03 Jun 1993, 2:00 pm - 4:00 pm

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Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 3.18

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SYNOPSIS: The Manjil, Iran, earthquake caused extensive liquefaction and liquefaction-induced damage to residential, commercial and public structures. This paper presents liquefaction case histories as well as the results from our analysis of the data. Based on the field observations made in Iran, liquefaction strength of clean sands for M_S=7.7 is established. The resulting liquefaction resistance versus density relationship is compared with the results published by Seed et al. (1983).

INTRODUCTION

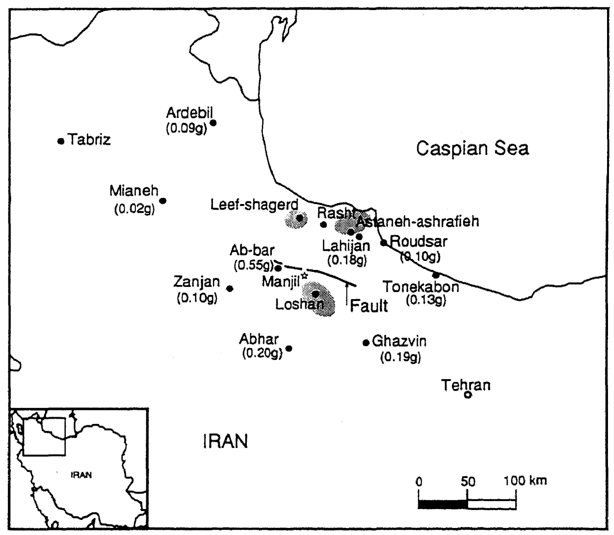
The Manjil, Iran earthquake, M_S=7.7 (Berberian et al. 1992) occurred on June 21, 1990 shortly after midnight local time. Official estimates indicate that more than 35,000 people lost their lives. Because of the rural nature of the populated region within the earthquake zone, the damage due to ground shaking was primarily to one and two-story single family houses. During the earthquake, liquefaction of foundation soils also played a significant role in the destruction of many houses and commercial and public buildings. There was dramatic evidence of this widespread liquefaction-induced damage as far away as 80 km from the fault.

The authors with the support of the Ministry of Housing and Urban Development of the government of Iran and the office of the governor of the Guilan Province investigated the liquefaction related aspects of the earthquake (Yegian & Ghahraman 1990). A comprehensive report is being prepared that will document the results of our extensive field investigations of the densities of the liquefied sands. In addition, the report will include the results of our analysis of the case histories on: liquefaction of level ground, pile and pier response in liquefied sands, liquefaction-induced foundation settlements and permenant ground deformations.

This paper describes the extent of our investigations, presents typical results from our field density tests and concludes with an analysis of the liquefaction case histories related to level ground conditions.

THE EARTHQUAKE

Figure 1 shows northwest region of Iran as well as the location of the fault. The fault is a right lateral thrust fault and has an effective length of about 80 km (Berberian et al. 1992). The epicenter of the earthquake is inferred to be at or near the town of Manjil. Within a region of 200 km from the fault, a number of strong motion accelerograms successfully recorded the ground motions. Figure 1 shows selected cities and towns and the corresponding recorded peak ground accelerations. Of particular interest is the record obtained in the city of Lahijan located 62 km from the fault. Figure 2 shows the acceleration-time history of this record (Naderzadeh 1991). Although the total duration of the record shown is about 60 seconds the effective duration of interest for liquefaction analysis is about 15 seconds. To illustrate this, the equivalent number of uniform cycles, N_{eq}, of the Lahijan record was computed, as a function of time, using the procedure suggested by



Region of widespread liquefaction

Fig. 1. Geographic Map of Northwestern Region of Iran

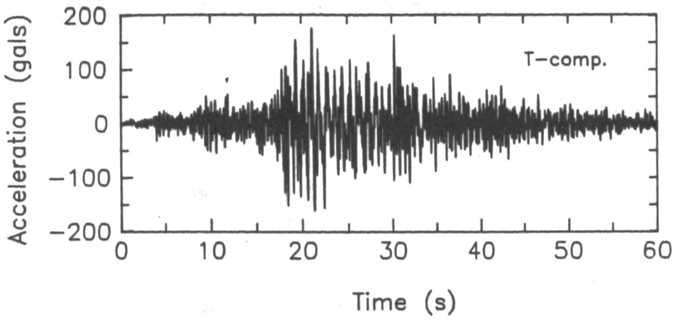


Fig. 2. The Ground Motion Recorded in Lahijan

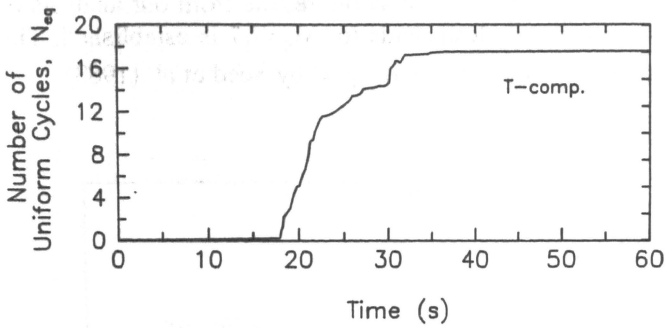


Fig. 3. The Equivalent Number of Uniform Cycles of the Lahijan Record

Seed et al. (1975). The results, presented in Figure 3, confirm that the record has a total of about 17 cycles of equivalent pulses and a duration of 15 seconds. For a magnitude M_S=7.7 earthquake, N_{eq}=17 cycles is consistent with what has been observed from other similar earthquakes (Seed et al. 1983).

LIQUEFACTION CASE HISTORIES

Figure 1 shows three regions where liquefaction was observed and were subsequently investigated by the authors. In Loshan, 15 km from the fault, extensive evidence of liquefaction was observed as shown in Figure 4. At this site, the performance of bridge piers and pile foundations in liquefied sands were investigated. These studies, however, are not within the scope of this paper. Near the Caspian Sea two regions were extensively investigated as shown in Figure 1; Astaneh-Ashrafieh region located to the east of the major city of Rasht, and Leef-Shagerd region to the west of Rasht. Typical case histories from these two regions are presented in this paper.

Figure 5 shows a map of the liquefied regions and the cities and towns where we have conducted Standard

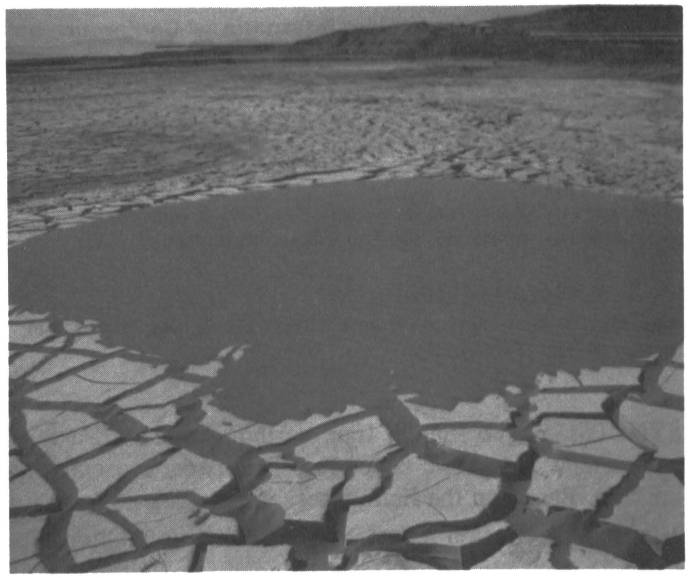


Fig. 4. Liquefied Sand Ejected Near the Banks of the Sefid River in Loshan

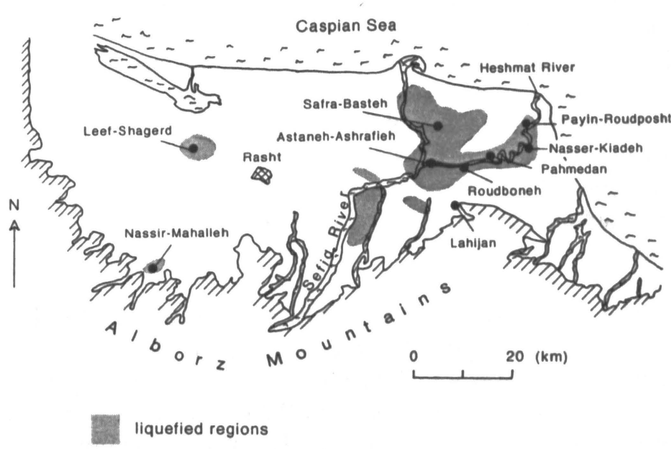


Fig. 5. Cities and Towns in the Liquefied Regions Where Field Investigations Were Made

Penetration Tests (SPT). Liquefaction to the east of Rasht occurred almost entirely in the levee deposits along the banks of the Sefid and Heshmat rivers (Figure 5). However, the liquefied sands to the west of Rasht are of marine origin. Figures 6 through 8 illustrate typical liquefaction-induced building settlement and damage. Figures 9 and 10 show typical boring logs and SPT, N-values from Astaneh-Ashrafieh and Roudboneh, respectively. The sands from this region are characterized as gray poorly graded fine sands with less than 10% silts. Also, in Figures 9 and 10 the grain size distribution curves of many samples of the liquefied sands obtained from these

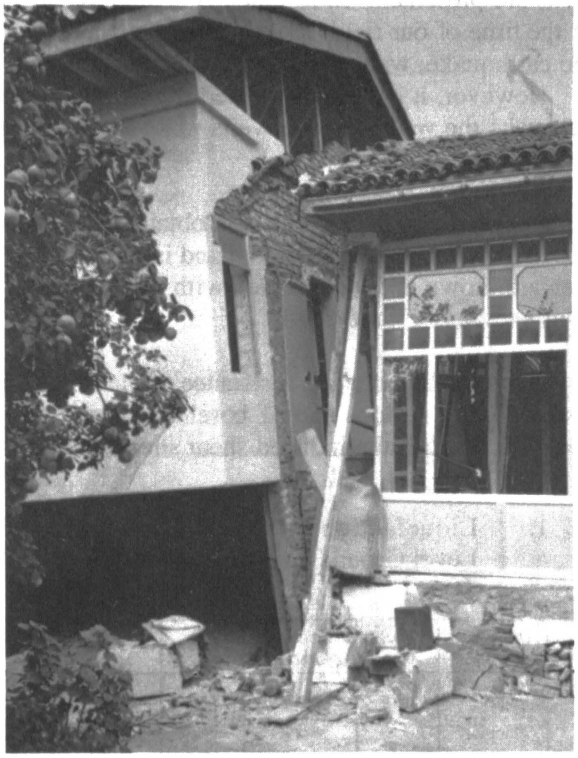


Fig. 6. Settlement and Tilt of a Building on Liquefied Sand in Astaneh-Ashrafieh

Fig. 7. Liquefaction-Induced Differential Settlement Between a House and an Adjacent Wall in Astaneh-Ashrafieh

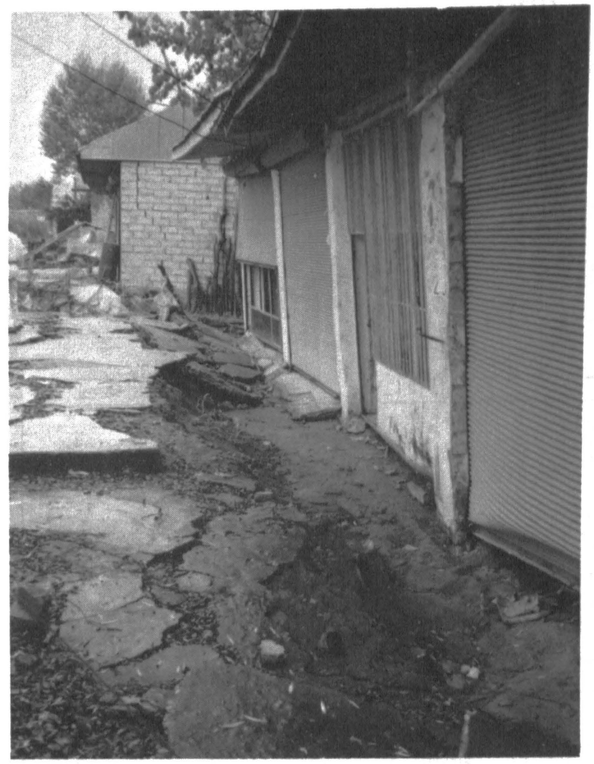


Fig. 8. Liquefaction-Induced Settlement of Single-Story Structures in Roudboneh

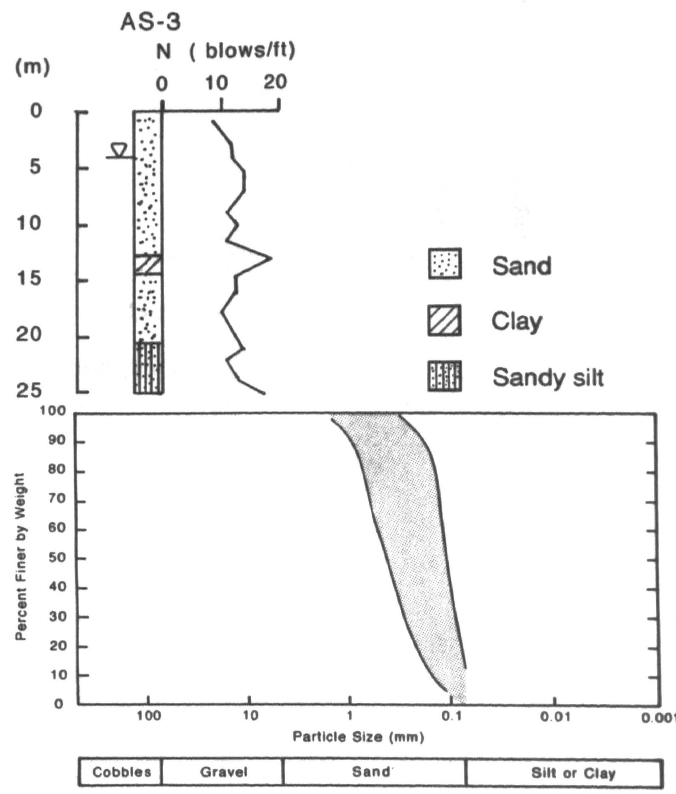


Fig. 9. Typical Boring Log and Range of Gradation of the Sands from the Liquefied Region in Astaneh-Ashrafieh

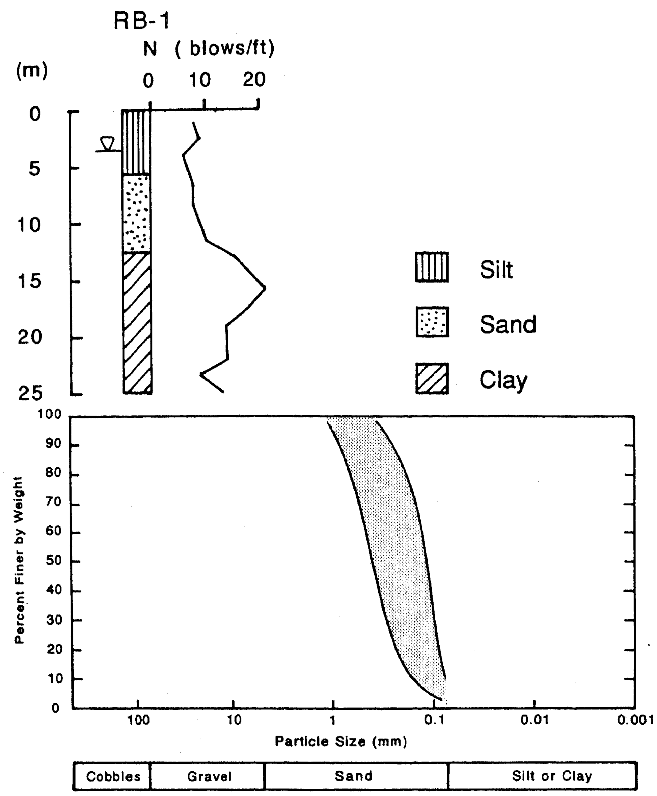


Fig. 10. Typical Boring Log and Range of Gradation of the Sands from the Liquefied Region in Roudboneh

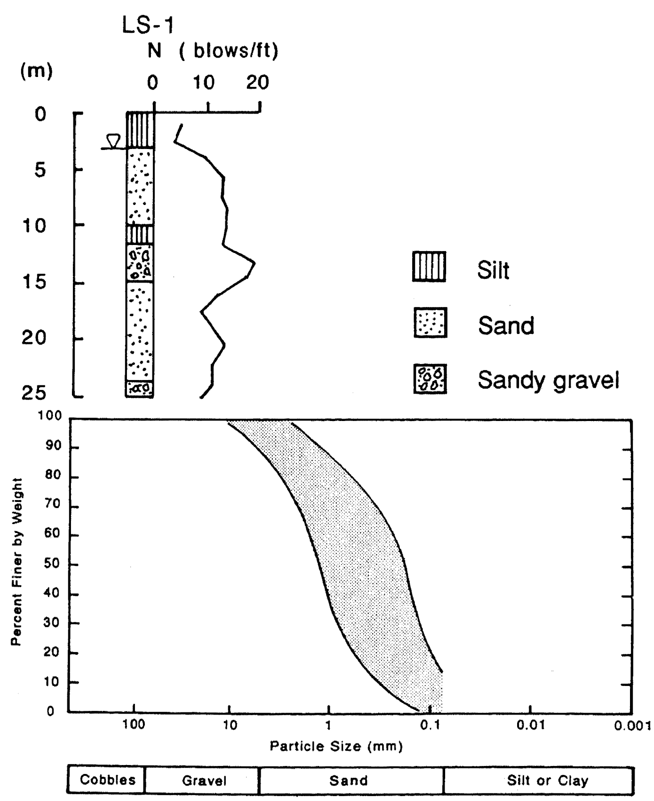


Fig. 11. Typical Boring Log and Range of Gradation of the Sands from the Liquefied Region in Leef-Shagerd

two towns are presented. In Astaneh-Ashrafieh the water table at the time of our field investigations, about a year after the earthquake, was 3 to 4 meters below the ground surface. However, it has been reported that at the time of the earthquake the water level in wells was about 2 meters below the ground surface.

Figure 11 shows typical boring log obtained in Leef-Shagerd. The sands in Leef-Shagerd and in Nassir-Mahalleh are brown and well graded with little silts and gravels as shown in Figure 11.

To evaluate the liquefaction resistance of the sands the SPT results from 9 regions and 31 boreholes were analyzed. The earthquake-induced shear stresses were

TABLE 1. Liquefaction Case History Data for Level Ground Conditions

Location	Distance (km)	Acc.* (g)	Boring Number	$(N_1)_{60}$ (ave.)	$\tau/\bar{\sigma}_v$ (ave.)	Liq.
Astaneh-Ashrafieh	65	0.18	AS-1	10.4	0.17	Yes
			AS-2	14.7	0.19	Yes
			AS-3	13.7	0.17	Yes
			AS-4	12.6	0.18	Yes
			AS-5	gravel	-----	No
			AS-6	10.6	0.19	Yes
			AS-7	clay	-----	No
			AS-8	12.9	0.17	No
			AS-9	10.6	0.19	Yes
			AS-10	15.1	0.16	Yes
			AS-11	14.9	0.17	Yes
			AS-12	11.2	0.20	Yes
			AS-13	12.6	0.18	Yes
			AS-14	17.5	0.18	No
			AS-15	27.6	0.17	No
			AS-16	13.9	0.18	No
Roudboneh	68	0.15	RB-1	8.2	0.13	Yes
			RB-2	8.8	0.12	Yes
			RB-4	8.9	0.14	Yes
Pahmedan	70	0.15	PA-1	12.5	0.14	Yes
			PA-2	13.4	0.14	Yes
Nasser-Kiadeh	75	0.12	NK-1	7.1	0.13	Yes
Payin-Roudposht	81	0.11	RP-1	8.6	0.09	Yes
			RP-2	11.5	0.10	Yes
Safra-Basteh	75	0.12	SB-1	14.1	0.17	Yes
Leef-Shagerd	55	0.20	LS-1	10.9	0.16	Yes
			LS-2	11.4	0.17	Yes
Nassir-Mahalleh	32	0.25	NM-1	11.6	0.22	Yes
			NM-2	10.5	0.20	Yes
Bala-Bala (Loshan)	15	0.40	Bridge	14.8	0.31	Yes
			Trestle	8.9	0.29	Yes

* from attenuation relationship developed based on recorded ground motions

calculated within the sand deposits using Seed et al.(1983) procedure. The peak ground accelerations for each site was estimated using the Lahijan record and utilizing an attenuation relationship that was established, by the authors, based on all the recorded motions from the Manjil, Iran Earthquake. The SPT, N-values were corrected for the effect of overburden pressure, again, in accordance with Seed et al. (1983). Table 1 summarizes the relevant data from these case histories. Figure 12 shows a plot of the data together with the strength curves published by Seed et al. (1983) for M=7.5 and M=8.5. It is noted that the SPT, N-values for the liquefied sands, prior to the earthquake might have been smaller than our reported values. Yet, data from other earthquake case histories indicate that the average SPT, N-values at a site changes very little because of the earthquake excitation (Ohsaki,1966). Notwithstanding, the Manjil earthquake data show that the strength of the sands during the M_S=7.7 earthquake is in general agreement with the range suggested by Seed et al. (1983) curves for M=7.5 and M=8.5. If one were to make a more conservative estimate of the liquefaction resistance of these sands for a similar, M_S=7.7, earthquake in the future, the strength values given by Seed et al. (1983) for M=8.5 would be more appropriate.

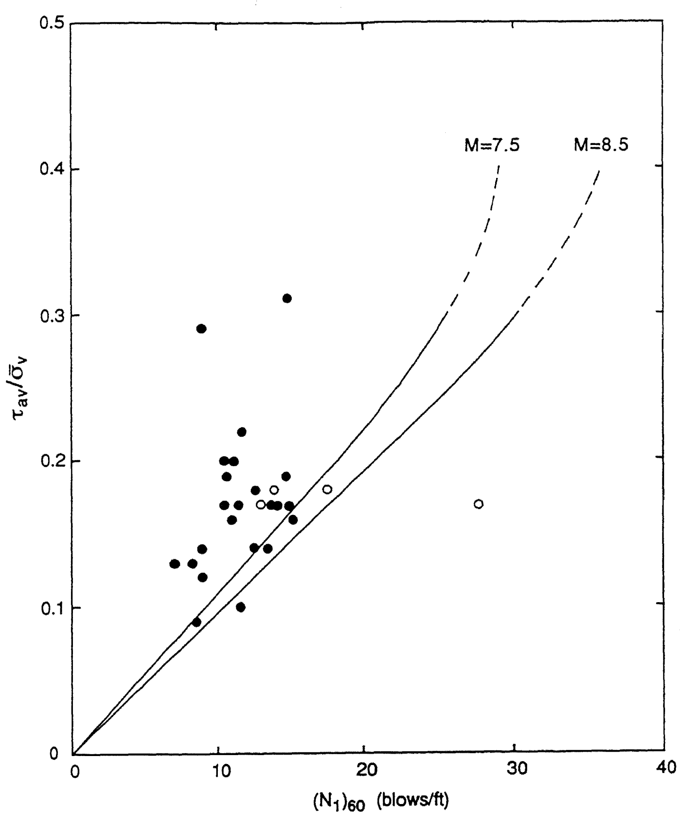


Fig. 12. Comparison of the Liquefaction Case History Data from Manjil, Iran Earthquake with the Liquefaction Resistance Curves of Seed et al. (1983)

CONCLUSIONS

Liquefaction case history data from the 1990 Manjil, Iran, Earthquake (M_S=7.7) are presented. Analysis of the data following the Seed et al. (1983) procedure shows that the liquefaction resistance of the sands investigated is in general agreement with that suggested by Seed et al. (1983) for M between 7.5 and 8.5.

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