THE LIQUEFACTION SUSCEPTIBILITY OF SOME GREEK SEISMIC AREAS AND THE FACTOR WHICH CONTROL IT.

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SUMMARY

The phenomenon of soil liquefaction is investigated by using field evidence of a number of earthquake. Observations and interpretations of damage associated with ground failure are presented. Liquefaction effects with special reference to the geological and hydraulogical environment are discussed. Of particular interest is the apparent correlation between soil conditions and the degree of the observed damage.

INTRODUCTION

Many failures of earth-structures and foundations on saturated sands have been attributed to the liquefaction of the sands. A common characteristic of all these failures is that the sands responsible for these would be considered loose in any classification system whether based on standard Penetration Tests, Dutch cone tests or relative density. These failures were triggered by earthquake shaking due to which the sand deformed until the shear stresses acting on the sand were reduced to very low values, as indicated by extreem flattening of the slopes, sinking (extreem settlement) of buildings and by flotation of lighter structures. Thus, in all cases there was a loss of shear strength that was not regained with continued deformation.

Considering that past experience can provide a useful guide for estimating possible ground failures associated with liquefaction, the authors analysed a number of greek earthquakes with special reference to the geology, topography and ground water conditions of the affected areas.

The main points which have been summarized and tabulated in table I, are followed by a brief discussion on the various factors which control liquefaction susceptibility.

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TABLE I

Tabulation of the effects attributed to liquefaction

Earthquake (Magnitude)	Geological Environment	Effects attributed to liquefaction	Reference
The Korinthe Loutraki Earthquake of 1928 (M = 6,25)	Holocene beach deposits and deltaic formations. Alluvial deposits overlying, pleistocene fissured marls.	Latteral spreading and subsidence. Fissures and cracks. Settlements and small-scale rock falls. Water Table at 0.6÷1,0 from ground level	(6)
The Nafpaktos earthquate of March 4, 1953	Alluvial loose deposits. Reclaimed land.	Surface cracking and settlements particularly at that part of the city founded on the alluvium and reclained land.	(11)
The distructive Earthquakes of the Ionyan islands of 1953 (August) (M = 6,5)	Cretaceous limestones, eocene limestones. Miocene well-cemented conglomerates and limestones. Pliocene marls and sandstones. Alluvial loose deposits with increasing thickness along the coast.	Tilting and settlements of buildings founded on the alluvium. The effects diminish with the age of the deposits. No damage observed on miocene, eocene, cretaceous limestones. Water Table within 1.0÷2,0 m. from ground level	(10)
The earthquake of Magnisia of April 19-21, 1955 (M = 6,1)	Recent saturated sandy deposits along the coast. Fill material. Dilluvial conglomerates.	Damage on foundations on saturated sands Water table almost at ground level No Damage observed on foundations on dilluvial conglomerates.	(8)
The earthquake of Megalopolis April 5 1965 (M = 6,0)	Piocene shales and poorly cemented sands tones pleistocene clays and marls, lacustrine clays and marls	Big slides in pleistocene and younger deposits. Two important slides in Pliocene sandy marls and sandstones. Slides developed on alluvial steeply - sided cones. Water Table within a few metres from Ground Level.	(1)

Earthquake (Magnitude)	Geological Environment	Effects attributed to liquefaction	Reference
The Peloponnesus earthquake of March 31 and July 6 1965 (M = 6,8) (M = 6,5)	Unstable formations of shales and sandy marls. Erratically cemented conglomerates.	Cracks and subaquous slides along the northern coast. Slides triggered on slopes of sandy marls. Mud volcanos along the water front due to liquefaction of under lying silty-sand-layers. Muddy water ejection from a depth of 37 m. The water Table within a few metres from ground level.	(1)
The earthquake of Kallithea Korinthias of April 20, 1970 (M = 5,75)	Neogene deposits consisted of clay marls and sand stones covered by: - cohesive anglomerates on the hilly areas, - quaternary river deposits along the coast and on plains.	Subaquous slides and slumping along the coast.	(9)
The Lefkas earthquake of November 1973 (M = 6,0)	Recent alluvial deposits.	Cracks and fissures along the dock due to disturbance of the rock fill. A big crack at Agios Nikitas accompanied by a slide due to liquefaction of underlying strata. The Water Table at a depth of 0,4 - 0,6 metres.	(5)
The Kopais earthquake of November,1974 (M = 5.25)	Lacustrine and river deposits, loose conglomerates over the valey of Kopais.	Settlements of old buildings founded on loose detritus and fill material.	(13)
The Corfu earthquake of May 1975 (M = 4.5)	Thick alluvial deposits overlying Neogene marls and sandstones.Low-to-Medium consiste ncy anglomerates. Loose, saturated river deposits and beach deposits of considerable thickness	Settlements and cracking.Landslides triggered by the earthquake due to liquefaction of underlying strata. Water Table at a small depth from Ground Level.	(12)

Earthquake (Magnitude)	Geological Environment	Effects attributed to liquefaction	Reference
The Trihonis earthquake of December 31, 1975 (M = 5,9)	Holocene alluvial deposits along the banks of Trihonis lake. Alluvial deposits over the valey of Kophra. Quaternary deposits on eocene flysch.	Settlements and titling due to liquefaction of deep-seated strata. Fissures and cracks on the alluvial valley of Kophra. Liquefaction of earth fills. No damage observed on buildings founded on flysch. Water Table within a few metres from Ground Level.	(4)
The Thessaloniki earthquake of June 20, 1978 (M = 6,5)	Holocene alluvial deposits Consolidated sand-dunes. River deposits. Sandy gravels.	Sand-blows along the banks of volvi lake. Fissures and cracks on the north bank of langada lake. Changes in W.L. observed in wells due to compression of fully saturated deep-seated alluvial deposits. Water Table at a depth of -7,0 m. approximately	(3), (2)

COCLUSIONS

The analysis of the earthquakes as presented in Table I has shown that liquefaction-induced failures have been a common cause of major damage during past earthquakes.

These ground failures have been mortly confined to specific geological environments. The analysis of the available data shows that certain geological and hydrological factors control liquefaction susceptibility :

i) Environment of deposition

Deposits most commonly disturbed by liquefaction have been those laid down in a fluvial environment. (Trihonis Earthquake, Thessaloniki Earthquake etc.).

Deltaic deposits, though not so widely spread as fluvial deposits, have also been commonly and in quite a few cases, catastrophically disturbed (The Korinthe earthquake of 1928).

Aeolian sand deposits, when saturated, have often been affected as well (Thessaloniki earthquake, the Korinthe earthquake of 1928).

Clay-rich deposits, flysch and sandstones are generally immune to liquefaction.

ii) Age of deposition

The Holocene alluvial deposits are the most vulverable ones to liquefaction.

Pliocene and Pleistocene deposits have often been affected depending on the cemmenting and compaction. The liquefaction susceptibility diminishes with age, cementing and compaction.
Eosene deposits are generally immune to liquefaction.

iii) Water table depth and depth of burial

Most of the liquefaction episodes have developed at relatively shallow depths and in areas where the water table was at ground level or within a few metres from ground surface.

Seed at al (1976) have shown experimentally, that, with the water table at shallow depths (⩽1,5 m), liquefaction develops between depths of 4,6-12 m. due to excess pore pressures set up during ground shaking. Such high pore pressures would be sufficient to lead to failure of footings founded in the depth zone. With the depth of 4,5 m; however, no significant pore-pressures set-up has been observed in the upper 3 m of soil even though the soil liquefied between 4.5-12 m. This is due to the fact that the pore pressures can dissipate upwards and merely result in a rise in the water table of a few metres without generating pore pressures above the water table. Thus the bearing capacity of small shallow footings founded at a depth of about 1,5 m might well be unaffected by the underlying zones of liquefaction except for the settlement accompanying the dissipation of pore water pressures in the liquefied zone .

This probably explains the fact that relatively small damage has generally been observed in zones with water table located at deep levels, whereas significant damage can most likely be attributed to the shallow depths of water table.

Liquefaction susceptibility seems to be dicreasing with water table and sediment depth.

The deeper the soil layer is burried the less vulnerable to liquefaction it is, due to the high confining pressures developed by the overburden..

iv) Topography and epicentral distance

Surveying of the affected areas in addition to statistical data collected on the number of damages has shown that the resulting damage depends rather on the topography than on the epicentral distances. Therefore no significant damage has generally been observed in mountainous areas, though the epicentral distances were shorter, whereas ground failures occurred at lowlands only a few metres above sea-level at large epicentral distances.

vi) Effect of permeability, compressibility and grain size.

The degree of sorting, the grain size, and the compressibility of the deposit are major factors controlling liquefaction.

Field evidence and past experience has generally shown that the smaller the permeability and compressibility of the surface layer, the greater becomes the loss in shear strength of the soil as a result of the upward seepage. Minimization of the liquefaction effects can be assessed by modifying the soil properties of the top layer. Densification would cause a reduction in the coefficients of permeability and compressibility and hence an-increase in

the initial shear strength τo and a reduction in the pore pressure during shear.
Therefore the net effect of densification may or may not be advantageous depending on the initial soil properties and the degree of densification.

It can therefore be cocluded that there must be a unique relationship between optimum permeability and initial strength to prevent liquefaction effects.

vi) Effect of the earthquake motions on the various geological formations.

Investigations carried out on seismic sites (i.e. Korinthia) have shown that earthquake-motions of alluvial deposits usually show remarkable characteristics in their amplitudes as well as in their periods.

The degree of damage caused by earthquakes has a close relation of the existence of alluvial formations.

The research was mainly based on the installation of portable seismographs used for seismic microzonation of the affected area of Korinthos. The position of these station was selected on the basis of the damage distribution of the earthquake. Considering that the recordings mainly referred to formations near the ground surface, if was shown that the earthquake damage was closely related to the thickness of the surface layer as well as to the geological formation itself. It should be noted that abnormally large displacement and acceleration amplitudes were recorded on thick alluvial deposits, whereas the predominant periods, amplitudes and total duration of tne principal earthquake motions were much smaller on harder formations (see figures 1,2)

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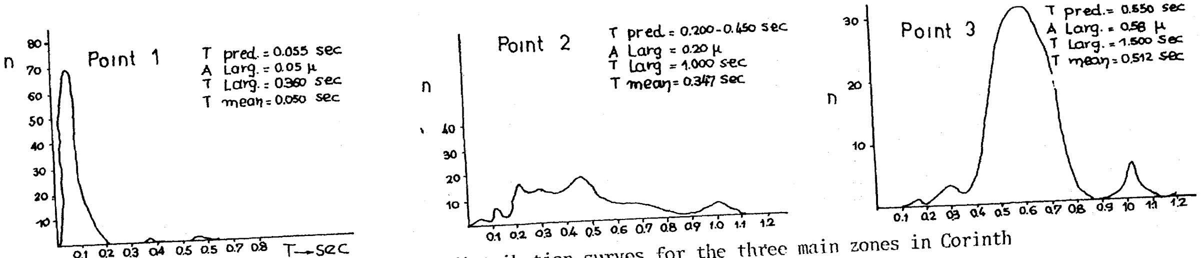

Fig. 2. Typical examples of period-distribution curves for the three main zones in Corinth

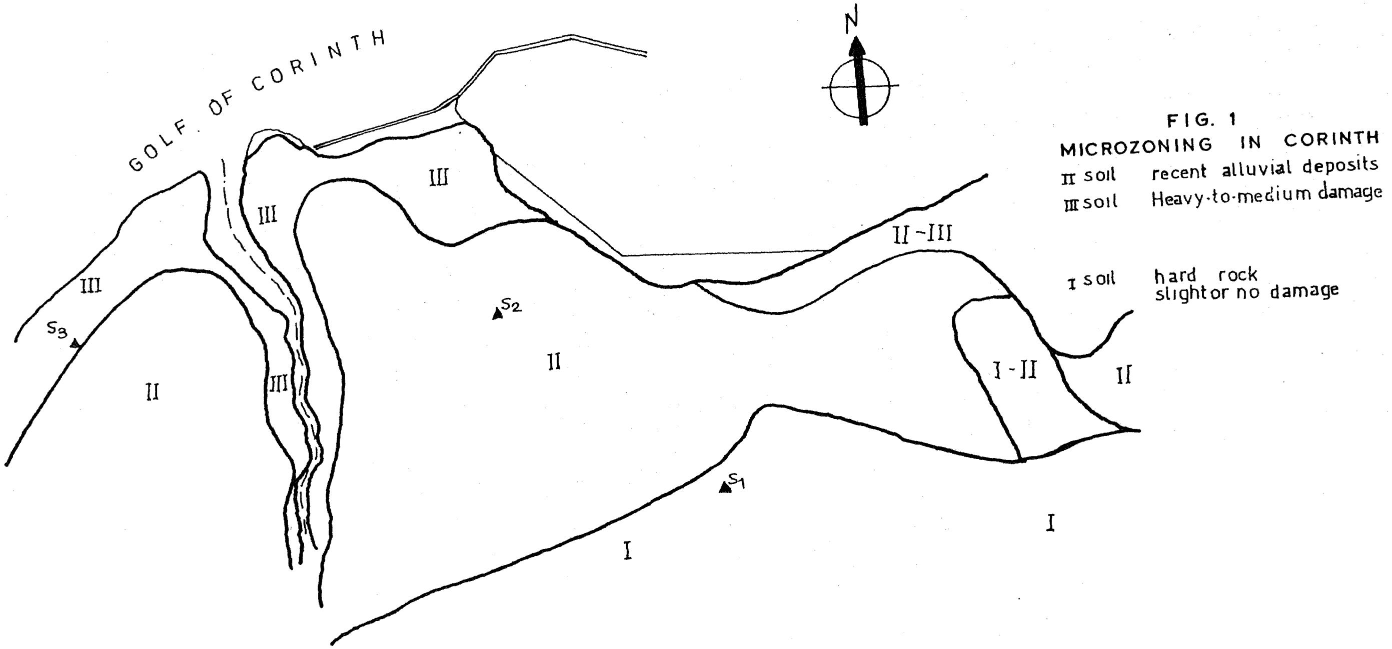

FIG. 1
MICROZONING IN CORINTH