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LIQUEFACTION PROCESS; AN REMARKABLE PHENOMENON ASSOCIATED WITH THE 1992 CAIRO EARTHQUAKE.

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ABSTRACT

During the 1992 Cairo earthquake; water with dark sands came directly out of the ground where had been no wells or boreholes at the epicentral area. Liquefaction process had been observed at several localities in the earthquake epicentral area such as Bedsa, Barnasht, El-Shorfa, and Gerza villages. This phenomenon (i.e. small volcanoes) had been detected perhaps for the first time in Egypt of recent years. Mechanical analysis and mineralogical investigations are carried out for samples collected from the liquefied dark sands. Mechanical analysis showed that the liquefied sands are very well sorted and fine to medium in their size, strongly fine skewed and platy kurtic. Mineralogical investigation showed the presence of quartz, zircon and rutile.

The magnitude of the earthquake; the grain size, grain shape, density and layer thickness of recent alluvial sands, thickness of impervious materials such as clays covering these sands and the level of the groundwater table are considered as the main factors controlling the liquefaction process. The liquefied sand sheets and cones may be genetically classified as positive earthquake micro relief landforms.

For urban development; it is necessary to determine the areas vulnerable to liquefaction potential hazard using suitable geological investigations (i.e. geomorphological, sedimentological and/or geophysical techniques) to avoid any future disasters.

The 1992 Cairo earthquake:

On October 12, 1992, a damaging earthquake measured 5.7 on Richter Scale, was epicentered near the village of Dahshur, about 18 km south of Cairo.

Egypt lies adjacent to a number of major plate tectonic boundaries which generate significant seismic activity. These tectonic zones include the Red Sea where the Arabian and African plates are slowly moving apart for several millimeteres per year. On the other hand, collision is taking place between the African plate and the subplate of southern Europe (Degg, 1993). In addition to being affected by large earthquakes along these zones, Egypt is occassionally subject to medium magnitude (5 to 6.5 on Richter Scale) earthquakes occurring along ordinary fault systems within the country itself. Along one of these faults, the 1992 Cairo earthquake happened.

Geographical distribution of liquefaction phenomenon through time and place :

Liquefaction phenomenon has been reported throughout the world as well as in history. In China; the Tanshang earthquake of July 28th, 1976 (which had a magnitude of 7.8 on the Richter scale) induced severe liquefaction in the depositional plain to the east and south of Tanshang. In this area; an entire house sank below the surface due to liquefaction (Kruse, 1988), and exacerbated building failures (Guang, 1988). Sand liquefaction was reported in Tianjin city during an earthquake in July 1988 (magnitude 7.8 on the Richter scale, (Jane, 1988).

Spontaneous liquefaction was associated with large earthquakes (magnitude 6 - 8 on the Richter scale in the Philippines, south-east Asia (Nutalaya, 1988). Beradi *et al*. (1991) identified 158 accounts of liquefaction associated with 31 different Italian earthquakes.

The descriptions of this phenomenon bear a resemblance to some historical accounts of earth activity in the Middle East. The town of Ganzah (present - day Armenia) in 1138 or 1139 A.D. was badly shaken and within its dependencies 230,000 people perished. The town itself sank and the place it occupied was covered with black water (Assoyuti in catalogue, Degg, 1993).

Field description of liquefaction phenomenon :

In the earthquake epicenter areas, people reported that water had come out of wells (without the need for pumping) for more than one hour after the earthquake. Also, it was reported that water oozed directly out of the ground where there had been no wells or boreholes.

The scale of this phenomenon (liquefaction) varied but in fields close to some villages (i.e. Bedsa village) less than 15 km south-east of the epicenter, farmers observed around 15 jets of water that rose up to several meters from the ground and flowed for up to one hour. (Fig. 1).

The radii of the circles of the jets range from 30 cm up to 5m. The ground became covered with black water and in places subsided between 20 cm and 30 cm. Beside Bedsa, the liquefaction phenomenon has been reported also in several villages in the epicenter areas such as Brenshet, Gerza (Fig. 2), El-Shorfa, and Gamaza EL-Kobra.

The black water (which carry dark coloured silt and sand) caused considerable destruction to crops in the fields such as onion and potato.

A land subsidence due to the earthquake was detected at the Cairo - Aswan Highway directly east of Bedsa (Fig. 3).

Mineralogical Investigation :

Mineralogical investigation, using X-ray diffraction techniques, was carried out for the samples which have been collected from the liquefied sands at the Bedsa and Gerza villages. A Shimadez X-ray

Fig. (1) : The liquefied sands erupted at Bedsa village. The difference between dark coloured sands and brownish field clays is obvious.

Fig. (2) : Liquefied sand sheets at Gerza village; considered as positive earthquake micro-relief landforms.

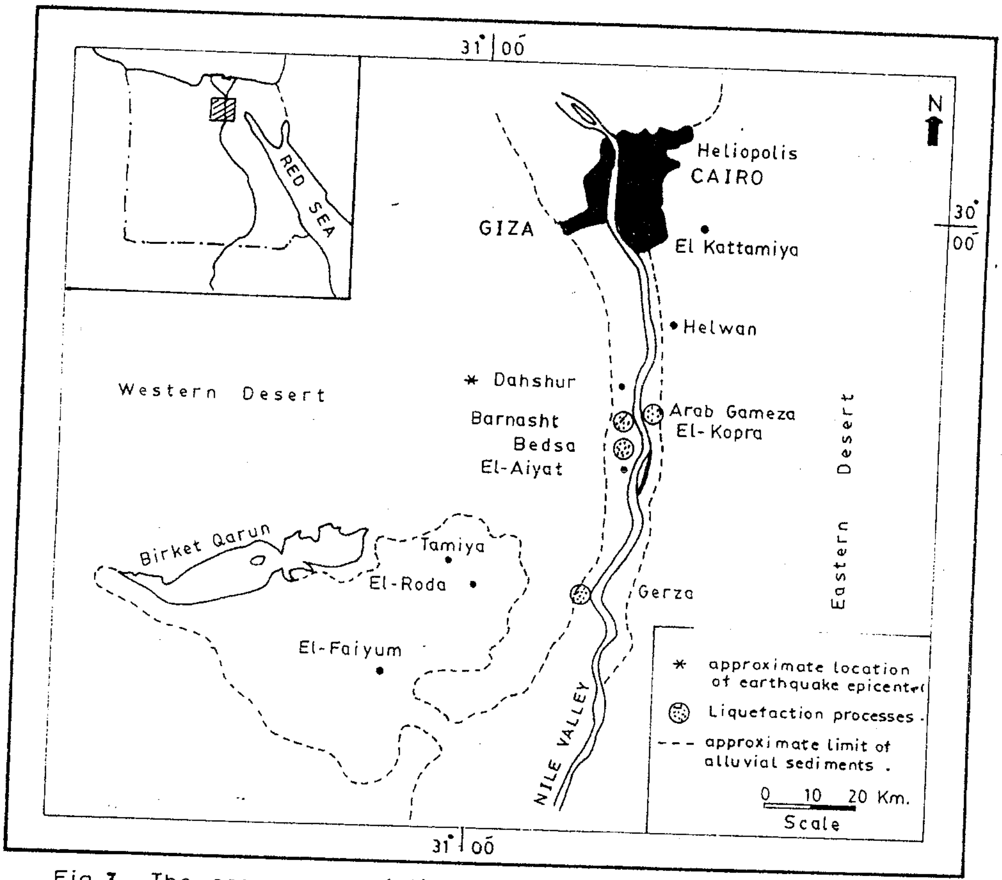

Fig.3 The occurrence of liquefaction processes in the 1992 earthquake affected areas.

Fig. 3 : The occurrence of liquefaction processes in the 1992 earthquake affected areas.

diffractometer (types D-3) of the Menofia University, Faculty of Science, Central laboratory, was used. Data are correlated with those of the ASTM Cards. From these data; it is concluded that the liquefied samples are generally characterized by the presence of quartz, zircon and rutile minerals. Tridymite and enstatite minerals are also detected (Tables, 1, 2 and Figures, 4, 5). The data obtained from the liquefied sands samples at Bedsa indicate the presence of quartz and rutile followed by zircon (Fig. 4 and table 1), while those obtained from the Gerza samples indicate the presence of quartz and zircon followed by rutile (Fig, 5 and Table 2).

Grain Size Analysis :

The data derived from grain size analysis of eleven liquefied sand samples were drawn on semilog paper using cummulative curves.

The calculated statistical parameters are listed in table (3). From this table, the following results can be achieved.

The median diameter (Md) of the collected liquefied sand samples varies between 0.325ϕ and 0.55ϕ with an average of 0.45ϕ. The graphic mean (Mz) for the collected sediment sample varies between 1.01ϕ and 1.09ϕ with an average of 1.05ϕ. From the above results, it was found that the mean size (Mz) exceed median diameter (Md). All of the collected sediment samples are fines to medium sand.

The majority of the collected sediment samples are very well sorted. The sorting coefficient varies between 0.02ϕ and 0.7ϕ with an average of 0.36ϕ.

The skewness of the collected sediment samples varies between 8.9 and 16.1 with an average of 12.5. The averages skewness may reflect its tendency to its presence as a fine fraction. The collected samples are strongly fine skewed.

Table (1) : X-Ray diffraction data of liquefied sand samples collected from Bedsa village.

Sample 1

20	I	I/I_o	Minerall
15.5	17.3	89.0	Rutile
24.5	9.6	49.5	Zircon
27.2	3.2	16.5	Quartz
30.5	19.4	100	Quartz
33.0	8.7	44.8	Rutile
35.0	2.3	11.8	Quartz
37.2	2.1	10.8	Quartz
40.0	1.0	5.1	
43.2	1.1	5.6	Rutilee
44.2	0.7	3.6	Tridymite
47.0	1.5	7.7	Rutile
49.2	0.9	4.6	
51.2	1.0	5.1	Zircon
52.0	1.0	5.6	Quartz

Sample 2

20	I	I/I_o	Minerall
25.0	1.4	6.6	Quartz
28.1	5.0	23.6	Tridymite
29.1	2.8	13.2	Zircon
31.2	21.2	100	Rutile
35.0	3.0	14.2	Quartz
38.0	4.0	18.8	Tridymite
39.2	1.2	5.7	Rutile
40.0	1.2	5.7	
41.0	2.6	12.3	Zircon
42.6	0.6	2.8	Quartz
44.2	3.6	16.9	Tridymite
46.2	3.3	15.6	Zircon
47.8	1.8	8.5	
48.2	3.5	16.5	Rutile
49.2	1.4	6.6	

Sample 3

20	I	I/I_o	Minerall
25.5	2.0	10.7	Quartz
27.8	1.6	8.6	
31.0	18.7	100	Quartz
34.2	18.1	96.8	Rutile
36.5	1.5	8.0	Quartz
38.0	2.3	12.3	Tridymite
41.0	4.0	21.4	Zircon
42.2	1.0	5.3	Zircon
42.8	1.1	5.9	Quartz
44.0	3.4	18.2	Zircon
45.8	1.0	5.3	
48.0	2.4	12.8	Quartz
50.5	3.3	17.6	Zircon
53.2	2.5	13.3	Quartz
54.2	2.3	12.3	Rutile
56.0	2.4	12.8	Quartz

Sample 4

20	I	I/I_o	Minerall
20.0	3.0	13.6	Enstatite
26.5	22.0	100	Rutile, Qz
27.4	0.7	3.2	Tridymite
28.5	1.5	6.8	Rutile
33.0	4.6	20.9	Rutile
36.5	7.0	31.8	Quartz
40.2	6.2	28.2	Zircon
44.3	7.7	35.0	Rutile
45.3	6.2	28.2	Quartz

Table (2) : X-Ray diffraction data of liquefied sand samples collected from Gerza village.

Sample 5

2θ	I	I/I_o	Minerall
23.7	1.9	16.0	Quartz
26.0	0.5	4.3	Tridymite
29.7	11.6	100	Zircon
32.5	8.0	68.0	Quartz
39.2	0.9	7.8	Rutile
42.5	1.1	9.5	Zircon, Qz
46.3	0.8	6.9	Tridymite
53.0	2.5	21.6	Quartz

Sample 6

2θ	I	I/I_o	Minerall
9.7	2.1	14.8	Tridymite
18.7	5.4	38.0	Quartz
21.0	1.4	9.8	Zircon
24.5	5.0	35.2	Zircon
27.5	14.2	100	Quartz
29.0	1.0	7.0	
31.0	1.6	11.3	Quartz
34.0	2.7	1.9	Zircon
37.5	3.0	21.1	Rutile
41.2	2.1	14.8	Quartz
43.2	1.8	12.7	Rutile
45.2	1.8	12.7	
46.0	2.6	18.3	Rutile
47.2	1.2	8.5	Quartz

Sample 7

20	I	I/I_o	Minerall
26.0	2.1	10.9	Tridymite
30.5	1.0	5.2	Quartz
32.4	19.3	100	Zircon
34.4	4.7	24.3	Quartz
38.7	2.8	14.5	Tridymite
42.2	3.5	18.1	Zircon
46.0	3.4	17.6	Rutile
47.1	0.6	3.1	
48.0	1.5	7.8	Quartz
50.2	3.1	16.1	Rutile
51.2	3.5	18.1	Zircon

The kurtosis of the collected sediment samples varies between 0.05ϕ and 0.3ϕ with an average of 0.17ϕ. The majority of the collected sediment samples are platy kurtic. The silt fraction ranges from 4.5% to 26% with an average of 12.2%.

Stratigraphic position of the Liquified Sands :

The erupted liquified sands may come from the subsurface prenile sediments which found in the borehole drilled at Barnashet village beneath the Neonile agricultural silt layers of the fertile land (Said, 1981).

They represent the water-bearing horizons in the valley and the delta of the Nile. The prenile sediments are loose, well sorted fine sands which belong to middle pleistocene in age.

The mineral analysis shows that the heavy minerals found in appreciable quantities. The identified heavy minerals are epidotes, pyroxenes, zircon, rutile, garnet and tourmaline.

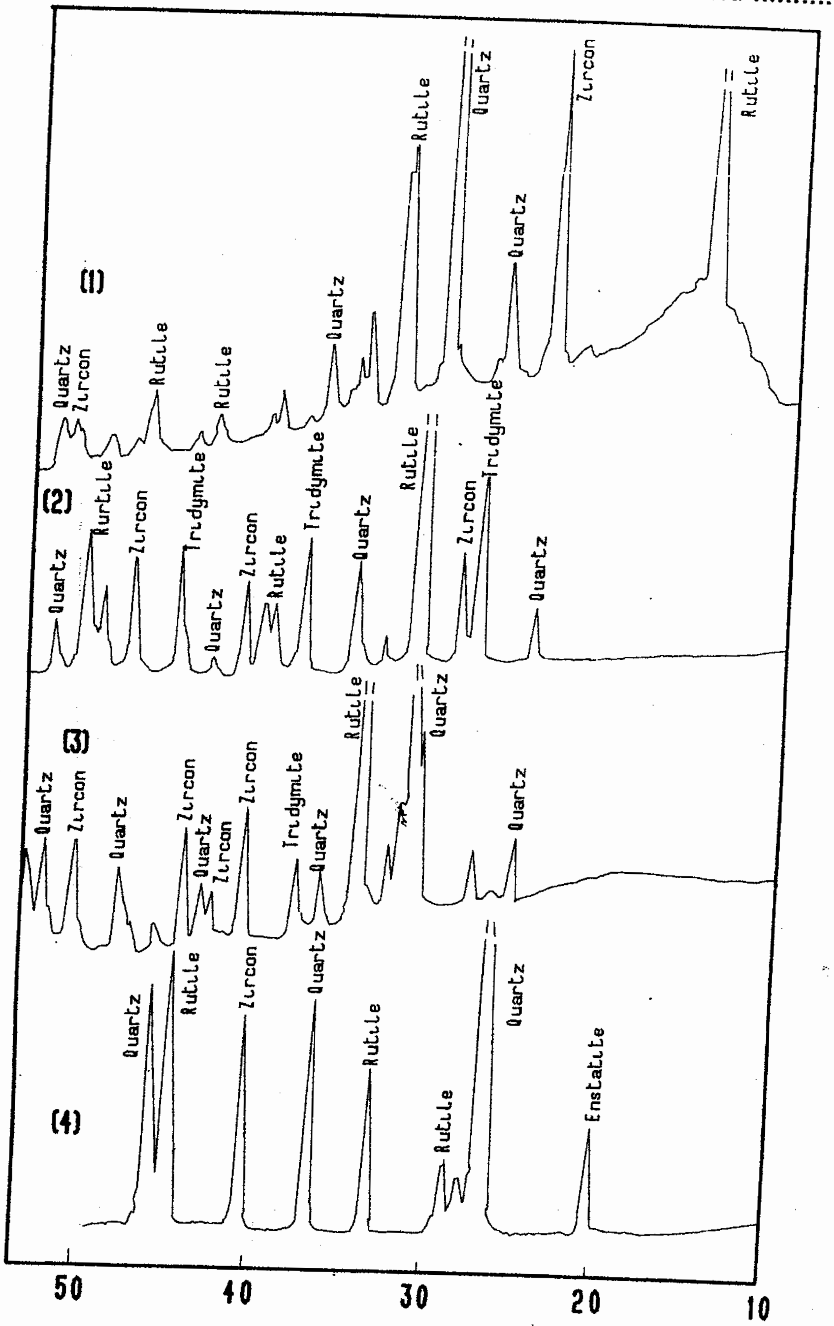

Fig. 4 : X-ray diffraction patterns of liquefied sands at bedsa village.

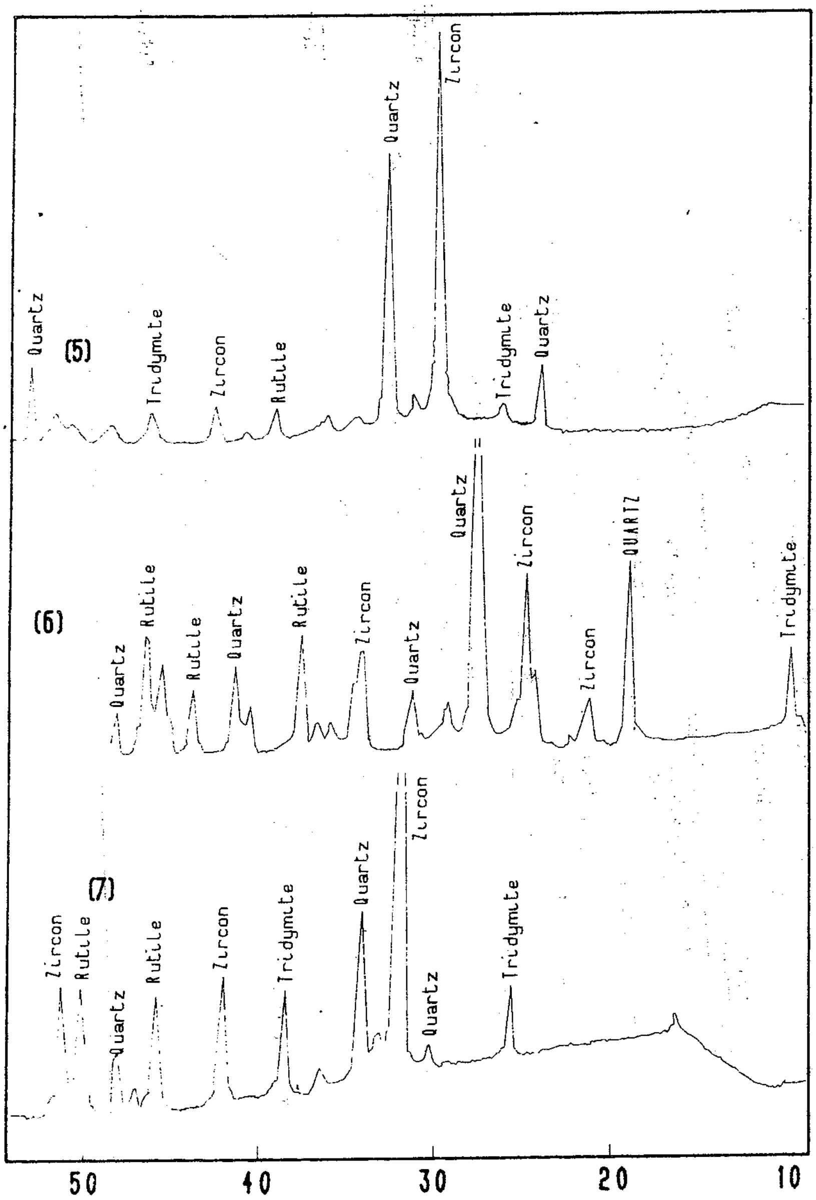

Fig. 5 : X-ray diffraction patterns of liquefied sands at gerza village.

The prenile sands considered as a fluviatile sediments of a through-flowing competent river which derived a large part of its waters and detritals from the Ethiopian highlands.

The prenile sediments of this stream reach great thicknesses which about 200m. are known from the subsurface of the modern valley beneath the agricultural layer deposited by the succeeding and extant Neonile.

The Neonile deposits are made up of silts and clays which belong to late pleistocene in age (Said, 1981).

Mechanism of liquefaction :

The liquefaction process was apparently severe in areas with a high frequency of occurrence of fluviatile channel facies which consists mainly of silty - sand deposits. The fluviatile channel facies has the grain size distribution characteristics and the specific gravity that make the sand succeptible to liquefaction in sufficient thickness (Kruse, 1988).

The liquefaction process may be explained as follows; when the earth shakes, the silt and fine sand particles undergo a repacking process and closure of some voids, so that pore - water pressures suddenly decreases and the sand grains become suspended in the liquid. All sand bodies loose their cohesion (which is already low) and become capable of flowing as liquefied sands. Under the continuous shaking action of earthquake disturbances, liquefied sand can even erupt through a thin cover of overlying material that is not susceptible to liquefaction (impervious materials covering the sand such as clay).

It is thus clear that the liquefaction process typically occurs in unconsolidated sediments with a high sands and water contents when *they are shaken violently* during an earthquake. This may be due to the dynamic behaviour of the unconsolidated sediment when it is disturbed. Under the action of an earthquake, the maximum acceleration of loose sediments is 2.4 to 4.4 times as much as for hard rock (Hu & Wan, 1987). Also, the duration of the subsequent relaxation period for sediments such as silt and fine sand is longer than for hard rock (Hu & Wan, 1987).

The factors controlling liquefaction process :

The major factors influencing the development of liquefaction process are the force of the earthquake, surface and subsurface characteristics, the thickness of different subsurface layers, the height of the ground water table and the relief (Hu and Wan, 1987).

Based on observations of earthquakes that have occurred in the plains of eastern China during recent years; the grain size of liquefied sand is generally in the range 0.03 - 0.1 mm. The ground water level in the liquefied sand beds in eastern China is generally within 3m of the surface. The alluvial sands are all of geologically recent age. The sand beds under consideration are 5 - 20 m thick. The liquefied sand erupting from underground is influenced by the thickness of the impervious materials covering the sand such as clay; its thickness is not more than 7 m. (Hu & Wan, 1987).

The earthquake force is another important factor affecting the process of liquefaction. It has been reported that the higher the earthquake magnitude, the larger the extent of liquefaction (Hu & Wan, 1987). There are no records in world historical documents of the eruption of liquefied sand if the earthquake magnitudes is less than 5 (Richter scale). (Liu, 1978; Beradi *et al.*, 1991).

The genetic classification of liquefied sand landforms :

Generally, earthquake landforms represent an abrupt disturbance of the ground surface. The time in which they are built is shorter than that of most other landforms. The most important geomorphological process concerns the behaviour of sediments when they are disturbed; materials properties such as cohesion and liquid limits become of vital significance.

The size of positive landforms is relatively small with heights usually less than 2 m. The liquefied sand sheets and cones may be considered as positive earthquake micro - relief landforms.

On the other hand, liquefied depressions may be considered as negative earthquake micro - relief landforms (Hu & Wan, 1987).

Hazard evaluation of liquefaction potential :

In the 1992 earthquake epicenter areas, the liquefaction processes happened in the agricultural fields not in the rural settlement. Otherwise, the loses recorded from these areas would have been very much higher. To anticipate and probably avoid disasters in the future, it is necessary to delineate the geographical boundaries of the areas vulnerable to liquefaction hazard. It is suggested to depend more on the use of geology in the planning and design stages of urban developments. The fluviatile channel facies apparently has the grain size distribution characteristics and the density that would make the sand susceptible to liquefaction. Sedimentological models may be used to determine other sedimentary facies which have the particular combination of grain size, grain shape and density of sands amenable to liquefaction (Kruse, 1988).

Engineering geological maps such as ultimate bearing pressure measurements (using geophysical techniques) may be made to detect the areas potentially susceptible to liquefaction. In earthquake active areas, the seismic coefficient of the area and the maximum value of the accumulated stress are important to be considered. The earthquake may enhance soil liquefaction if the total loading value exceeds the ultimate bearing capacity of the materials. The allowable bearing capacity is the maximum load to be considered to avoid shear failure or sand liquefaction (Abdel - Hamid, 1994).

Alexander (1991) suggested the use of geomorphological maps to determine the boundaries of the areas vulnerable to liquefaction hazards. Geomorphological mapping isolates the various constituents of the geomorphic system, either as static components, such as landforms, or as static representations of dynamic phenomena such as environmental process and change.

Summary and Conclusion :

Water with dark sands erupted diectly out of the ground (i.e. small Volcanoes) at the epicentral area during the 1992 Cairo earthquake (its force 5.7 on Richter Scale). The liquefied dark silty sand consists mainly from quartz, zircon and rutile grain minerals. The liquefied dark fraction are very well sorted and fine to medium in their size, strongly fine skewed and platy kurtic. The silt fraction ranges from 4.5% to 26% with an average of 12.2%.

From the present study results as well as those collected throughout time and place around the world about the liquefaction process; its appeared that the factors controlling this phenomenon are earthquake force as an endogenous geomorphic agent (not less than 5 on Richter Scale); alluvial silty sands, recent in its geological age. range 0.03 - 0.1 mm. in its size, found as beds with considerable thickness (i.e. 5 - 20m.); the groundwater level within 3 m. of the surface and the overlying material, if any, should not exceed 7m. thick.

To avoid any future disasters for urban development; the geographical boundaries of areas vulnerable to liquefaction potential hazard should be delineated (i.e. using geographical information system techniques).

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