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On the earthquake induced liquefaction in Astaneh, Iran

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ABSTRACT: During the Manjil earthquake of June 20 1990, Iran, a vast area in Caspian province of Gilan experienced liquefaction. Most of the places with clear signs of liquefaction were located in fluvial plain of Sefidrud and its tributaries especially in abandoned channels of this river. The most extensive damages induced by liquefaction occurred in Astaneh some 75 km northeast of epicenter. To understand the reasons as to the causes of this liquefaction and map it in Astaneh, a research program was established including surface and subsurface investigations and in-situ and laboratory testing. In this paper, the extent of liquefaction induced damage in these area is briefly reviewed and the results of this research are described.

INTRODUCTION:

A catastrophic and destructive earthquake occurred just 30 minutes after midnight of June 21 1990, local time (21 hr June 20 1990 GMT) in provinces of Gilan and Zanjan located at northwest of Iran. The tremor of the quake was strongly felt in Tehran some 200 km far from epicenter. The number of fatalities is reported to be more than 40,000 people and the damaged area is reported to be more than 10,000km². The characteristics of this strong earthquake is reported elsewhere (Moinfar and Naderzadeh, 1990, Berberian and Qorashi 1991, Ishihara et al 1992).

Liquefaction, landsliding, rock falling, site amplification and foundation problems were the earthquake geotechnical engineering considerations which were observed due to the Manjil earthquake of June 20 1990. Research on any of these aspects are going on and the results of these investigations will be released in near future. Detailed information about the geotechnical considerations of this earthquake is given by Haeri (1990), Haeri (1991) and Ishihara et al (1992).

Liquefaction of level or gentle sloping ground occurred in a vast area in Gilan plain mostly from 50 to 90 km far from epicenter. The most extensive damage occurred in Astaneh and Rudbaneh some 75 km northeast of epicenter. Comparison of the liquefaction induced ground damage with the geological report and map of the region (Annells et al 1975), indicate that the ground damage induced by liquefaction is mainly located at levee deposits of the present and abandoned channels of Sefidrud river (Fig.1). The Sefidrud channel has changed its coarse of movement several times due to the Caspian sea water level fall (Annells et al 1975) and or surface faulting (Berberian and Qorashi 1991). The latest coarse of Sefidrud bed before its present channels is Heshmatrud and Aliakbari rivers (Kohneh Sefidrud) passing through Astaneh and Rudbaneh and meandering and flowing towards the Caspian sea. As shown in Fig.1, levee deposit shown by dark color, covers a wide area and the earthquake induced liquefaction occurred mostly in such a soil formation containing loose sand and silty sand. In this area the water table is generally high being at about 1m to 2m below the ground level at the time of earthquake.

To understand the reasons as to the occurrence of this liquefaction especially in Astaneh, a careful surface study of the site was performed to map the zones with the signs of liquefaction. However most of the affected lands were rice farms and therefore it was not an easy task to distinguish between the

Figure 1. Geological map of Sefidrud delta and its tributaries.

sites with or without signs of liquefaction in such a wide area.

Sand and silty sand liquefaction caused extensive damage such as destruction and heavy cracking of houses due to total and differential settlement and foundation bearing failure, disposition of irrigation canal linings, damage to pipes and buried utilities, damage to pavements and roads, sand boils in homes, rice farms and water wells. For detailed information about the liquefaction induced damage due to the Manjil earthquake, the reader may refer to Zolfaghary (1991), Haeri (1991) a & b, Ishihara et al (1992).

GROUND DAMAGE INDUCED BY LIQUEFACTION IN ASTANEH

City of Astaneh is located some 75 km northeast of epicenter and 37 km west of Rasht, the center of Gilan province, Iran. Liquefaction induced total and differential settlement of structures, which in turn resulted in heavy damage to and destruction of many houses. Appearance of extensive open cracks and sand boils from ground surface and water wells caused sever damages to residential area of the city of Astaneh. Such damages are frequent in the affected area and some examples are presented herein.

Figure 2 shows the extent of damage incurred to a house in Astaneh, due to liquefaction. As it is clear from this figure, the house is unrepairable. Sand boil from a room floor is seen from Fig.3 and the result of sand boil from a water well can be seen in Fig.4. Differential settlement between a house and its adjacent wall is shown in Fig.5. Evidences from ground deformations induced by liquefaction in Astaneh indicate that both densification and loosening of the ground have occurred due to the earthquake induced liquefaction in soil containing sand and silty sand which is present near the ground surface. Therefore earthquakes of similar intensity can repeatedly cause liquefaction.

Figure 3. Sand boil from a room floor in Astaneh.

The signs of liquefaction were visible only in two sections of the city of Astaneh as shown in Fig.6. High ground water table in relatively shallow loose fine sand and silty sand and a sever ground shaking induced liquefaction in these sections of the city and the sort of unconformities reported previously could be seen in many places in these two sections of the city. The fact that in other parts of the city no such damages could be seen reveals that liquefaction of level ground is the sole responsible for incurred damage in the city of Astaneh.

RESEARCH ON EARTHQUAKE INDUCED LIQUEFACTION IN ASTANEH

Evidences from the damage incurred to the ground induced by liquefaction in Astaneh indicate that the depth of liquefaction is not very deep. The liquefaction induced damage is concentrated in two sections of the city as shown in Fig.6. No subsurface investigation had been performed in the city before the earthquake and no engineering subsurface soil information was available.

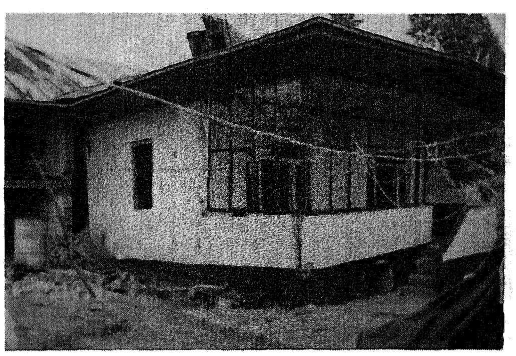

Figure 2. Extent of liquefaction induced damage to a house in Astaneh.

Figure 4. Sand boil from a water well in Astaneh.

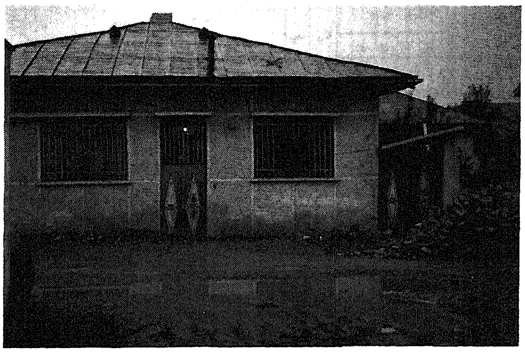

Figure 5. Liquefaction induced differential settlement between a house and its adjacent wall in Astaneh.

To understand the liquefaction mechanism and to answer questions concerning the liquefaction process in this city, a subsurface investigation performed composed of nine bore holes drilled, three in northeast and four in southwest zones of liquefaction and two in other parts of the city. The location of bore holes are shown in Fig.6. Although the soil condition changed during and after the earthquake, the heave and settlement of the ground surface in different locations tell us that both loosening and densification of the soil have occurred as a result of liquefaction. Thus, the subsurface investigation could clarify questions as to the liquefaction in Astaneh. The main questions could be why the liquefaction did occur and whether under similar conditions the liquefaction will occur or not.

In this paper, results of in-situ tests preformed at bore holes no.2 (BH2) and no.8 (BH8) located respectively at northeast and southwest sections of the liquefied parts of the city of Astaneh, and no.4 (BH4) and no.9 (BH9) located at other parts of the city are

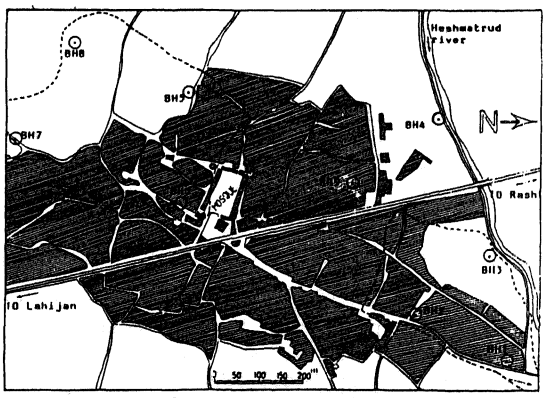

Figure 6. Map of the city of Astaneh. Borders of liquefied zones are shown by dashed lines.

respectively shown in Figs. 7 to 10. These figures also include the laboratory tests on samples taken from the above mentioned bore holes.

To perform SPT test at each location a 10 cm diameter hole was drilled to the considered depth using rotary drilling technique. To keep the holes open, a mixture of water and bentonite was used. SPT was carefully performed at every meter of the holes. For this purpose a safety hammer was employed. As the procedures of drilling and testing were exactly the same as those recommended by Seed et al (1983), the correction factor in this respect can be taken as one.

The magnitude of Manjil earthquake is reported by different sources, varying from M_s=7.3 to M_s=7.7. Thus for this analysis consideration of M_s=7.5 could be reasonable. No accelerograph was installed at Astaneh at the time when Manjil earthquake occurred. However the maximum horizontal acceleration recorded at Lahijan some 10 km southwest of Astaneh, was 0.17g. This accelerograph is installed on alluvial deposits of elder age compared to that of Astaneh. As the distance from Lahijan to epicenter is less than that of Astaneh, we may consider the maximum horizontal ground acceleration induced by Manjil earthquake at Astaneh to be 0.15g.

Most of the soil presented at liquefied sections contain clean sands or sands with little amount of fines. Therefore, to evaluate the cyclic strength of these soils, the chart given by Seed et al (1983) can directly be used (Fig.11). From Fig.11 we can see that for N_1<20 and M=7.5 the variation of cyclic stress ratio with N_1 (modified N-value) is linear.

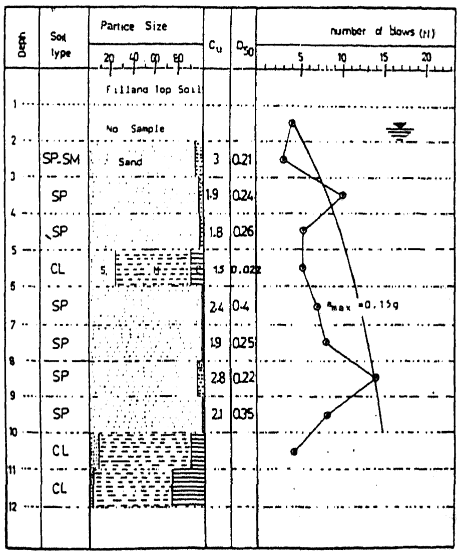

Figure 7. In-situ and laboratory tests on soils present at BH2 (zone of liquefaction).

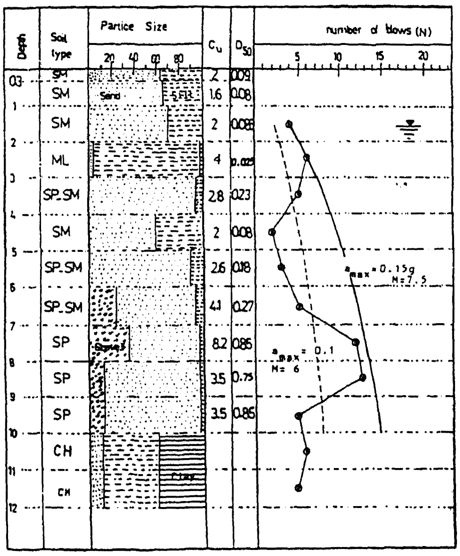

Figure 8. In-situ and laboratory tests on soils present at BH8 (zone of liquefaction).

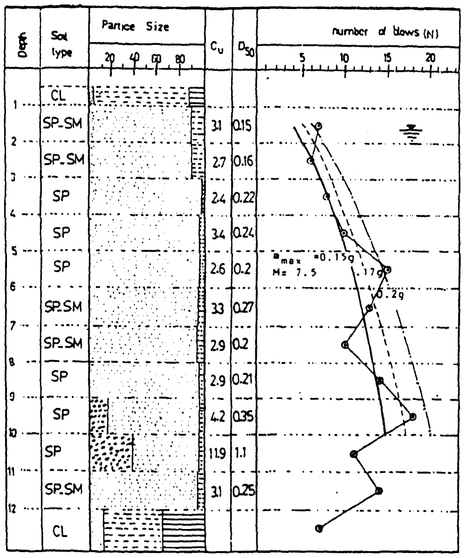

Figure 10. Results of in-situ and laboratory tests on soils present at BH9 (No liquefaction zone).

Therefore we can write:

$$\frac{\tau_{av}}{\sigma_o'} = C_M \cdot N_1 \qquad (1)$$

where C_M= 0,0107 for M=7.5 and N_1<20, τ_{av} and σ_o' are the average cyclic strength and the effective overburden pressure on sand under consideration, respectively.

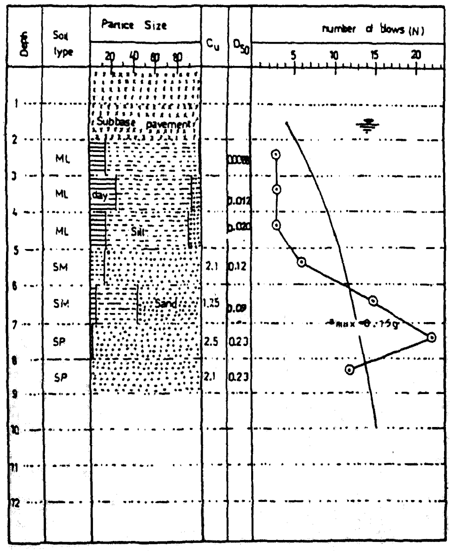

Figure 9. Results of in-situ and laboratory tests on soils present at BH4 (No liquefaction zone).

We may substitute for N_1 as:

$$N_1 = C_{ER} \cdot C_N \cdot N \qquad (2)$$

where N is the measured SPT value, C_{ER} is the correction factor for the hammer energy and C_N is the correction factor for effective overburden pressure. Therefore:

$$\frac{\tau_{av}}{\sigma_o'} = C_M \cdot C_N \cdot C_{ER} \cdot N \qquad (3)$$

On the other hand, the cyclic stress ratio developed in the field due to earthquake shaking can be computed from an equation of the form as below, given by Seed and Idriss (1971):

$$\frac{\tau_{av}}{\sigma_o'} = 0.65 \frac{a_{max}}{g} \cdot \frac{\sigma_o}{\sigma_o'} \cdot r_d \qquad (4)$$

in which a_{max} is maximum acceleration at the ground surface; σ_o is total overburden pressure on sand layer under consideration; σ_o' is initial effective overburden pressure on sand layer under consideration; and r_d is stress reduction factor varying from 1 at the ground surface to about 0.9 at a depth of about 10 m.

Equating the right hand sides of equations (3) and (4) and solving for N we get:

$$N = \frac{1}{C_M \cdot C_N \cdot C_{ER}} 0.65 \cdot \frac{a_{max}}{g} \cdot \frac{\sigma_o}{\sigma_o'} \cdot r_d \qquad (5)$$

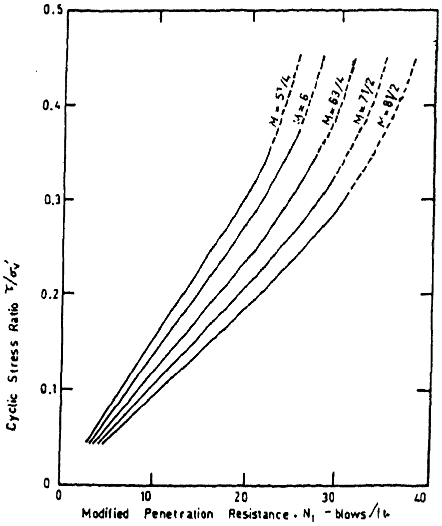

Figure 11. Liquefaction cyclic stress ratio vs modified SPT N_1-value.

The reduction factor r_d can be substituted by $r_d=1-0.01d$ where d is the considered depth in meter. The water table might be considered to be at a depth of d_w, therefore σ_o' and σ_o can easily be calculated. The correction factor C_N can be computed using the equation given by Peck et al (1974) as:

$$C_N = 0.77 \log \frac{20}{\sigma_o'} \qquad (6)$$

For this analysis $C_{ER}=1$ and $C_M=0.0107$ and for this site $a_{max}/g=0.15$. Therefore, substituting the right values in the right hand side of Equation (5), we can get the required N-value for liquefaction resistance. More details and assessment charts obtained from this procedure have been presented in a research accomplished by Zolfaghary (1991).

Equation (5) is plotted in Figs.7 to 10. The comparison of measured N-value with the required N-value for liquefaction (Eq.5), indicates the total thickness at which the liquefaction did occur due to the Manjil earthquake or may occur under a similar condition.

The soil condition at the site where BH2 is located, is such that from 2m deep to 2.5m deep liquefaction is possible. From 2.5m to 3.5m deep liquefaction is not possible due to presence of a relatively denser sand where as it is possible from 3.5m to 5m and from 6m to 10m deep. Liquefaction may not occur from 5m to 6m deep because of the presence of a cohesive layer at this depth (Fig.7).

As it is seen from Fig.8, the liquefaction can be induced in the sands present below the water table at almost total depth of the site where BH8 is located. The thickness of liquefiable soil at locations where BH2 and BH8 are drilled is well enough to produce high water pressure thrust leading to break through the topsoil present at these locations. Therefore the liquefaction became visible due to the Manjil earthquake of June 20 1990 in sections of the city of Astaneh where these two bore holes are located.

The same procedure described for BH2 and BH8 accomplished for BH4 located in the section of the city with no signs of liquefaction. As seen from Fig.9 at least three meters of cohesive material is present at the upper part of the soil underlaying a compacted granular material of pavement. Results of the analysis for sandy parts of this cross section indicates that liquefaction can occur in a thin layer of loose sand and silt at a depth of 5m below ground surface and in layer of a medium sand at a depth of about 8m. These two narrow and relatively deep strata did not have enough thrust to break through the dense sand present at 6m to 7m deep and the thick cohesive soil present near the ground surface.

The same procedure as described before was also performed for BH9 located in another part of the city without indication of liquefaction. Figure 10 contains the results of this analysis. As it is seen from this figure the sand is present at almost total depth of the hole, however, this sand is relatively dense and therefore liquefaction did not occur due to Manjil earthquake at this site.

Results of continuation of analysis indicates that an earthquake of similar magnitude with a maximum horizontal acceleration of 0.17g can produce a minor and that of 0.2g can produce a heavy liquefaction at the site where BH9 is located. This is shown in Fig.10 as well. Also an earthquake of M=6 with a maximum ground acceleration of 0.1g may still induce liquefaction at a site where BH8 is located (see Fig.8). Therefore, it is vital to perform a dense and careful study of liquefaction potential in all sections of the city of Astaneh in order to evaluate the level of hazard which threatens this city concerning the earthquake induced liquefaction and its destructive consequences.

CONCLUSIONS:

During the Manjil earthquake of June 20 1990, Iran, a vast area in Caspian province of Gilan experienced liquefaction. Most of the places with clear signs of liquefaction were located in fluvial plain of Sefidrud and its tributaries especially in abandoned channels of this river. The most extensive damages induced by liquefaction occurred in Astaneh some 75 km northeast of epicenter. To understand the reasons as to the causes of this liquefaction and map it in Astaneh, a research program was established including surface and subsurface investigations and insitu and laboratory testing. In this paper, the extent of liquefaction induced damage in this area is briefly reviewed and the results of this investigation are described.

Liquefaction induced total and differential settlement of structures, which in turn, resulted in heavy damage to and destruction of many houses in Astaneh. Appearance of extensive open cracks and sand boils from ground surface and water wells caused sever damages to residential area of the city of Astaneh. The signs of liquefaction were visible only in two sections of the city of Astaneh. High ground water table in relatively shallow loose fine sand and silty sand and a sever ground shaking induced liquefaction in these two sections of the city. Thanks to the presence of relatively thick cohesive soil or relatively dense sand near the ground surface, no sign concerning the liquefaction appeared in other sections of the city. However, the present investigation indicates that a more sever ground shaking may result in liquefaction in some other parts of the city in addition to the presently damaged sections of the city. This in part magnifies the necessity of further dense and careful study of liquefaction in the city of Astaneh.

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