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INSTABILITY OF COASTAL LOWLANDS DUE TO SEISMIC ACTIVITIES

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ABSTRACT: In certain regions of the world the coastal lowlands consist of a two to three meters of impervious material supported by a layer of sand and underlain by a thick layer of stiff marine clay. One such region is in the vicinity of the City of Bushire (Bushehr) located in the northern shores of the Persian Gulf. Here the top layer is a two to three meter thick coquina layer, resting on a very loose sand deposit of almost constant thickness (about 50-60 cm) having a gentle slope of about 5-10 degrees towards the sea. A sever earthquake in this region several centuries ago completely destroyed the City of Siraf which, at the time, was the most important port of the Persian Gulf on the Silk Route. The present paper presents an analysis of the situation using the CANAsand Constitutive Model and the ID technique proposed by the Author and his Colleagues at Institute of Lowland Technology, Saga University, Poorooshasb et al (1996).

Key words: Coastal lowlands, earthquake, liquefaction

INTRODUCTION

The present paper is in sequence to another analysis presented by the Author to the VIII Asian Regional Conference held in Kyoto, see Poorooshasb and Fletcher (1987). Thus some of the historical details presented are the same as those presented in the Kyoto paper.

Several years ago, the then Imperial Iranian Navy, proposed the construction of certain port facilities near the existing port of Bushire (Bushehr) located on the northern shores of the Persian Gulf. Subsurface investigations, however, disclosed the existence of a thin layer of loose to very loose sand layer sandwiched between a surficial layer of coquina of about 2 to 3 meters thickness and an under-laying deep layer of stiff marine clay. The Navy was advised of the susceptibility of the sand layer to liquefaction and the authorities in charge agreed to relocate the project to an alternative site.

Subsequently, and through literature search, it was discovered that certain planes of the northern shores of the Persian Gulf (including sites in the vicinity of Bushehr) have indeed experienced catastrophic failures which, in the opinion of the Author, were the results of the type of instability (liquefaction) just pointed out. In their classic book, Ambrayseys and Melville (1982) have presented a detailed account of these historic events. For example, they state that the Port of Siraf $(27.7^o N, 52.3^o E)$ " Described in the ninth century as the chief emporium for trade with China and India…." in the year 978 "……was effected by a more destructive earthquake, and although there is no mention of a seismic sea-wave associated with the event, it has been suggested that as a result of the shock, a large part of the water-front sank below the sea…." Elsewhere the same authors state"…. the subsidence of the ground in the vicinity of Bushire c.1780 is mentioned also by Michoux 1911…..and it may be due to submarine *sliding*……." With reference, apparently, to the same earthquake they write "… a general subsidence of the land around the port was also noticed in Bushire."

In view of the importance of the problem in the coastal lowlands it was decide to carry out an investigation of the situation the results of which are presented below.

ANALYSIS

The soil deformation characteristics, (the so called constitutive model) is described by the CANAsand model. A description of this model, as well as the ID numerical technique used in the analysis, was presented to the First International Symposium on Lowland Technology, Saga University, see Poorooshasb (1998.) Thus their reproduction here is redundant. It is sufficient to show two stress-strain curves, one representing a dense sand behavior and the other the behavior of a loose sand sample, see Figs 1(a) and 1(b). The voids ratios selected are 0.5 (close to compact state) and .75 (close to the critical state) and both tests were conducted under constant normal stress of 20 kPa. The loose sample shows a high degree of compaction (reduction in volume), when subjected to stress reversals, while the dense sample shows very little volume reduction.

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Note: Discussion on this paper is open until December 25, 2003.

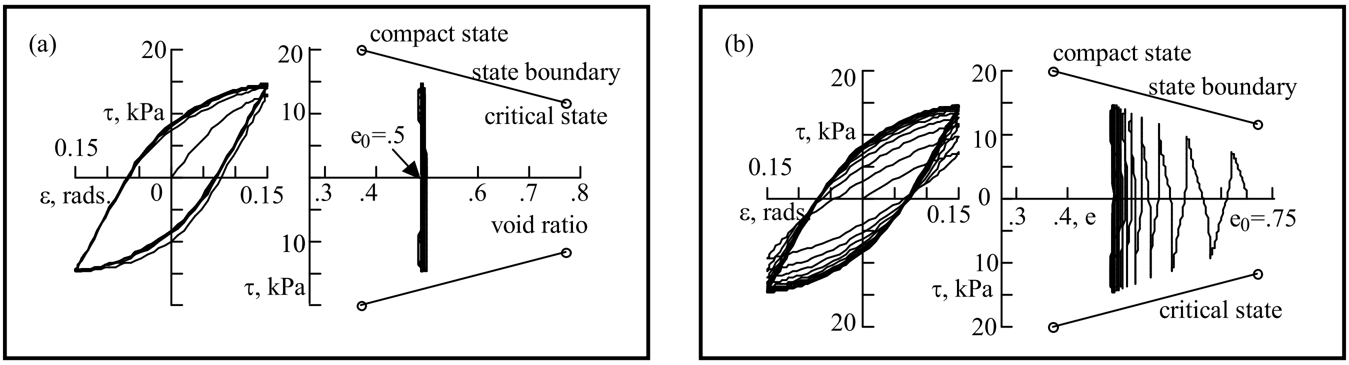

Fig. 1 Behavior of a dense (a) and a very loose sand sample (b) subjected to a constant normal stress (drained) simple shear test according to the CANAsand model

Before leaving this section it is worth mentioning that the acceleration/time record used in this study is the Loma Prieta Earthquake of 1989 as recorded in the Diamond Heights recording station, see Fig. 2.

DENSE SAND LAYER

A set of four tests were performed assuming sand layer sandwiched between the upper coquina layer and the stiff marine clay to be dense (e=0.5). The thickness of the sand layer was assumed to be 0.6 meters and that of the top layer 2 meters. In the first test the upper layer was assumed to be impervious and the layers were horizontal, i.e. not sloping towards the sea. Fig. 3 shows the results of the analysis.

A permanent horizontal ground shift *at the termination of the ground shaking period (40 seconds)* of about 1 meters is recorded. This value is, however very small compared to the results shown in Fig. 4, where the ground was assumed to be sloping at an angle of 5 degrees towards the sea. Here the calculated ground shift is of the order of 50 meters! It is emphasized that the exact value of these calculated ground shifts, are of no significance. Once instability ensues the system has failed and the magnitude of the evaluated shift depends on for how long a person is prepared to execute (run) the program.

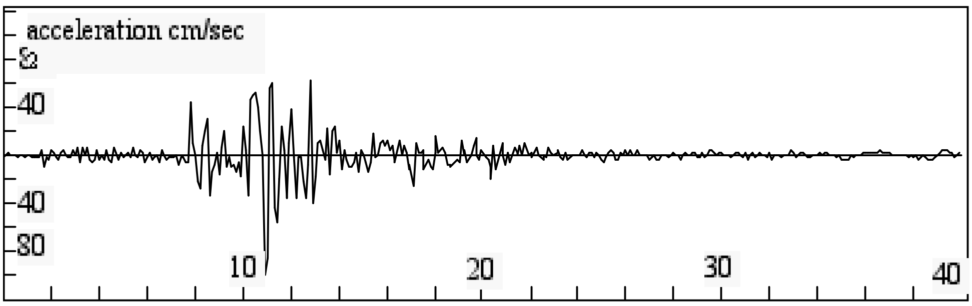

Fig. 2 The record of acceleration used in the present study

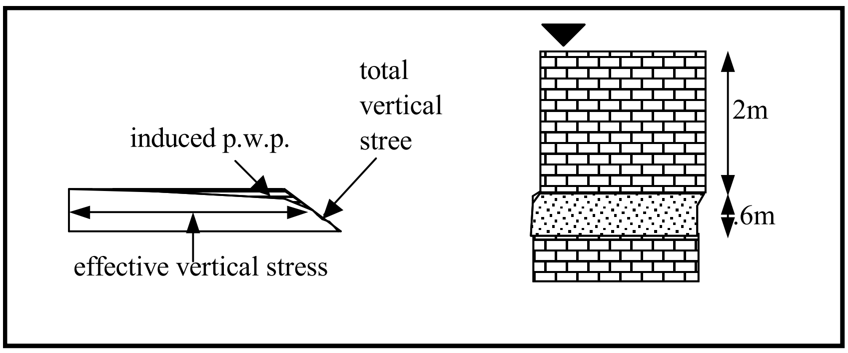

Fig. 3 Dense sand layer (e=.5) sandwiched between two impervious layers. Slope of the layer =0. For the sand coefficient of permeability =.01 cm/sec

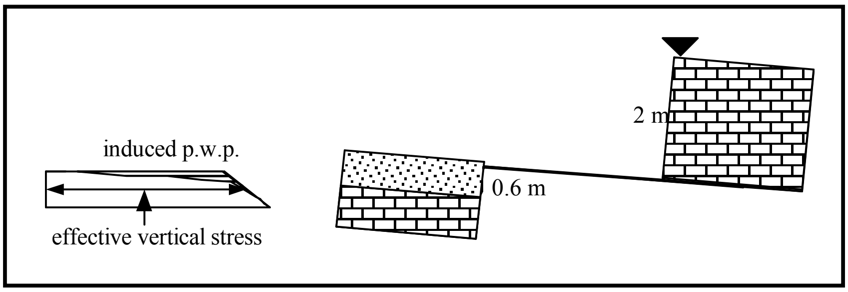

Fig. 4 Dense sand layer (e=.5) sandwiched between two impervious layers. Slope of the layer $=5^o$. For the sand coefficient of permeability =.01 cm/sec

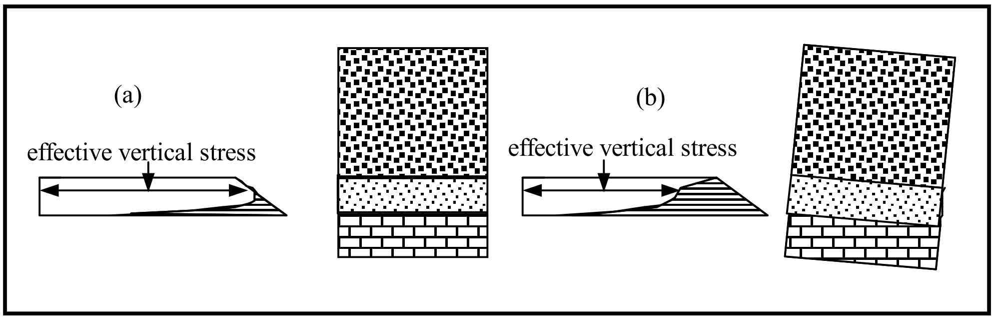

Fig. 5 Dense sand layer (e=.5) sandwiched between two impervious layers. Slope of the layers (a)=0, (b) $=5^o$. For the sand coefficient of permeability =.01 cm/sec. Physical dimensions the same as in Figs 3 and 4

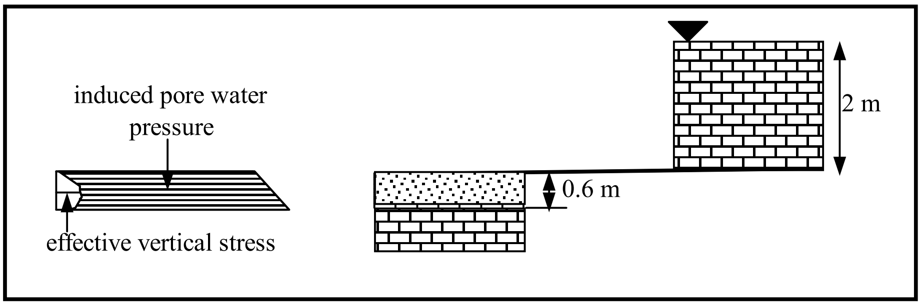

Fig. 6 Very loose sand layer (e=0.75) sandwiched between two impervious layers. Slope of the layers=0. For the sand coefficient of permeability =.01 cm/sec

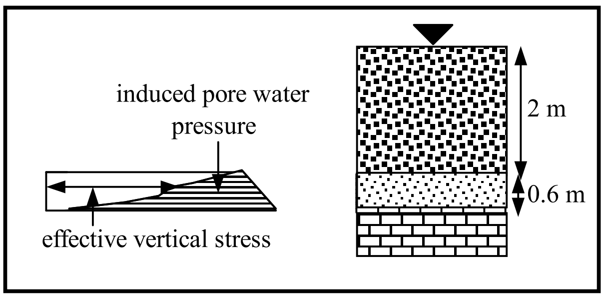

Fig. 7 Very loose sand layer (e=0.75) sandwiched between two impervious layers. Slope of the layers =0. For the sand coefficient of permeability =.01 cm/sec. Top layer free draining

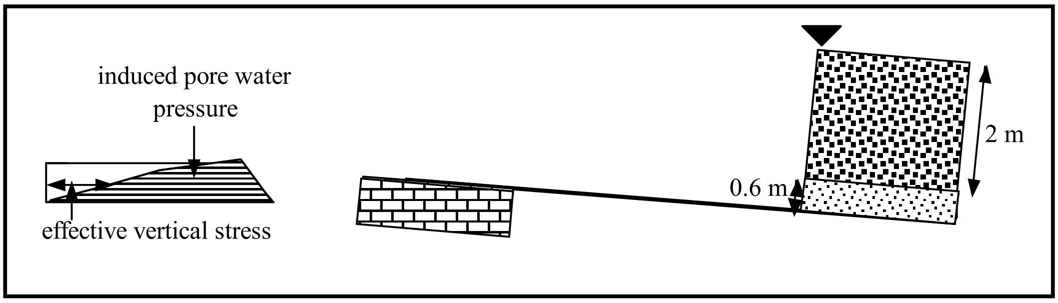

Fig. 8 Very loose sand layer (e=.75) sandwiched between two impervious layers. Slope of the layers $=5^o$. For the sand coefficient of permeability =.01 cm/sec. Top layer free draining

Since in both cases the liquefied zone was just underneath of the top impervious layer a question naturally presented itself: Would it be possible to stabilize the system if the top layer was made pervious, for example by installation of vertical sand drains or gravel columns? Figures 5,a and 5,b may provide an answer. None of the two systems show any signs of permanent ground shift or total loss of effective stress.

The situation is quite different for the system that includes the loose sand layer however. Figures 6 and 7 show the behavior of such cases where the sandwiched layer has a void ratio of 0.75 (close to the critical void ratio of 0.8). For the situation shown in Fig. 6 the upper layer is assumed to be impervious and as noted very large lateral movements are recorded. If the top layer is provided with sand drains or stone columns then large magnitude movements are not present, Fig. 7. The developed pore water pressure at the base of sand layer is very large however: A stronger earthquake would certainly cause catastrophic failure of the system.

From Fig. 7 it appears that perhaps provision of the sand drains may be sufficient to stabilize the system. That this is not the so, may be seen from Figure 8 where a free draining upper layer is supported by the sand layer.

The system shown in Fig. 8 is having a gentle slope of 5^o towards the sea. Large lateral movements are indicative of the system failure *in spite of the provision of free drainage.* All that the provision of drainage has accomplished is to relocate the position of the liquefied layer from the base of the impervious upper layer to the base of the loose sand layer.

Finally Fig. 9 shows the behavior of the same system as shown in Figure 8. Here, no drainage is provided and, as expected, the system is experiencing total failure: Multi level liquefaction is taking place.

CONCLUDING REMARKS

Instability of coastal planes have several causes. One is related to plate techtonics where large, near vertical displacements along a fault line may take place. From the study of a geological cross section placed at the disposal of the Author at ILT, Saga University, Japan, he is of the opinion that the formation of the Ariaki Sea is indeed the result of one such movement. The exact location of such occurrences is not possible and thus neither is their prevention.

Another cause of instability is associated with large magnitude of sloping layers that contain one or more layers of sand. If the slope of the layers is towards the land then the damage due to an earthquake would be mild and

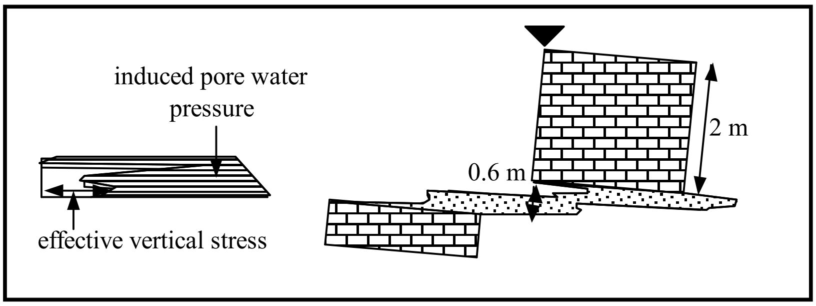

Fig. 9 Very loose sand layer (e=0.75) sandwiched between two impervious layers. Slope of the layers $=5^o$. For the sand coefficient of permeability =.01 cm/sec. Top layer impervious

generally associated with land subsidence. On the other hand layers sloping towards the sea can sustain large magnitude ground shifts. If the sand layer(s) involved is dense to very dense then provision of top drainage (say by means of vertical sand or gravel drains) would be effective in reducing the risk of damage. On the other hand if the sand layers are loose to very loose such measures are totally ineffective.

ACKNOWLEDGEMENT

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