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Liquefaction During the October 12, 1992 Egyptian Dahshure Earthquake

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SYNOPSIS: On October 12, 1992 a moderate earthquake $M_B = 5.9$ ($M_S = 5.2$) occurred about 18 km southwest of the center of Cairo and resulted in significant damage to numerous poorly constructed structures. Soil liquefaction associated with the occurrence of large sand-boils was observed close to the epicenter. As a consequence, a main road suffered a maximum settlement of about 1.75 m. In this study, the earthquake characteristics, soil profiles and resulting liquefaction are discussed. The observed liquefaction mechanisms provide valuable information on the seismic response of Nile deposited alluvial soils. Such soils constitute much of the inhabited area of Egypt.

INTRODUCTION

The October 12, 1992 Cairo (Dahshure) Earthquake ($M_B = 5.9$) occurred at about 3:00 p.m. It was estimated that about 8,300 dwellings were destroyed, 561 people were killed, and 6,500 were injured (Hadjian, et al., 1992; JICA, 1992; Khater, 1993; Sycora, et al., 1993; Thenhaus, et al., 1993; Wight, 1992; Youssef, et al., 1992). No strong motion instruments were available to record the imparted seismic excitation. In fact, before this earthquake, Cairo had not experienced any appreciable destructive seismic excitation since 1847 (Kebeasy, 1990).

The observed liquefaction near the earthquake epicenter occurred in an agricultural area of alluvial Nile deposits. Throughout centuries, the Nile River flooded the plains along its path every summer (until the construction of the Aswan High Dam in 1971). In the flood period, sediments carried by the water were deposited to constitute agricultural land along the Nile Valley and Delta (Fig. 1). The October 12, 1992 earthquake demonstrated that liquefaction may be an important seismic response mechanism at many densely populated locations along the Nile's South to North path throughout Egypt (Fig. 1).

SEISMICITY OF EGYPT

Egypt may be considered as an area of moderate seismicity. Evidence of earthquakes dates back to as early as B.C. 2200 (Kebeasy, 1990). It is believed that three main seismically active trends exist (Fig. 1): i) along the Mediterranean, ii) along the Gulf of Aqaba in the Northern Red Sea, and iii) along the Northern Red Sea-Gulf of Suez (active extensional tectonics). Kebeasy, et al. (1981) report 12 moderate earthquakes $5.0 < M < 7.0$ to have caused significant damage in the densely populated areas of Northern Egypt during the last 1,000 years. These areas (Fig. 1) include cities along the Mediterranean (such as Alexandria), the Nile Delta, Cairo, and El-Fayum (about 100 km Southwest of Cairo). Two moderate, but destructive, earthquakes occurred in 1303 and 1847 at El-Fayum (near the epicenter of the recent 1992 earthquake; Fig. 1). In 1847 (estimated M = 6.2), 3,000 houses and 42 Mosques were reported to have been destroyed (Kebeasy, et al., 1981; Ambraseys, 1991). Based on

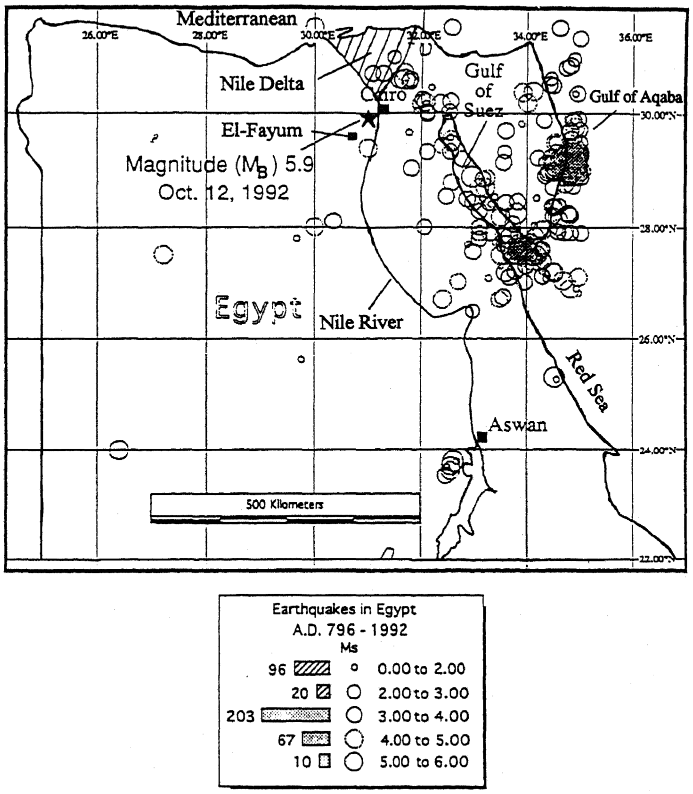

Fig. 1. Distribution of earthquake epicenters in Egypt, A.D. 796-1992 (after Thenhaus, et al., 1993).

historical records, it is inevitable that future destructive earthquakes will continue to occur in Egypt.

THE OCTOBER 12, 1992 EARTHQUAKE

The $M_B = 5.9$ ($M_S = 5.2$) earthquake epicenter was located Southwest of Cairo (Fig. 1) near the City of Dahshure. Currently, the information available about epicentral coordinates, provided by the National Earthquake Information Service (NEIS), are latitude 29.89° N and longitude 31.22° E (Thenhaus, et al., 1993). Focal depth below ground surface was estimated at about 25 km, with no visible surface fault dislocation. A Northwest-striking fault plane (Fig. 2) was thought to be probable based on the documented information about local geology (Thenhaus, et al., 1993).

A map that depicts the Modified Mercalli Intensity (MMI) distribution is shown in Fig. 3. Soil liquefaction was observed in the maximum MMI zone VIII near the Village of Manshiyat Fadil on the West side of the Nile River (Fig. 3).

MECHANISM OF SAND-BOILS

One of the most commonly observed manifestations of soil liquefaction is the occurrence of sand boils along the ground surface (NRC, 1985). In the United States, significant sand boils have been observed during the earthquakes of Charleston 1886 (Clough and Martin, 1990), San Francisco 1906 (Lawson, 1908; Youd and Hoose, 1976), Alaska 1964 (Seed, 1970), Imperial Valley 1979 (Muir and Scott, 1982), and Loma Prieta 1989 (Bennett, 1990; Seed, et al., 1990; Bardet and Kapuskar, 1993), among others. These volcano-like features indicate that the earthquake shaking has generated high excess pore water pressures within the soil deposit (liquefaction), causing upward flow of water laden with soil sediments. Such flow, which is apt to concentrate in channels of relatively higher permeability (due to soil inhomogeneity), eventually erupts to the surface in the form of a sand boil (Elgamal, et al., 1990). The outflowing water typically carries sediments from the liquefied and overlying layers.

Housner (1958) discussed the formation of sand boils in terms of soil porosity, permeability, elasticity, and degree of consolidation. Sand boils were attributed to inhomogeneities in permeability near the ground surface. Scott and Zuckerman (1972) presented both experimental and analytical studies on the mechanics of liquefaction and sand boil formation in sandy soil deposits. They found that the presence of silt or a similar fine grained layer at the surface (above the liquefied layer) was conducive to the generation of sand boils. In contrast to "piping," sand boils were observed to propagate from the source of pressure to the outlet by a mechanism of cavity formation. Adalier (1992) also demonstrated that stratified soil profiles are conducive to sand boil formation. It was shown that low permeability and cohesion of an overlying upper layer may lead to the formation of large sand boils, as the extruded water mainly travels through cracks and weak zones within this upper layer.

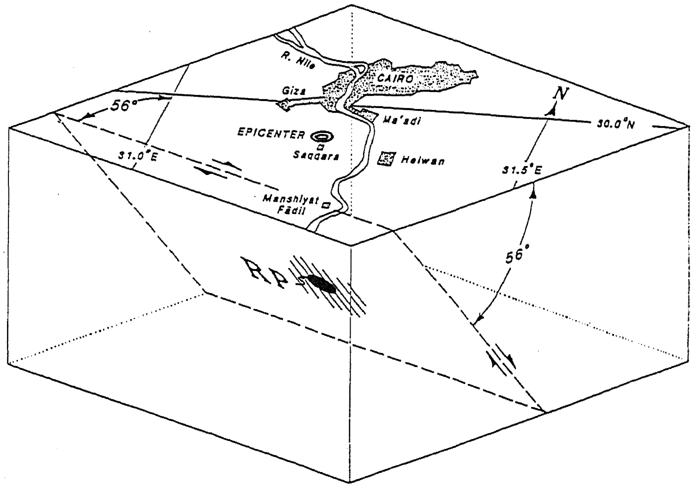

Fig. 2. A transparent earth model of the Cairo region for the 12 October 1992 earthquake. The block is a 60.6 km square on the surface and 40 km deep. Intercepts of the plane of the activated fault are shown with dashed lines, but new rupture is confined to the black patch labelled "RP" (radius 2.6 km); down-dip parallel rulings show unbroken parts of the fault plane around the rupture patch. Arrow pairs show relative horizontal and vertical sense of motion at the rupture patch. Adapted from data of NEIS and G. Ekstrom and M. Salganik of Harvard University (Thenhaus, et al., 1993).

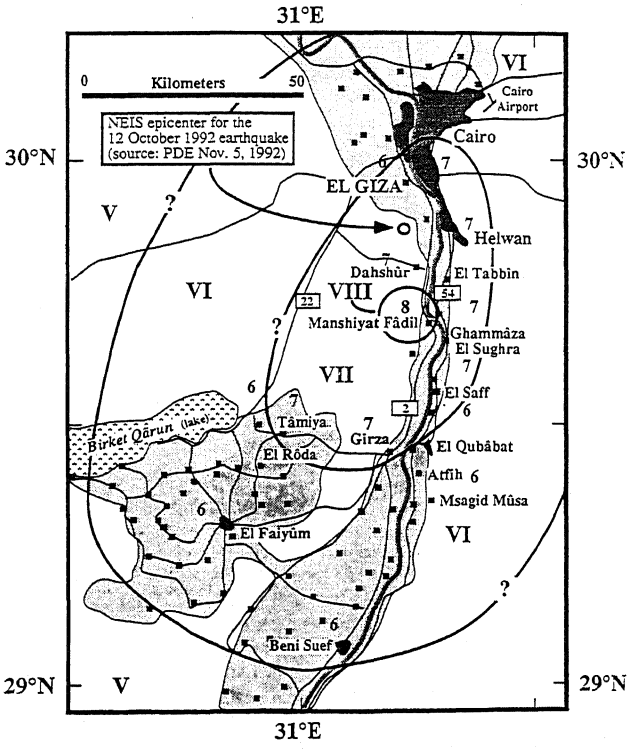

Fig. 3. Modified Mercalli Intensity (MMI) distribution, October 12, 1992 Dahshure, Egypt earthquake (Thenhaus, et al., 1993). PDE: Preliminary Determination of Epicenters, USGS, NEIS, Golden, CO.

LIQUEFACTION NEAR EARTHQUAKE EPICENTER

Two sites about 2.0 km apart (in the MMI zone VIII of Fig. 3) displayed significant sand boil activity as described below. Both sites are located on the West side of the Nile River, near the village of Manshiyat–Fadil (Fig. 3). This locality is seen to essentially coincide with the intersection of the activated fault plane with the Nile River (Fig. 2). Thus, liquefaction may have been triggered by the strongest near–epicenter shaking, as similar soils may be expected to exist along the Nile Valley throughout this area (Fig. 3).

Site I: Upper Egypt (Giza–Assyut) Road West of the Nile

One of the two main roads that connect Cairo and Giza to the South of Egypt (Upper Egypt) was found to have settled (at El–Atff, near the Village of El–Beleda) by as much as 1.75 m shortly after the earthquake (Fig. 4). The road is composed of 2 traffic lanes in each direction with an intermediate median and is about 25 m in width (Fig. 5). At the location of observed settlement (about 1.0 km away from the Nile), the road is bordered on one side by an irrigation canal; and on the other by a drain and agricultural land (Fig. 5). After the earthquake, the road was promptly repaired by: i) building a new sub–base of crushed stone to bring the road to its original elevation, ii) restoring the shoulders and slopes on both sides of the road, and iii) placing a new asphalt pavement (Fig. 4).

Fig. 4. Liquefaction induced settlement at Upper Egypt Road West of the Nile: 1) road elevation after earthquake (2 right lanes); 2) original road elevation being restored during repair (2 left lanes).

It is believed that soil liquefaction below the road was the primary reason behind the observed 1.75 m settlement. This settlement was gradual over a distance of about 200 m, and essentially uniform along the entire 25 m road width. Liquefaction effects were evident in the agricultural field adjacent to the road (Fig. 5). In this field, water laden with sediment erupted through fissures and spread along the ridged (due to prior plowing) agricultural ground surface (Figs. 6 and 7). The fissures appeared at a distance of about 20 m away from the road, adjacent to the zone of settlement (Fig. 5).

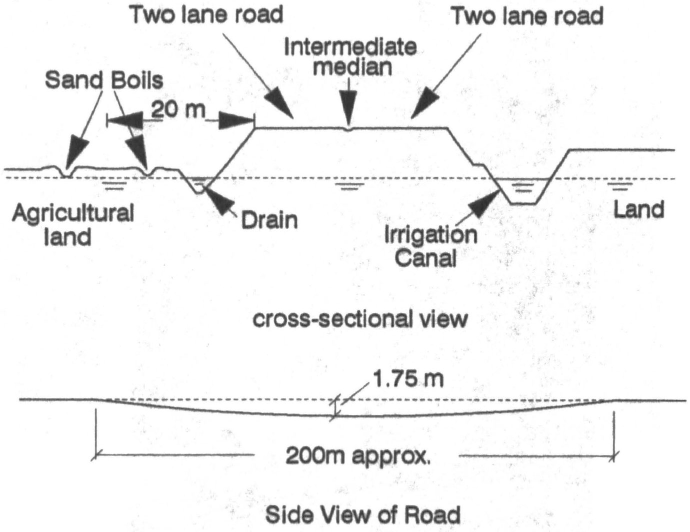

Fig. 5. Cross–sectional view of Upper Egypt Road site; and side–view after earthquake.

No clear signs of lateral spreading were observed, however. Settlement was essentially vertical and was probably driven by the relatively higher elevation of the road with respect to the surrounding terrain (Fig. 5); thus constituting a localized overburden vertical stress. No sediments were observed to have flowed into the adjacent canal or drain (some sediment migration might have occurred below the water level).

Fig. 6. Ground fissure and sediment eruption.

A soil profile from a boring near the road, taken after the earthquake is shown in Fig. 8. This profile denotes that liquefaction could have occurred anywhere within the zone bounded by elevations –3.0 m to –9.0 m. In this zone, significant stratification is evident, and low SPT silts and sands appear to be prone to liquefaction. Indeed, the soil ejected to ground surface during liquefaction was thought to be mostly constituted of fine silty sand. A more thorough program of site investigation and laboratory dynamic testing is needed in order to clarify the involved liquefaction mechanisms at this site.

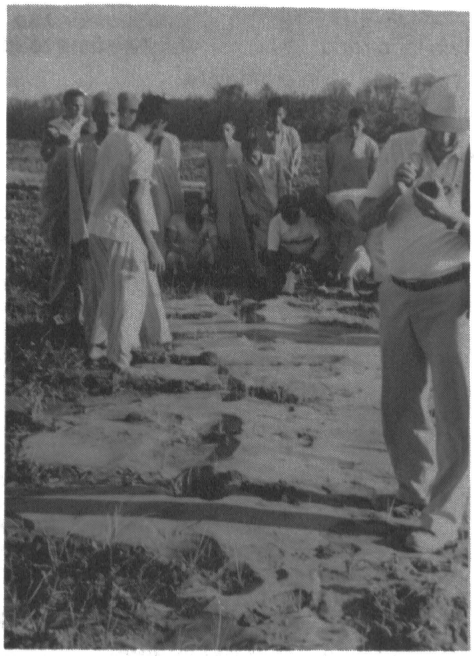

Fig. 7. Close-up of sediment eruption shown in Fig. 6.

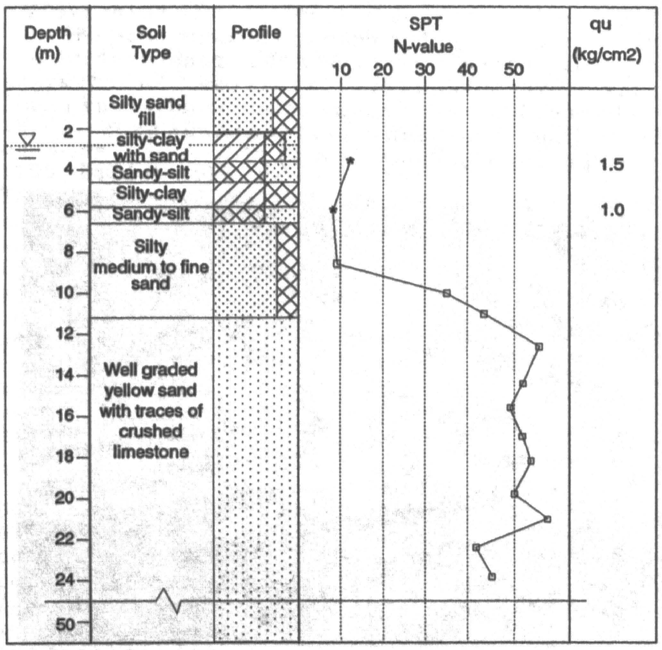

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Fig. 8. Soil profile near the road settlement area.

Site II. Bedsa Village

The Village of Bedsa, about 2 km away from the road settlement zone consisted mostly of 1- and 2-story adobe buildings that were severely damaged during seismic excitation. In a nearby agricultural field (away from Site I), large sand-boil craters occurred at the locations shown schematically in Fig. 9 (2.5 km away from the Nile, and 1.0 km West of El-Beleda Village). These craters are shown in Figs. 10-15.

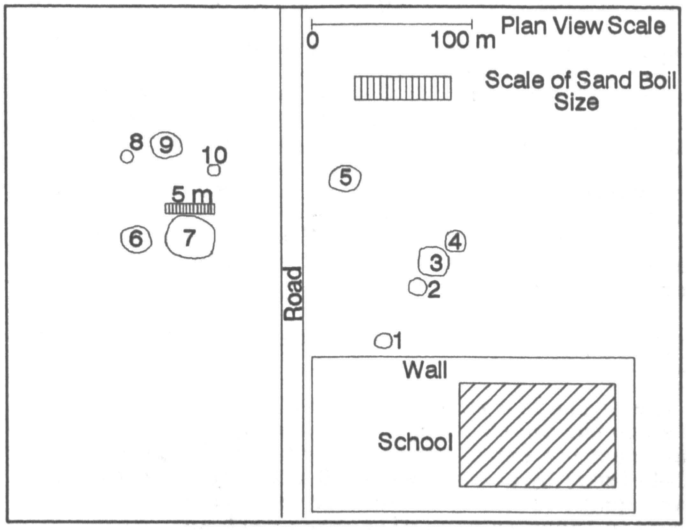

Fig. 9. Schematic of sand boil locations at Bedsa Village.

Fig. 10a. An abandoned steel pipe covered with a concrete block moved upwards relative to the surrounding soil.

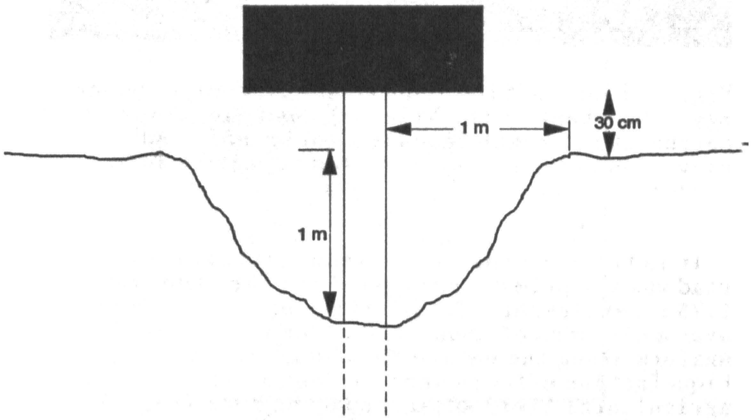

Fig. 10b. Schematic of sand boil formed around steel pipe (Fig. 10a) after earthquake (observed on videotape). Crater No. 1 of Fig. 9.

Fig. 11. Craters No. 2, 3, and 4 of Fig. 9.

Fig. 12. Crater No. 5 of Fig. 9.

Fig. 13. Craters No. 6, 7, 8, 9, and 10 of Fig. 9.

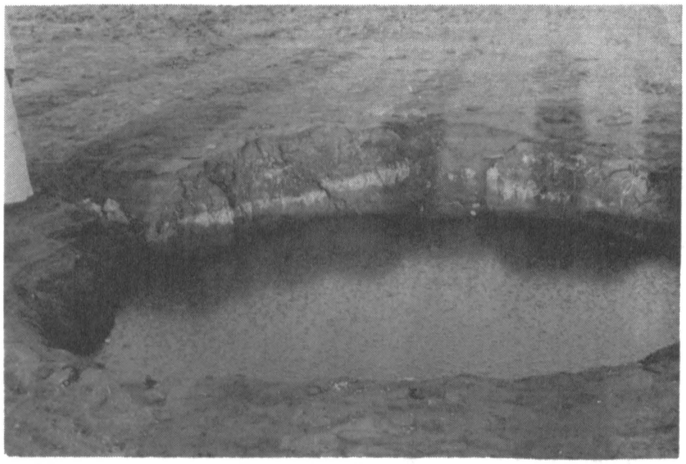

Fig. 14. Close-up of Crater No. 7 of Fig. 9.

Fig. 15. Close-up of Craters No. 8 and 9 of Fig. 9.

Sand-boil activity was reported to have initiated immediately after the earthquake. Ejection of sediment was thought to have continued for about 45 minutes after the primary shaking event. Initially, the ejected sediment was claimed to have reached a height of 2 m or more above ground surface. No indications of lateral spreading were observed at this site of fairly flat terrain.

The ejected soil was found to spread evenly by runoff, and cover a large area of ground surface around each crater. About 20,000 m^2 of surface area were covered with ejected soil to a thickness of approximately 0.1 m (2,000 m^3 of soil were ejected). A preliminary grain size analysis of the ejected sediments is shown in Fig. 16. As may be noted, about 65% is fine sand, with a 30% content of even finer silt- and clay-size particles (mostly silt as noted by visual inspection). These fine particles appear to have remained in suspension after ejection, and were thus spread along the ground surface by the observed runoff process. The estimated 45 minute duration of sand-boil activity might have been influenced by the presence of this significant fine-particle content. Such fine particles were shown to reduce permeability and

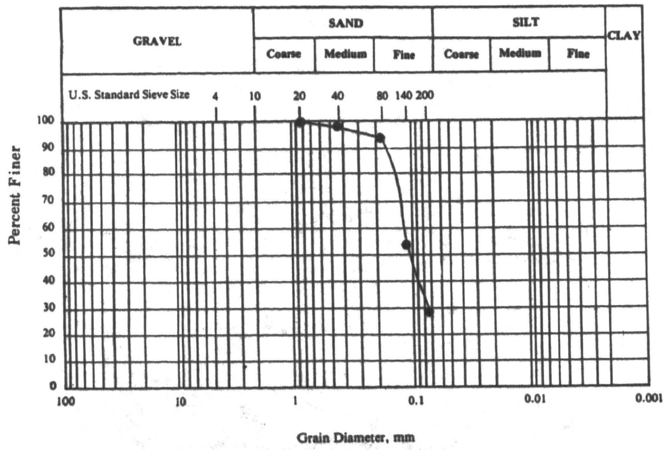

Fig. 16. Preliminary grain size distribution of ejected material.

greatly prolong the post-liquefaction soil-resolidification phase (Adalier, 1992).

The ejected soil was distinctly gray in color (original ground-surface soil was brown). Careful visual inspection revealed the presence of shiny particles (roughly 5%), that were thought to denote the possible presence of micaceous materials that may have influenced the observed liquefaction (Idriss, 1992). A sample of the ejected soil is currently being chemically analyzed in order to identify its constituent minerals.

Figure 17 depicts the soil profile obtained from a boring at Bedsa. Underlying a low permeability silty-clay stratum, low SPT blow counts are seen to prevail in the upper 7.0 m of liquefiable sandy and silty soil materials (elev. -8 m to -15 m). The gray color of these materials is similar to that of the sediments ejected to ground-surface during the sand-boil process. Accurate continuous boring data, and SPT/CPT results are needed at Bedsa in order to further analyze the involved pore-pressure buildup and post-liquefaction mechanisms.

SUMMARY AND CONCLUSIONS

The earthquake of October 12, 1992 resulted in soil liquefaction and significant sand-boil activity in its maximum MMI zone VIII. A main road was found to have settled by as much as 1.75 m due to this liquefaction. In addition, large sand-boil craters occurred in an agricultural field at the Village of Bedsa.

The soil profile characteristics at Bedsa might bear significant similarity to large areas along the densely populated Nile Valley and Delta. Consequently, this liquefaction case history is of particular importance, and might be representative of the seismic response of vast areas along the Nile Valley. A thorough analysis of this case history would establish a valuable benchmark for liquefaction susceptibility analyses of Nile sedimented soils throughout its valley.

ACKNOWLEDGMENTS

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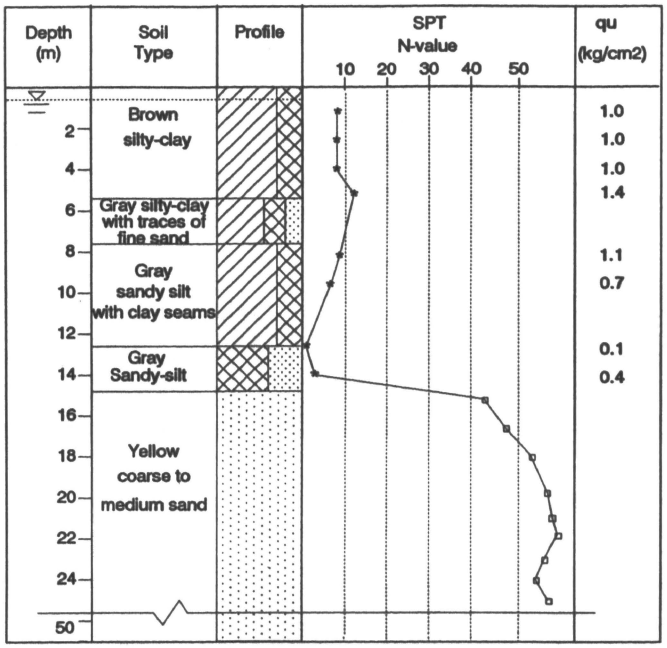

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Fig. 17. Soil profile near sand boils at Bedsa.

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