Paper No. 177, Bulletin, I. S. E. T. Vol. 14. No. 3, pp. 101–109 September 1977

POSSIBILITY OF LIQUEFACTION DURING AN EARTHQUAKE

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INTRODUCTION

It has been observed many times that foundation soil consisting of saturated sands behaved like a fluid during earthquakes and the liquefaction of foundation soil in such cases has often been the main cause of catastrophic damage to structures resulting in loss of life and property. The additional safety in the superstructure by designing it for bigger forces is not of any help in the event of liquefaction of soil during an earthquake. Therefore it is extremely important to examine the possibility of liquefaction of a site during an anticipated earthquake and take remedial measures if necessary before the construction activity is started.

For understanding the liquefaction behaviour of saturated sand laboratory investigations (1) on vibration tables on large size samples and (2) on traxial and simple shear apparatus under cyclic loading conditions on small samples have been carried out. From the review of the available literature conclusively it can be stated that no uniform agreement todate has been achieved from different tests performed by different investigators. The test results both quantitatively as well as qualitatively are affected by the method of test and test equipment used.

A very comprehensive test programme has been run on small samples with triaxial and simple shear conditions under cyclic loads. A method has been made available to predict the possibility of liquefaction at a site during an earthquake. The method uses the test data obtained from small sample tests under cyclic loading conditions (Seed and Idriss 1967 and 1971). In the present paper the results obtained using this method for some typical problems are critically examined and the critical comments on the method are included.

A REVIEW OF PROCEDURE

Seed and Idriss (1967) have proposed a general method for predicting the possibility of liquefaction during an earthquake which makes use of laboratory data of cyclic triaxial loading tests. The application of this procedure requires ground response analysis and the testing of representative soil samples under cyclic loading conditions. It assumes that the shear stresses developed at any point in a soil deposit during an earthquake are due to the upward propagation of shear waves in the deposit. This involves the following steps.

1. Establish the soil conditions and the design earthquake in the base rock. This involves assuming of a suitable accelerogram at some depth in the base rock.

2. Determine the response of the overlying soils to the base motion giving time

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history of shear stresses included by the design earthquake at different depths within the deposit.

3. Convert the stress history at various depths into an equivalent uniform cyclic stress for a significant number of cycles and plot the equivalent uniform stress induced during the earthquake as a function of depth as shown in Figure 1.

4. With the help of laboratory test data determine the cyclic shear stresses which would have to be developed at various depths to cause liquefaction in the same number of cycles determined in step 3. These stresses are determined by cyclic loading triaxial tests on representative samples under various confining pressures. The stresses required to cause liquefaction may then be plotted as a function of depth as shown in Figure 1.

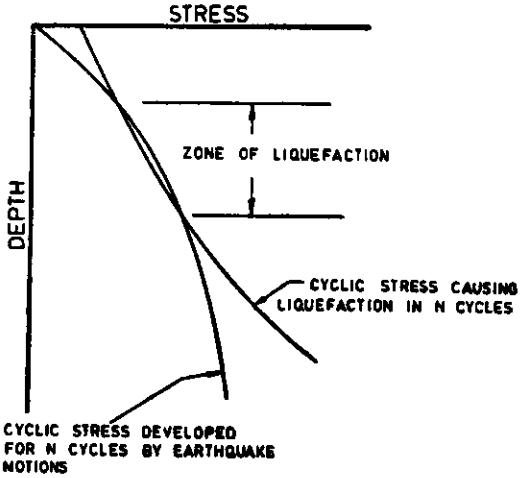

Fig. 1 Evaluation of liquefaction potential

5. Compare the shear stress induced by the earthquake with those required to cause liquefaction to determine if a zone of possible liquefaction exists.

Subsequently Seed and Idriss (1971) proposed a simplified procedure which is simplified version of general method. This method has been used in the present analysis. In essence the procedure offers a simple way of estimating the equivalent uniform shear stress induced during the earthquakes, the number of significant cycles of that stress and the shear stress to cause liquefaction in the same number of cycles.

This involves the following steps.

1. Estimate the maximum ground acceleration a_{max} during an earthquake.

2. The maximum shear stresses (T_{max}) at some depth (h) can be obtained using following equation with reasonable accuracy

$$(T_{max}) = \gamma h/g \times a_{max} \times r_d$$

where γ is unit weight of soil g acceleration due to gravity and r_d is a stress reduction factor.

3. Average equivalent uniform shear stress T_{av} induced during the earthquake is taken to be 65% of maximum shear stress T_{max}. The number of cycles of this stress has been taken to be dependent on earthquake magnitude only as given below:

Earthquake magnitude	Number of significant cycles
7	10
7½	20
8	30

Since the above method of equivalent number of cycles is too much subjective a method for converting accelerogram or stress history into equivalent uniform average acceleration or stress of significant number of cycles by appropriate weighting of acceleration or stress level has been given by Lee and Chan (1972), which has been used in the present analysis.

4. Plot the stresses induced during the earthquake with depth for the above number of significant cycles as shown in Figure 1.

5. For evaluating liquefaction zone stresses causing liquefaction may be determined from extensive laboratory tests to be performed on representative samples as indicated earlier in general method. A simplified procedure may also be used which makes use of the available data on triaxial testing in the following way.

The results of number of investigations on triaxial apparatus of soils with different grain sizes represented by the fifty percent grain size D_{50} and at a relative density of 50% are summarized by Seed and Idriss (1971). The results of these tests are expressed in terms of the stress ratio ($\sigma d_c/2\sigma_0$) causing liquefaction in 10 cycles and 30 cycles where σd_c is the cyclic deviator stress and σ_0 is initial ambient pressure under which the sample was consolidated. The stress ratio causing liquefaction at other relative densities less than 80% can be taken to be approximately linearly varying with relative density.

It has been estimated that the stress to cause liquefaction in field is less than those required in triaxial testing. The above ratios have to be reduced by a factor C_r which depends on relative density D_r (Seed and Idriss 1971). This ratio multiplied by overburden pressure will give the stress causing liquefaction and can be plotted in Fig. 1 to indicate the liquefaction zone.

EVALUATION OF POSSIBILITY OF LIQUEFACTION

Typical simple cases of uniform saturated sand deposits were analysed with the above method. The site has been considered to be subjected to an earthquake shown in Figure 2. In order to evaluate the possibility of liquefaction of a deposit, it is necessary to determine whether the shear stress induced at any depth by the earthquake is sufficiently large in comparison to stress required to cause liquefaction.

Consider for example, a deposit of sand with relative density of 30% for which

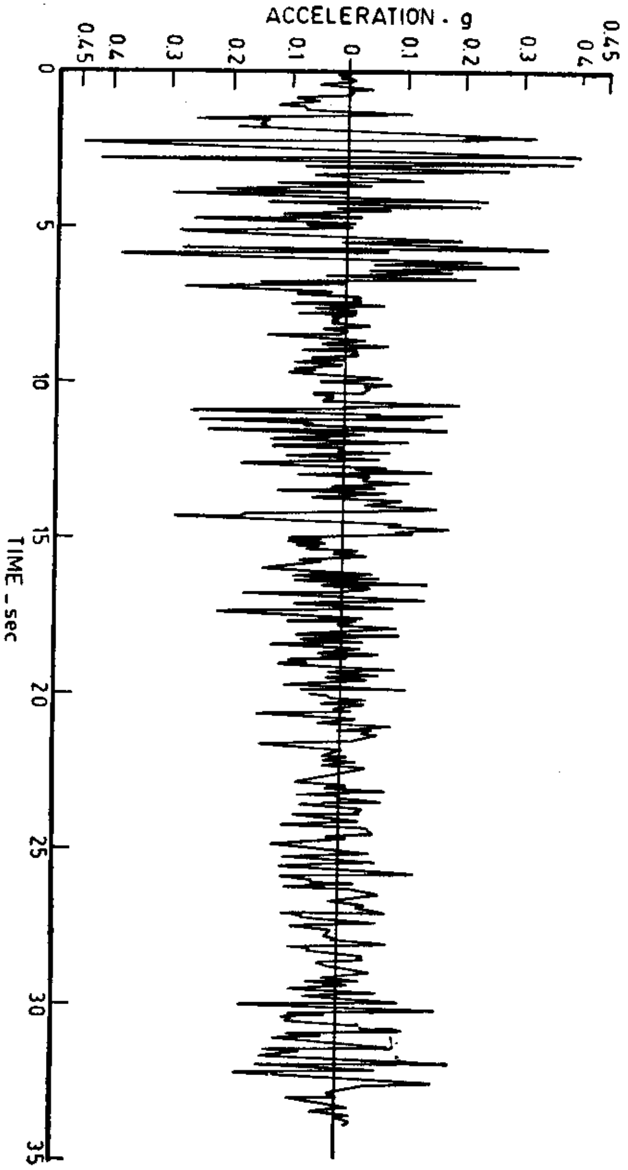

Fig. 2 Estimated earthquake for site

fifty percent grain size D_{50} is 0.2 mm. The water table is at ground surface which is subjected to the above earthquake. This earthquake has been considered to be equivalent to 14 cycles of 65% of 0.45g (peak acceleration) i.e. 0.2925g using the method of Lee and Chan (1972).

The average shear stress induced at 5m depth in 14 cycles will be

$$T_{av} = .965 \times 5 \times \frac{1.9 \times 10^3}{g} \times .2925g$$

$$= 2680 \text{ kg/m}^2 \qquad (\gamma = 1.9 \text{ gm/cc})$$

$$\gamma_d = .965 \text{ for } 30\% \ D_r$$

Shear stress required to cause liquefaction will be determined as explained above and for 14 cycles it will be linearly interpolated between values for 10 and 30 cycles. The stress ratio to cause liquefaction in 14 cycles for 50% relative density is 0.2344. The shear stress τ to cause liquefaction in 14 cycles at 5m depth for 30% relative density is given by

$$\tau = 0.2344 \times 0.9 \times 5 \times 10^3 \times 30/50 \times 0.55$$

$$= 348 \text{ kg/m}^2$$

$$(C_r = 0.55 \text{ for } 30\% \ D_r, \ \gamma_{sub} = 0.9 \text{ gm/cc})$$

Similarly stress induced and stress required to cause liquefaction at other depths were also computed. These results are plotted in Figure 3. It can be seen that according to this analysis the sand deposit would liquefy to great depths.

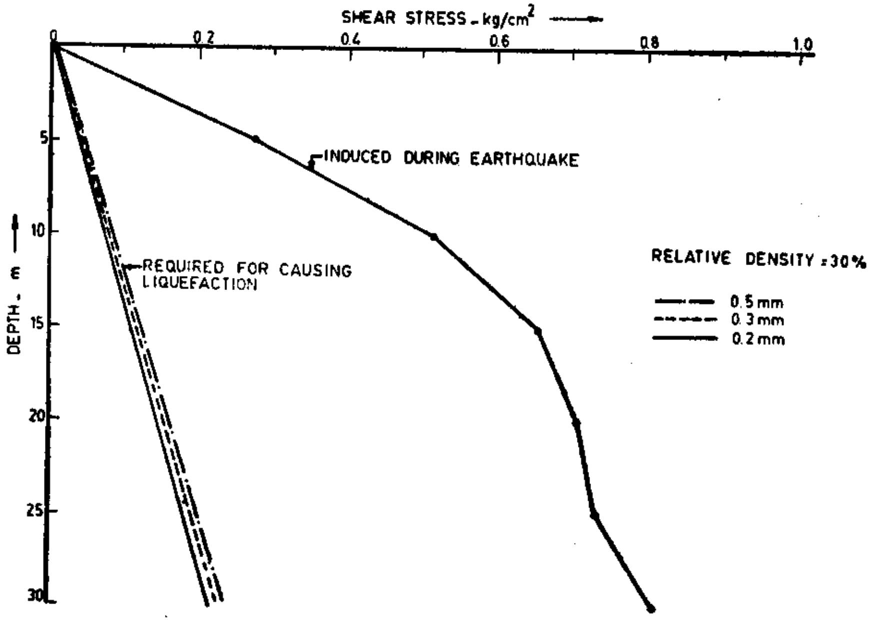

Fig. 3 Shear stresses versus depth

Figure 3 also shows the analysis for uniform sand deposits of 30% relative density and mean grain size of sand D_{50} of 0.3mm and 0.5mm. The analysis show that during the earthquake all the sand deposits considered would liquefy to great depths.

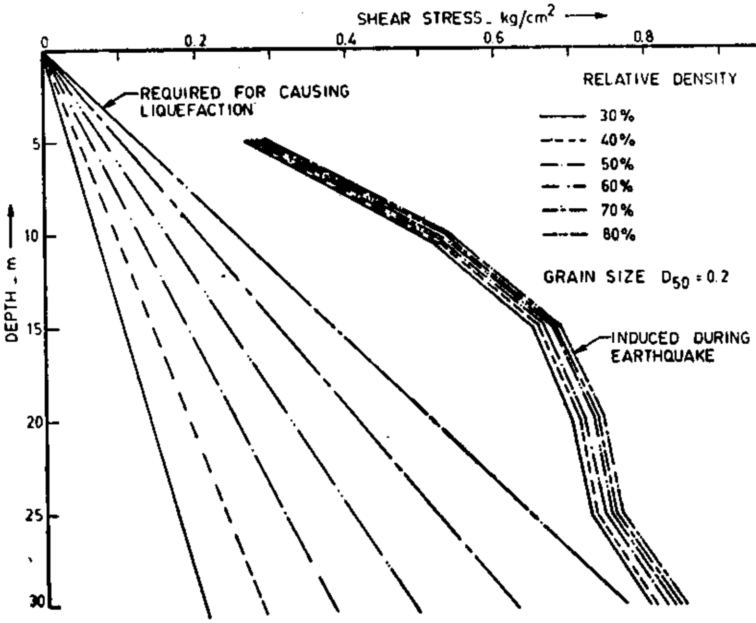

Fig. 4 Shear stresses versus depth

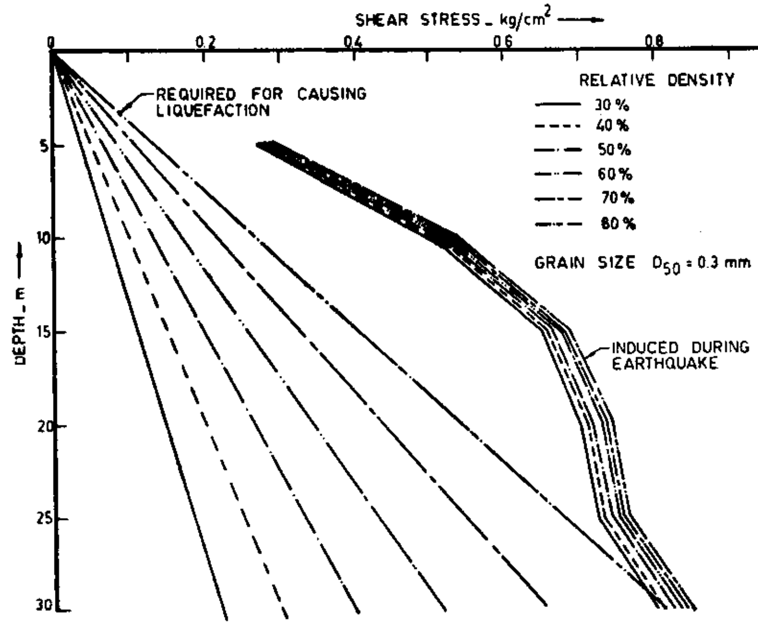

Fig. 5 Shear stresses versus depth

Figure 4 shows the effect of relative density on the liquefaction potential for the deposit of D_{50} of 0.2mm. Similar information is drawn for D_{50} of 0.3 and 0.5m in Figures 5 and 6 respectively. It can be observed that the sand could liquefy to great depths. The analysis shows that at 80% relative density also it could liquefy to about 30m depths. This result does not seem to be true and needs a critical examination from practical point of view.

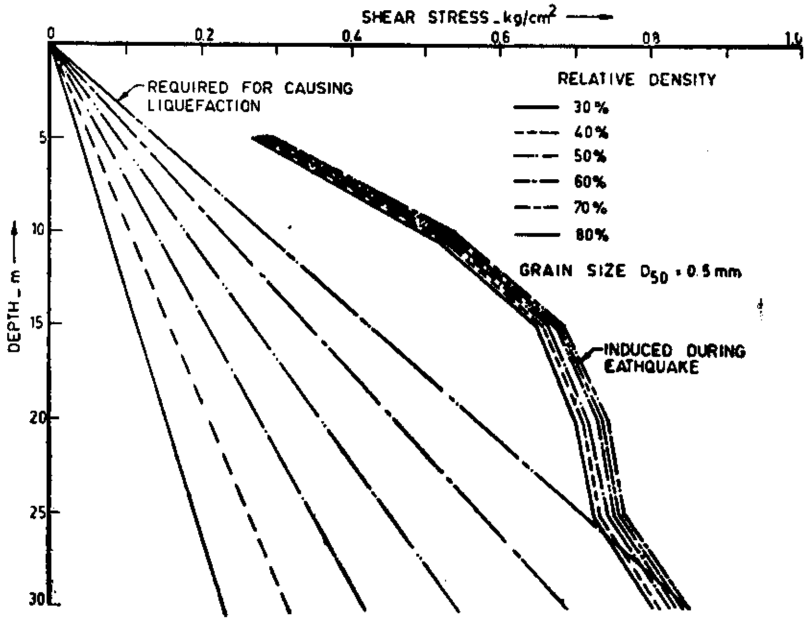

Fig. 6 Shear stresses versus depth

Effect of consideration of earthquake, equivalent to different cycles of different average acceleration is shown in figure 7. The earthquake was equivalent to 9 cycles of 75% of peak acceleration, 14 cycles of 65% peak accelerations and 36 cycles of 50% of peak acceleration with the use of method of Lee and Chan (1972). It is observed that stresses required to cause liquefaction are not much different but there is considerable difference in induced stresses affecting the results to great extent. Therefore choosing an appropriate value of average acceleration is important in this method and the effect cannot be neglected.

Therefore the method of analysis needs a careful discussion on the limitations of the laboratory test data used in analysis and on the method of approach.

DISCUSSION

It has been observed from this analysis that dense sands can also liquefy to great extent. The results obtained from this analysis needs considerable judgement as discussed below. It is well known that when loose saturated sands are sheared, they tend to decrease in volume and produce an increase in pore pressure under undrained conditions. While dense sands tend to dilate and produce negative pore pressure under undrained conditions and any interlocking has to be broken. It can be thought that whatever the process of shear, dense sands should break their interlocking and produce an increase in volume, or a negative pore water pressure during shear.

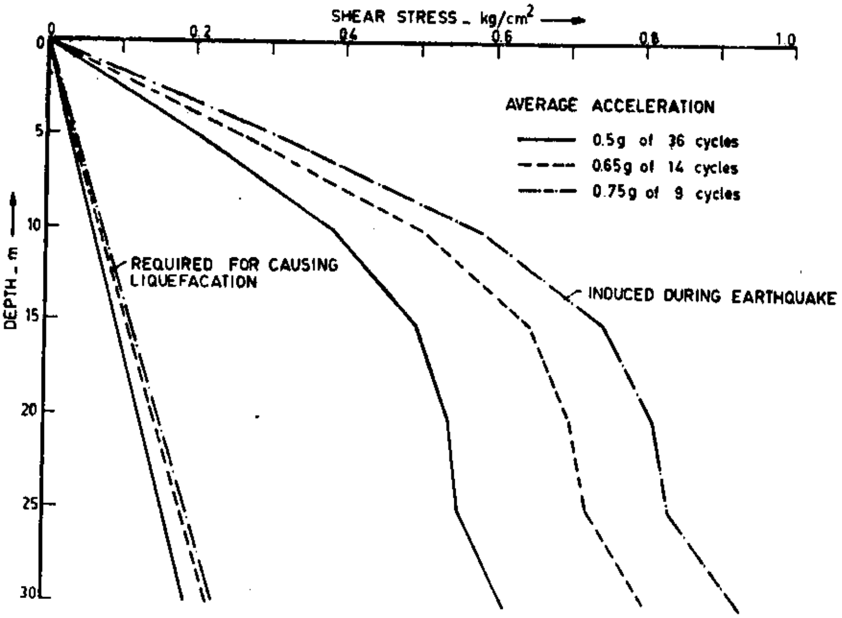

Fig. 7 Shear stresses versus depth

During the shake table studies it was observed that sand may not liquefy if it is at relative densities of more than 65% and development of negative pore water pressures at a relative density of 70% or above was also observed (Gupta and Prakash 1977). A. Casagrande also observed dilation in case of medium dense to dense sands on small sample studies under cyclic loading triaxial tests and concluded that if sand is at relative density of more than 50% it may not liquefy (Green & Ferguson 1971).

One of the important aspects of the problem is consideration of progressive development of liquefaction and spreading of liquefying zone. Liquefaction of any zone in a sand deposit in first few cycles of an earthquake reduces the overburden pressure on lower layers. This may cause favourable conditions for liquefaction to develop in lower layers in next few cycles thereby further reducing the overburden pressure on deeper layers. In this way liquefaction may travel to sufficient deep layers during the earthquake. In the analysis as proposed by Seed and Idriss (1967, 1971) this aspect of the problem is not considered. The equivalent number of cycles cannot take care of the above behaviour.

Cyclic triaxial or simple shear tests used to determine the cyclic shear stress likely to cause liquefaction are subject to considerable limitations (Pea cock and Seed 1968). Castro and Poulos (1977) believe that observed behaviour of cyclic deformations in dense clean sands under cyclic loading triaxial or simple shear tests are due to test error, redistribution of void ratio which is not representative of field behaviour. Therefore they are of the openion that use of cyclic load test results for clean sands should be avoided for quantitative evaluation of in situ deformations.

Therefore the laboratory data on small samples used in the analysis requires a careful judgement and it seems that it is in error. Secondly the actual behaviour of saturated sand masses during the earthquake is also not taken care of in the analysis as discussed above. Thus it seems reasonable to think that the method of analysis as proposed by Seed and Idriss is in error and there is a need to develop a more rational method,

CONCLUSIONS

1. The method available for assessing the possibility of liquefaction which makes use of laboratory test data on small samples under cyclic triaxial or simple shear conditions seems to be in much error and should be used only with due care.

2. There is a need to develop a more rational method.

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