Missouri University of Science and Technology

Scholars' Mine

International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

2001 - Fourth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

29 Mar 2001, 7:30 pm - 9:30 pm

The Crack Development Due to Liquefaction of Sand Lenses During Earthquake Loading

S. M. Mir Mohammad Hosseini

Amir Kabir University of Technology, Iran

F. Nateghi-A.

IIEES, Iran

THE CRACK DEVELOPMENT DUE TO LIQUEFACTION OF SAND LENSES DURING EARTHQUAKE LOADING

S. M. Mir Mohammad Hosseinii
Associate prof . of Amirkabir University of Technology
Tehran - po. Box 15875 - Fax No.21-2574966 - IRAN
Email: mirh53@hotmail.com

F. Nateghi-A.
Professor, IIEES
P.O. 19395/3913 Tehran, IRAN
Email: Nateghi@dena.iiees.ac.ir

ABSTRACT

The failure of sand lenses during earthquake loadings has caused many damages to the ground and yet its mechanism has not been investigated extensively. In this paper the results of an analytical studies involving the mechanism of crack development of a sand lens due to liquefaction, are presented. A single loose and saturated sand lens embedded inside a stiff clay deposit, which will liquefy due to the earthquake loading, is modeled by finite element method. The principles of fracture mechanics were used and the soil behavior was considered as a non-linear elasto-plastic material. The computer package of NISA was used and the failure mechanism of the lens was analysed by this package. Finally, the crack development and the angle of developed crack from the tip of the lens to the horizontal was calculated and discussed.

INTRODUCTION

The destructive and large landslides involving liquefaction of sand lenses during heavy earthquakes, have caused researchers to focus on the triggering cause of these instabilities by study the behavior of sand lenses. The liquefaction which normally happens in a loose saturated sand layer during strong ground motions, is likely to occur within the loose saturated sand lenses embedded inside a relatively stiff and impermeable deposit, and may be hence the main cause of landslides and slope instabilities during earthquakes. Furthermore, There are evidences showing the liquefaction of sand lenses in large landslides all over the world. Consequently, it has now become clear that liquefaction of sand lenses is an effective factor triggering the ground failure. Moreover, the impact of sand lenses on the surrounding soils will be severe, when it is embedded in clay deposit. In this case the excess pore water pressure of the saturated sand lens can not dissipate rapidly leading to faster liquefaction of the lens. The largest landslides are those occurred in this condition.

The relation between landslides and liquefaction of existing lenses have been evident for many years, however, the mechanism of the influence of the lens failure on the surrounding soil has not been explained, since it was first mentioned by Vallejo in 1988, using the linear elastic failure mechanics theory. He assumed that, after liquefaction, the lens behaves as an under - pressure crack, inside which a compressed liquid tends to propagate into the surrounding soil. Thus the case can be diverted to a common problem in the failure mechanics , and by using this theory the development of so called primary crack under over - burden pressure and earthquake loading , could be investigated as the secondary cracks . According to Vallejos analysis in case of existing only s single lens, the secondary crack develops to the ground surface by an angle of 70.5^0. In case of a series of sand lenses the secondary cracks develop from the tip of the lenses, so that they connect to each other. He then stated that if the surfacial soil layers are rested on a layer including several separated sand lenses, they will liquefy and form an extended continuos under-pressure liquid, during an earthquake, upon which the top layers are laid. Consequently they will easily slide as the ground shaking continues.

In this study the liquefaction of a sand embedded inside a stiff clay deposit was modeled by finite element method. The fundamental of the failure mechanics theory has been employed for studying the crack development of the liquefied sand lens. The results of the computer modeling, the details of which are given in the following sections, show that the crack develops by an angle very close to what introduced by vallejo, and observed in the joint experimental studies by Holchin & Vallejo (1995) .

MODELING OF THE SOIL MEDIUM

The computer package of NISA II was used for analysing the case of interest by finite element method. A ground section of width w, and height h, containing a sand lens of length 2a and

width 2b has been considered for investigation (fig. 1).
As can be seen, the selected mesh has been planned so that the elements become smaller as get closer to the sand lens, because of stress concentration in this zone. The boundary conditions are selected so that, while at rest pressure is applied to the model at its two side faces, the shear force of the earthquake can be imposed to it by means of a horizontal constraint at its bottom face. In this situation the relative fixity of the selected section is provided as well. The vertical constraint in the bottom face of the lens plays the supporting

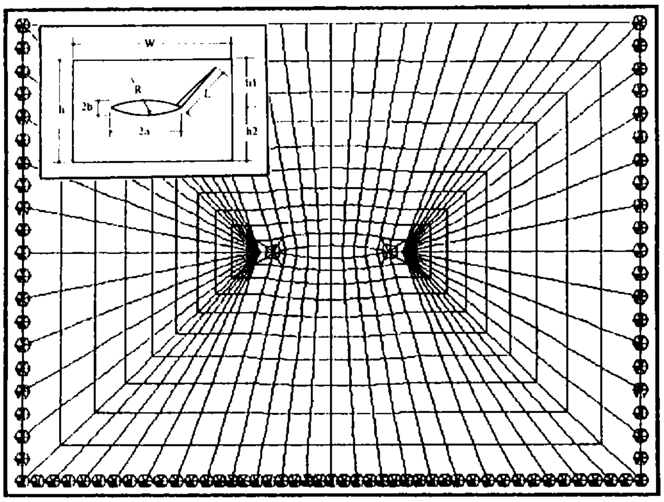

Fig. 1. The geometric and selected mesh for the sand lens and The surrounding medium

role of the model on the soil underneath. Although, the selected elements are of four face, but to model the conditions of the crack, the singular elements have been used at the two tips of the lens (fig. 2). The soil was assumed to have elasto-plastic behavior and the Droger - Proger model was used as the failure criterion. The gravity force was also applied to the model by means of the body force facilities available in the NISA II package.

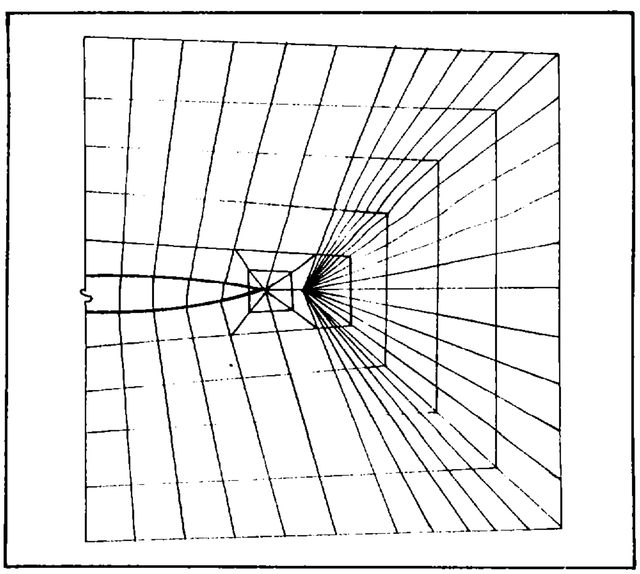

Fig. 2- The selected elements at the tip of the lens.

MODELING OF LIQUEFIED LENS DURING EARTHQUAKE

I- Earthquake Occurrence And New Boundary Conditions

After application of gravity forces and calculation of the soil inertial stresses, now the earthquake loading has to be applied and the probable liquefaction of the sand lens should be investigated. The earthquake force was applied to the model as an inertial force from the whole mass of the system, by using 0.65 peak ground acceleration, as suggested by Seed and Idriss . As it was already mentioned, the horizontal displacement of the model in the two slide faces was prevented. Thus in case of existing boundary conditions, the free displacement of the model in the horizontal direction is not allowed. However, this condition that was provided to satisfy the at rest lateral pressure state to the model, has to be somehow changed during application of the peak ground acceleration of earthquake.

For this reason a special computer program in Pascal was written by which the two side supports of the model can be substituted by some forces after application of the inertial forces. Since the induced acceleration acts equally in the model and in the surrounding soil, they are always moving in the same direction by the same velocity. As a result there are no new forces produced between these two sections and the at rest lateral pressure, anticipated by the above program for the two side faces seems to be sufficient.

II) Liquefaction of the Lens

The sand lens will liquefy in case of being saturated and loose enough to lose its strength due to excess pore pressure generated during earthquake. To model the liquefaction of the sand lens, the critical acceleration causing the phenomenon, should be initially estimated. The critical acceleration required to induce liquefaction was calculated according to the Seed and Idriss method.

Doing that, the shear stresses leading to liquefaction of the lens was estimated by considering the intensity of the ground shaking and properties of the sand inside lens. Then having the depth of the lens the shear stresses induced that level, were calculated in terms of earthquake acceleration, and the acceleration, thus is required to liquefy the lens was determined. In order to model the lens medium when the earthquake acceleration reached to the critical value, it was converted to a medium, having the properties of a liquid , by using the gap/frictional elements in the NISA package whose behavioral model is shown in fig. 3 .

The characteristics of the gap/frictional elements are so that , they can simulate the liquefied soil inside the lens appropriately . Firstly, like a liquid, they can show only the compressive behavior, that is, having no shear strength (fig. 4) Secondly, as these elements have sliding behavior as well , the negligible shear strength of the liquefied sand against shear forces of the earthquake , can be ignored by setting the sliding stiffens to the zero , leading to simulate the shear behavior of the liquid by a good approximation . Thirdly, the, δ, parameter (i. e: the initial opening of this element) can be used to adjust the triggering time of the element . In this regard parameter can be defined so that , the element has no effect before liquefaction , but after this moment the opening is omitted and it can get in touch with the surrounding medium .

On the other hand, the effect of the solid elements of the lens on the surrounding medium has been specified and applied to the model in the form of reaction forces, by using the results of the analysis prior to liquefaction, leading to omit the elements (fig. 5) . In order to substitute the effect of the solid

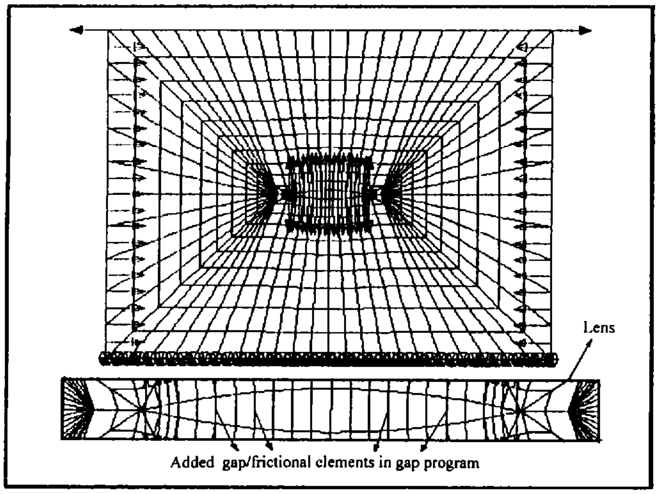

Fig. 3- The gap/frictional elements for modeling the liquefied lens .

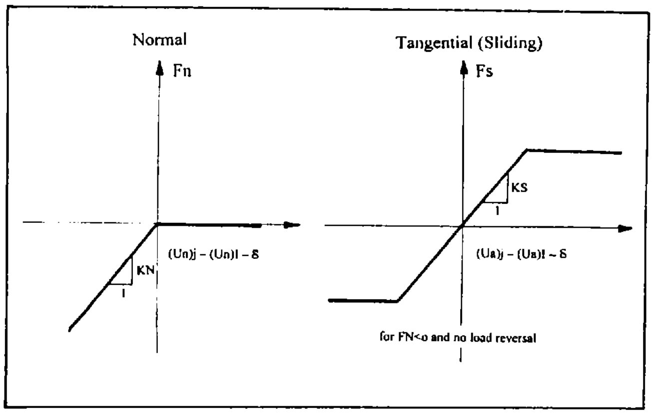

Fig. 4- The force - deflection relationship for the gap/frictional elements .

element of the lens instead of elements themselves, a computer program in Pascal was written as well, to search the case comprehensively.

Thus the effect of the solid medium can be omitted by applying a load to the opposite direction of the reaction forces (fig. 6) . It should be noted that this loading was exactly applied in the time of liquefaction after which , only the gap/frictional elements behaved , which represented the changed properties of the sand lens after liquefaction .

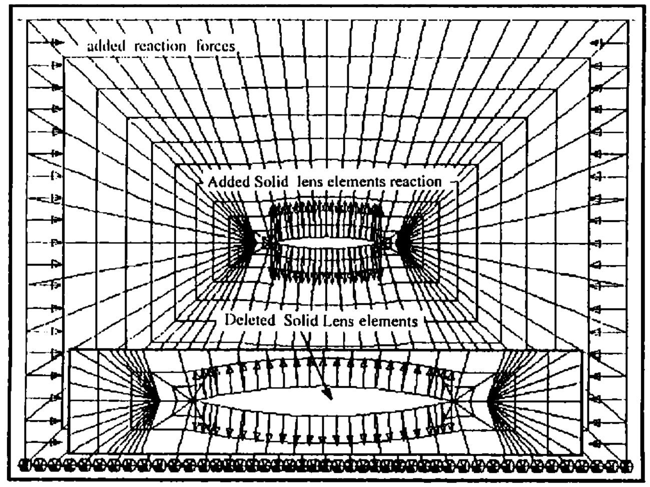

Fig. 5- The model obtained from insert program (deleted solid elements of the lens).

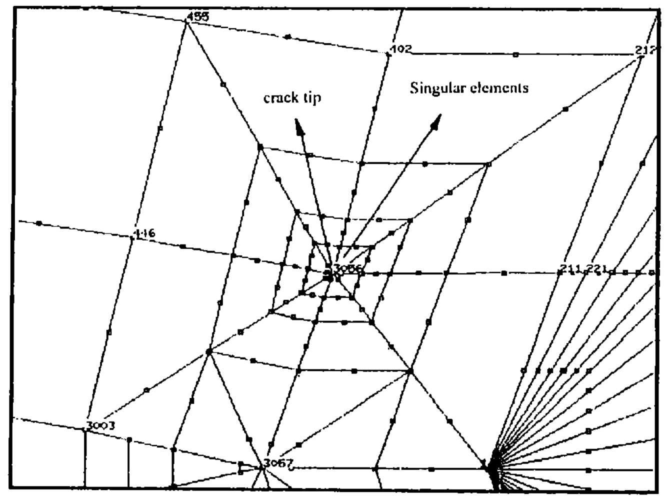

Fig. 6- The model obtained from Liquef program (beginning of liquefaction).

THE FAILURE MECHANISM AND CRACK DEVELOPMENT

The failure analysis was carried out by using the results of numerical analyses immediately after liquefaction of the lens, in order to investigate the probable cracking of the lens. In the failure analysis, the stress intensity ratio was firstly estimated, then based on these ratios in case I and II, the crack development was investigated , using Sih and Erdogan (1963) method .

Another computer program was written in Pascal to do the process of the failure analysis. After appearance of the crack , the model must be able to create and analyse it appropriately . A special computer program was developed to create this crack of a given length. This crack was again produced so that, due to certain conditions, to have singular elements at its tip (fig. 7) . The numerical analysis was again carried out to get new results of crack development in the new condition. This process of crack development continued until the failure analysis led to an stable cracking. The smaller the assumed length of the crack, the more accurate results were obtained.

Since the cracked model was again analysed , the gap/frictional elements were inserted during crack producing process , as well to enable the model providing the uncracked condition in case of the crack being closed . Thus , the shear and compressive behaviors of the element were defined so that to show the shear and compressive behavior of uncraked soil as well . The gap/frictional elements after opening the crack can be seen in fig. 8 .

SUMMARY AND CONCLUSION

In the present study the failure mechanism of a sand lens inside the clay deposit, by concentration on the crack development , under earthquake loading was investigated numerically . The non-linear finite element method was used,

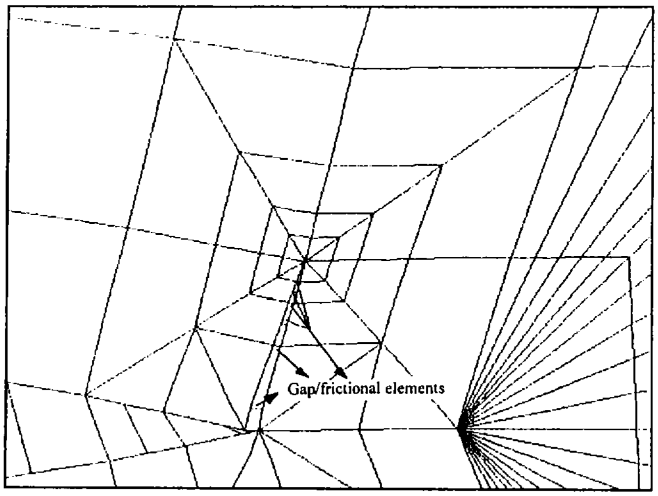

Fig. 7- The final mesh for the tip of the lens .

and the soil deposit surrounding the sand lens was analysed , using linear elastic fracture mechanics . NISA II was utilized as the main computer package. Several subroutines were developed to provide the appropriate boundary condition, to create a crack of given length, and to implement the development process of the crack. As can be seen in fig. 9 the path of developed crack is in a zigzag form.

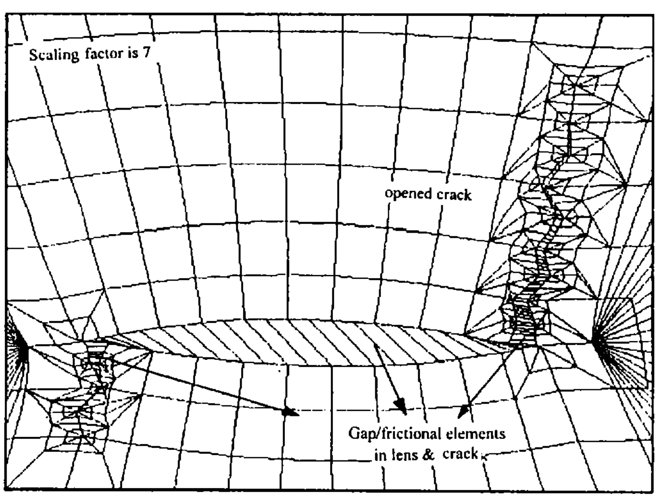

Fig. 8- The zigzag path of the developed crack..

The best line fitting the tip points of the zigzag way introduces an angle of 72^0 to the horizontal. Thus it can be concluded that when an embedded sand lens liquefies due to the earthquake loading, a crack will induce from its tip which develops towards the ground surface by an angle of 72^0 .

The value of this angle is in good agreement with that was introduced by vallejo (1988) and Holchin & Vallejo (1995) in an experimental study. Therefore, the numerical analysis similar to what, carried out in this paper can be employed to study the influence of the liquefied sand lenses on the earthquake induced landslides.

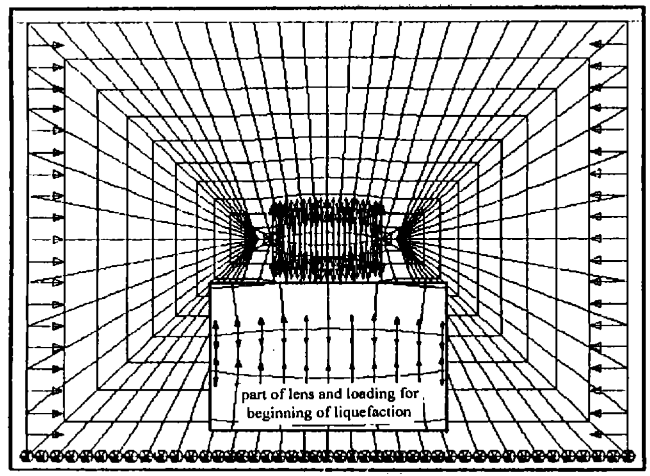

Fig. 9- The gap/ frictional elements after opening the crack.

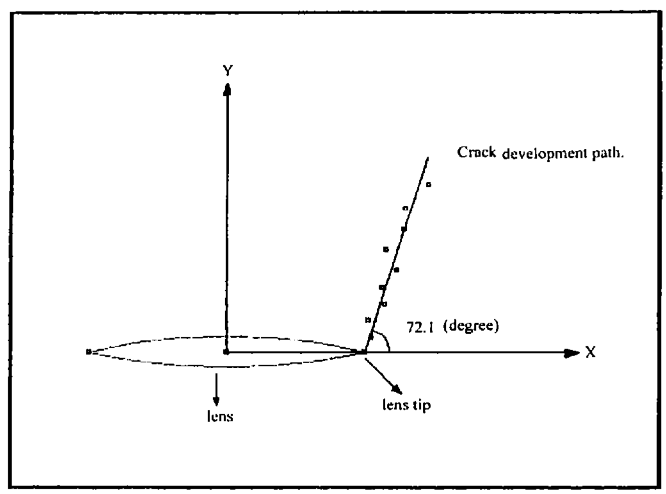

Fig. 10- The path and the direction of the developed crack .

REFERENCES

Eradogan , R. & Sih , G. C., On the crack extension in plates under plain loading and transverse shear , J. of Basic Eng., ASME , 1963 , Vol. 85 , pp. 519-527 .

Holchin , J. D. Vallejo , L. E., The liquefaction of sand lenses due to cyclic loading, Proc . 3rd. Int. conf. on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, Vol I , Missouri , 1995 , pp. 253-259 .

NISA , Version 5.2.0. Eng. Mech. Research Corporation, 1995

Vallejo , L. E.,The liquefaction of sand lenses during an earthquake , Proc . Earthquake Eng . & Soil Dynamics II-Recent Advances in Ground Motion Evaluation , ASCE , Geotechnical Special Publication , No2 , 1988, pp. 493-507 .

Seed , H. B. & Idriss , I. M., Simplified procedure for evaluating soil liquefaction potential , J. SMFD , ASCE , 1971 , vol 97 , No 9 , pp . 1249-1243.

Turbo Pascal , Version 7.0 Copyright (c) 1982 , Borland Int .

Yeshia , N. A. B., On the use of T-Criterion in fracture mechanics , Eng. Fracture Mechanics , 1985 , Vol. 22 , pp. 189-199 .