuan Province (N31.0^0, E103.4^0). The earthquake caused severe damage to human lives and provincial economy, including 69159 casualties, 374141 injured, 17469 missing and 617.729 billion yuan of economic loss (by June 12, 2008). Liquefaction, which resulted to serious destruction to schools, manufactories, residence houses, crop fields, aqueducts, dams, bridges, roads etc. have been observed in large scale. Such phenomena as sand boils, surface failure, subsidence, land spreading and wall cracks have been commonly found in the liquefied regions. Furthermore, three features can be outlined about the characteristics of the liquefaction phenomena. (1) Liquefaction behaviors have been observed in low intensity regions, e.g. regions of seismic intensity of VI, and some of the liquefied soils were medium sands and fine sands. (2) Gravelly-soil liquefaction has been observed. (3) Structure destruction has commonly caused by the liquefaction rather than ground shaking. However, the liquefaction investigation has not been finished, thus further research will be conducted.

KEYWORDS: liquefaction, Wenchuan Earthquake, liquefaction investigation, liquefaction-induced destruction

1. INTRODUCTION

At 14:28 May 12 2008, a historical devastating earthquake of magnitude 8.0, the epicenter of which locates at Wenchuan (N31.0^0, E103.4^0) struck Sichuan Province, causing severe loss both to human lives and national economy. By June 12 2008, the recorded casualties were 69159 as well as 374141 injured, 17469 missing. This is one of the catastrophic earthquakes occurred in China since 20th century. During the post-earthquake in-situ investigation, liquefaction phenomena have been commonly observed. The liquefaction of soil also caused severe damage to people properties and structures other than ground shaking.

Liquefaction is one of the most significant, complex and controversial topics in geotechnical earthquake engineering. Its devastating effects sprang to the attention of geotechnical engineers in a three-month period in 1964 when the Good Friday earthquake in Alaska was followed by the Niigata earthquake in Japan. In the recently 40 years, liquefaction has been studied extensively by thousands of researchers around the world. During the post-earthquake in-situ investigation of Wenchuan earthquake, many liquefied sites have been detected. And corresponding damage induced by the effects of liquefaction, e.g. ground surface failure, ground subsidence, fractures in roads, settlement/differential settlement of buildings, have been commonly found in the liquefied sites.

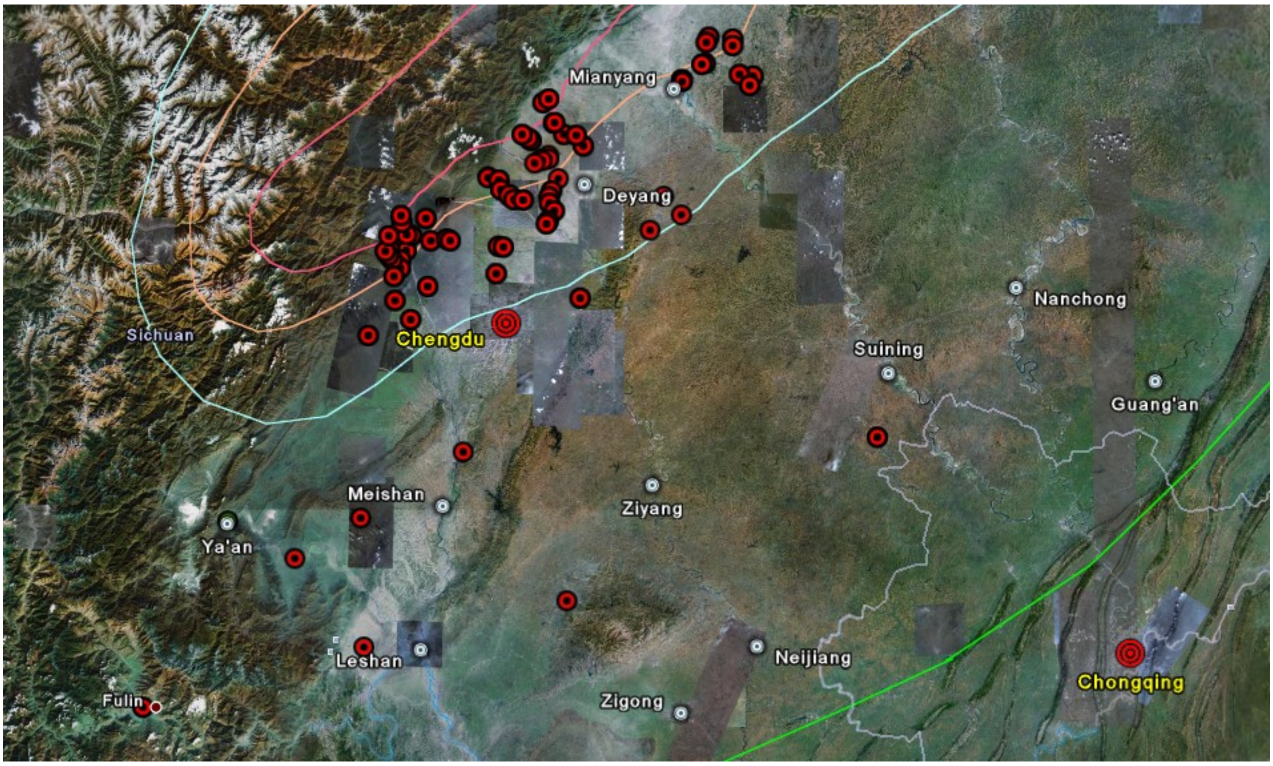

Figure 1 The distribution map of liquefied sites (Red points represent the observed liquefied sites)

Figure 1 presents the distribution map of the observed liquefied sites. The red points represent the sites where liquefaction phenomena such as sand boils and sand ejection etc. were observed. The colorful lines bounded the regions of different seismic intensities, e.g. intensity VI, VII and VIII, IX etc. Noticeably, liquefied sites are bounded within a long narrow belt region which is almost parallel to the orientation of the active fault (Longmen fault) which generated the magnificent disastrous earthquake. However, there are not satisfactory explanations for this feature rather than one assumption of the ever existence of riverbed. Thus further investigation will be conducted in the future.

2. INFLUENCE OF LIQUEFACTION

2.1 Liquefaction-induced destruction

Earthquake-induced liquefaction can be significantly destructive, causing severe damage to buildings, roads, bridges, dams, and crop fields etc. In the post earthquake in-situ investigation of Wenchuan Earthquake, the liquefaction-induced destructions have been commonly found. Figure 2 to figure 8 present some examples of liquefaction hazard. However, most of the liquefaction phenomena were observed in crop fields, e.g. ground subsidence, ground cracks, sand ejection and big holes resulted from sand ejection etc. Liquefaction-induced structure damages have also been observed.

Figure 2 Liquefaction-induced settlement/differential settlement in Wenchuan Earthquake (Photo by L. Chen)

Figure 3 Liquefaction-induced destruction to bridge and road (Photo by Z. Cao and F. Meng)

Figure 4 Liquefaction-induced destruction to factories (Photo by N. Gao)

Figure 5 Liquefaction-induced destruction to residences (Photo by Z. Cao)

Figure 6 Liquefaction-induced destruction to aqueduct and reservoir (Photo by Z. Cao)

Figure 7 Liquefaction-induced destruction to fishpond and swimming pool (Photo by E. Guo and Z. Cao)

Figure 8 Liquefaction-induced damage to crop fields (Photo by Z. Cao)

2.2 Features of liquefaction behaviors caused by Wenchuan Earthquake

Wenchuan Earthquake-induced liquefaction is worthy of researching because it is quite different from the previous liquefaction behaviors. And previous empirical methodologies are not qualified to explain the newfound phenomena. Thus new theories and methods will have to be proposed and new seismic design code concerning liquefaction will have to be improved. To summarize the characteristic of the newfound liquefaction phenomena, some typical and salient points can be outlined hereafter.

Gravelly soil liquefied, which could be proved by the sands ejected due to liquefaction (figure 9). This kind of phenomenon has been previously observed both in the field (Coulter and Migliacio, 1996; Chang, 1978; Youd et al., 1985; Yegian et al., 1994) and in the laboratory (Wong et al., 1975; Evans and Seed, 1987). The sand boil in the left picture shown in figure 9 has been commonly observed in previous earthquakes while the ejected gravels in the right picture were hardly related to liquefaction behavior. The grain size of soil is one of predominant influence factors on liquefaction behaviors. For many years liquefaction-related phenomena were thought to be limited to sands. Fine-grained soils were considered incapable of generating the high pore pressure commonly associated with liquefaction and coarser-grained soils were considered too permeable to sustain any generated pore pressure. Gravelly soil can also be susceptible to liquefaction.

Figure 9 Sand boils and gravely sand ejected (Photo by Z. Cao)

Belt-distribution style of the observed liquefaction sites. As shown in figure 2, most of the observed liquefaction sites are bounded within a narrow geological belt. This behavior concerns closely to local geological conditions. Soil deposits that are susceptible to liquefaction are formed within a relatively narrow range of geological environments (Youd, 1991). The depositional environment, hydrological environment and age of a soil deposit all contribution to its liquefaction susceptibility (Youd and Hoose, 1977). Therefore, further and deep investigation, e.g. borehole, will be carried out to evaluate the liquefaction potential.

Liquefaction behaviors have been observed in the regions of seismic intensity of VI, corresponding to 50gal of peak ground acceleration. Seismic intensity is a comprehensive index to measure the strength of earthquake and the degree of destruction caused by earthquakes and still in use for seismic design and seismic zonation map in China. It is thought that no liquefaction potential exits in the regions of seismic intensity less than VI according to Code for Seismic Design of Buildings used in China. Because there is no evidence of liquefaction phenomenon observed in regions of seismic intensity less than VI previously. Thus liquefaction potential for low seismic intensity regions must be renewed and evaluated properly.

Liquefaction can occur in deep soil, e.g. more than 15 meters deep. Laboratory triaxial test (Yuan, Sun et al.) on the specimen taken from the soil of 19.3 meters deep demonstrates this valuable point. The specimen was sampled from the liquefied site of Shengli Village and remoulded in laboratory. However, it requires further and more detailed research.

3. TYPICAL LIQUEFACTION EXAMPLE

Liquefaction has caused serious damage to structures and other facilities during Wenchuan Earthquake. One of the typical examples is Banqiao Middle School. The major teaching building is a 3-story frame-structural building. The whole building was not seriously damaged resulting directly from ground shaking, shown in figure 10. The local water table is 2.8m.

Figure 10 The major teaching building after the earthquake (outside and inside) (Photo by W. Wang)

The major teaching building differentially settles due to liquefaction, shown in figure 11. Liquefied sands ejected could be observed almost everywhere in the schoolyard. To investigate the local site condition, a bolehole was made close to the building. Figure 12 illustrates the soil samples from the bolehole.

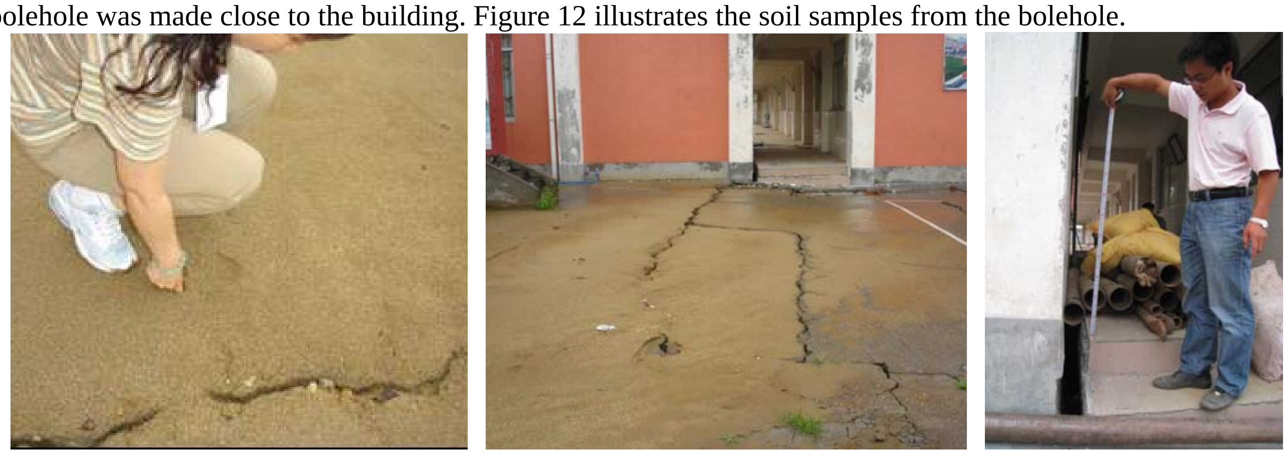

Figure 11 Sand boils and sandy soils ejected (Photo by Z. Cao)

Figure 12 Soils sampled from the bolehole (left picture shows soils of 0 to 6.65m and right picture shows soils of 6.65m to 15.4m) (Photo by W. Wang)

Figure 13 Sandy soil sampled compared with the sands ejected (Photo by W. Wang)

As shown in figure 12, the gravelly soils are noticeably thick, ranging from about 3m to about 8m, and very loose. This kind of geological site condition is remarkable common after 3 investigation boleholes were made in Deyang Area. In figure 12, the liquefied soil locates at 12.5 meters by comparing the sands ejected and the sands sampled from the bolehole. This could be an evidence for deep liquefaction behavior of soil.

The major teaching building has differentially settled along the width direction of the building. But there was no obvious evidence of differential settlement along the length direction. Furthermore, there is one similar building close to the major teaching building, there is no noticeable, however, settlement/differential settlement. The two buildings are of different orientations. The relative displacements between the two buildings exist, seen in figure 11 (right).

Liquefaction hazard and potential can be particularly significant and must be evaluated and taken into account seriously during seismic design of buildings. Previous post-earthquake investigations indicate that destructions of structures/buildings were possibly not caused by ground shaking, e.g. Niigata earthquake 1964 in Japan, but liquefaction of soil underlying. The resistance of building meets the requirements of seismic design while the liquefaction potential and hazard were neglected.

4. CONCLUSIONS

The influence of liquefaction due to Wenchuan earthquake on the geotechnical engineering has been observed in various forms during the post-earthquake in-situ investigation. The features can be outlined about the characteristics of the liquefied sites. (1) Liquefaction of soil occurred in low intensity regions, e.g. regions of seismic intensity of VI, and some of the liquefied sands were medium sands and fine sands. (2) Gravelly soils have liquefied. (3) Structure destruction has commonly caused by the liquefaction rather than ground shaking. (4) The liquefied sites were mostly bounded within a long narrow belt region. Concerning on these characteristics, the previous criteria of liquefaction can not be suit for the evaluation of the newfound liquefaction behaviors. Thus improved criteria and requirements need to be proposed to properly evaluate liquefaction susceptibility and potential. However, the liquefaction investigation has not been completed, thus further research will be conducted.

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