Liquefaction potential of sand by torsional shear test

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ABSTRACT: The liquefaction potential of saturated sand is estimated by using torsional shear. Laboratory tests indicate distinct patterns between torsional moment and rotation angle of cylinder embedded in sand for contracting and dilative behavior. Using corresponding relations, shear stress versus shear strain of sand adjacent to cylindrical surface is evaluated. By slightly modifying the standard penetration test, torsion shear tests were carried out. The predictions of liquefaction potential by torsional shear compares favorably with the predictions of standard penetration tests for liquefaction potential.

1 INTRODUCTION

The liquefaction potential of saturated sand is basically estimated by using standard penetration tests (SPT) and cone penetration test (CPT or CPTU). These tests produce volumetric stresses in the soil and thus the generation of pore pressure due to shear is not directly measured. To overcome this difficulty recently Atkinson and Jessett (1990) and Charlie et al (1995) developed the piezovane. They were thus able to measure pore pressure decrease for dilative sand and pore pressure increase for contractive sand during torsion of the vane apparatus. The torsional in situ field test is desirable, because it produces basically shear strains and thus by measuring torque and rotation angle of the cylinder being subjected to rotation, the shear stress versus shear strain can be measured.

Laboratory tests were done on cylindrical bar of 2.5 cm diameter embedded in sand for a length of 20 cm for different relative densities of sand. Theoretical development relates torsion on the cylinder to shear stress on adjacent soil and rotation angle to shear strain. By plotting shear stress versus shear strain, distinct pattern of behavior is noticed for dilative and contractive sands.

Field torsional tests on SPT were carried out by modifying the SPT slightly. The pattern of sand behavior makes it possible to estimate the liquefaction potential for contractive behavior.

2 TORSONAL SHEAR TEST THEORY

If the cylindrical bar embedded in the soil is subjected to rotation as shown in Fig. 1, then for the soil at depth h assuming lateral stress to be p_0 and for fully elastic case ($r_e = r_0$) it can be shown that (Dehghani, 1998) as indicated in Fig. 2.

$$t_{rJ} = t_0 \left(\frac{r_0}{r} \right)^2 \qquad (1)$$

$$e_r = e_q = 0 \qquad (2)$$

$$g_{rq} = \frac{1}{r}\frac{du_r}{dq} + \frac{du_q}{d_r} - \frac{u_q}{r} = \frac{t_0}{G}\left(\frac{r_0}{r} \right)^2 \qquad (3)$$

Where p_0 is lateral pressure, σ_r is radial stress, σ_θ is circumferential stress, $\tau_{r\theta}$ is shear stress, ε_r is radial strain, ε_θ is circumferential strain, $\gamma_{r\theta}$ is shear strain, G is the shear modulus, u is the displacement , r_0 is the bar radius, and r is the radial distance. τ_0 is the shear stress at the cylinder boundary.

It is interesting to note that the soil surrounding the cylindrical bar is behaving basically in pure shear and the change of volume is zero. Also from equation (3) , it can be seen that

$$\frac{u_q}{r} = \left(\frac{-t_0}{2G}\right)\left(\frac{r_0}{r}\right)^2 = -\frac{d_{rq}}{2} = a \qquad (4)$$

Where α is the rotation angle. Thus the shear strain is twice the rotation angle.

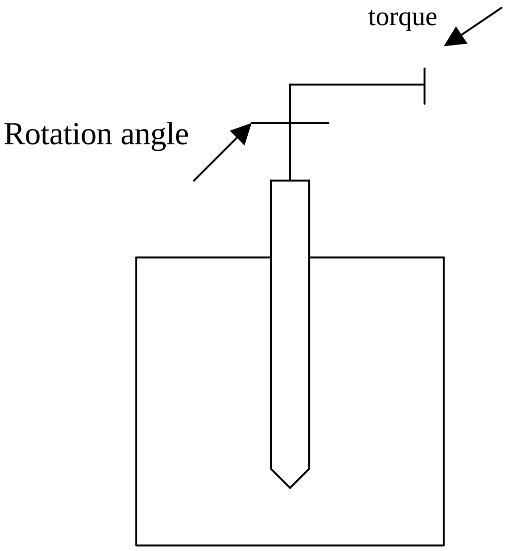

Figure 1. The torsional shear apparatus

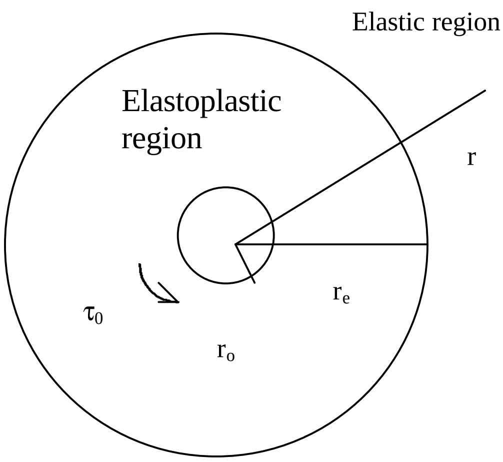

Figure 2 The elastic and elasto plastic region

In the elasto plastic region, assuming Mohr Coulomb failure criteria, it can be shown that

$$s = p_i\left(\frac{r}{r_0}\right)^Q \qquad r_e = r_0\left(\frac{p_0}{p_i}\right)^{\left(\frac{1}{Q}\right)} \qquad Q = 2\tan^2 j$$

$$t = Gg \qquad when \quad g \le \frac{p_0 \tan j}{G} \qquad otherwise$$

$$t = \left(\frac{2(1+n)k_f \tan j \ \tan y}{2(1+n)k_f \tan j \ \tan y + (1-n)(1+k_f)}\right)x$$

$$G(g - g_0) + t_0 \qquad (5)$$

(Dehghani 1998)
It is also concluded that

$$t_0 = p_0 \tan j \quad where \quad k_f = \left(\frac{1}{1+2\tan^2 j}\right) \ (6)$$

Where φ is the friction angle and ψ is the dilation angle. The general pattern is shown in Figure 3.

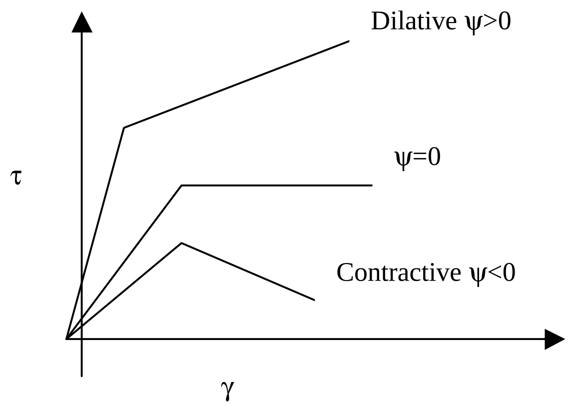

Figure 3. Contractive and dilative behavior

Thus it can be seen that for Mohr Coulomb soil, the soil adjacent to the cylindrical bar is acting in undrained behavior and thus shear stress is proportional to shear strain at the elastic range and it then decreases for Contractive soil and increases for dilative soil.

3 TORSIONAL SHEAR TEST LABORATORY TESTING.

During the laboratory testing the cylinder (roughened at the periphery to prevent slippage between the cylinder and the soil) equipped with a torquemeter and rotation angel measuring system as shown in Figure 1. Two sands were tested. The property of the sands is shown in Table1.

Table 1 The property of the two sands tested

Property	Sand 1	Sand 2
D_{50} mm	0.28	0.75
e max	0.93	0.89
e min	0.57	0.52
G	2.64	2.65
Cu	2.7	5.6
Cc	0.9	0.9

The grain size distribution of the two sands is shown in Figure 4.

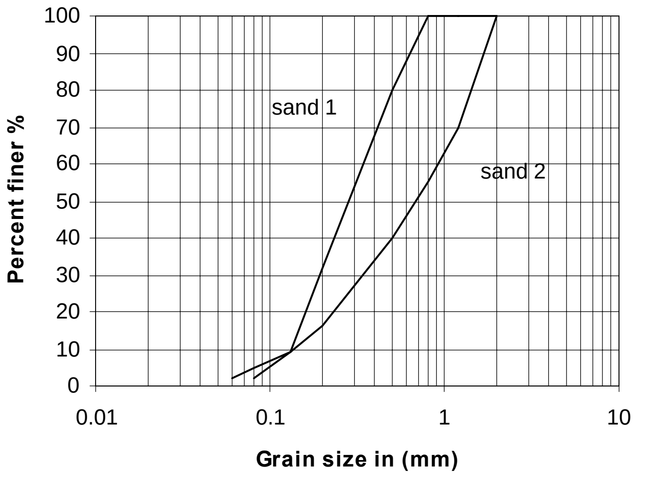

Figure 4 The grain size distribution of sands

Triaxial tests under undrained condition were run for the two sands on 5 by 12 cm samples. The steady state line for the two sands is shown on figure 5 and the steady state condition for the two sands is shown in figure 6.

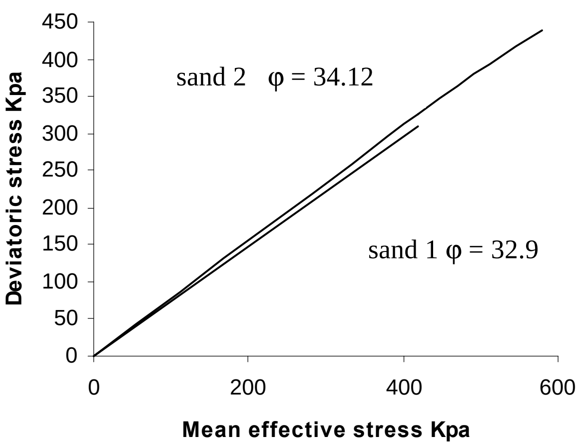

Figure 5 Steady state lines

After having measured the properties of the two sands under triaxial conditions torsional shear tests were carried out. The results of the tests are presented after converting the torque to shear stress and the rotation angle to shear strain. The test results for different relative densities for the tow sands are shown on Figure 7 and Figure 8.

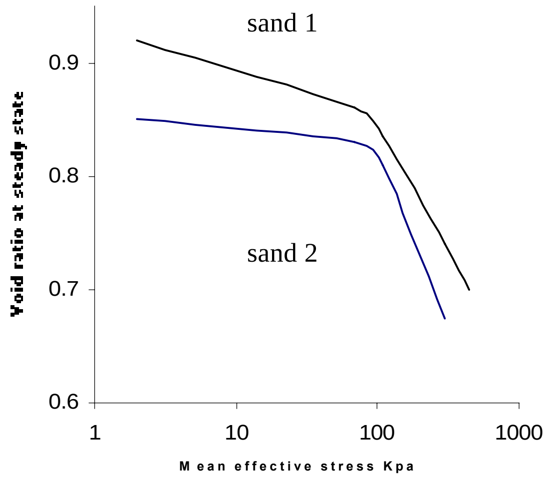

Figure 6 Steady state conditions

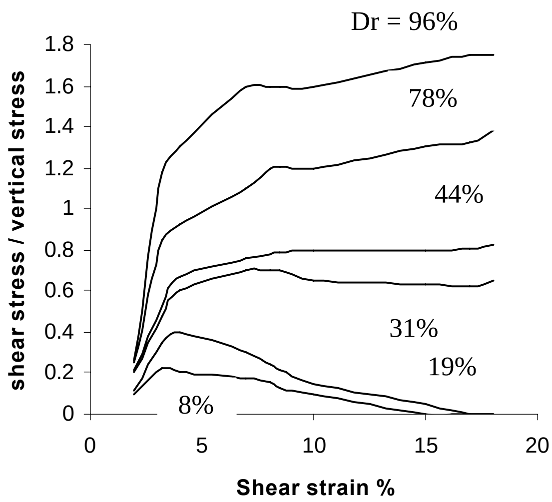

Figure 7 Torsional shear test on sand 1

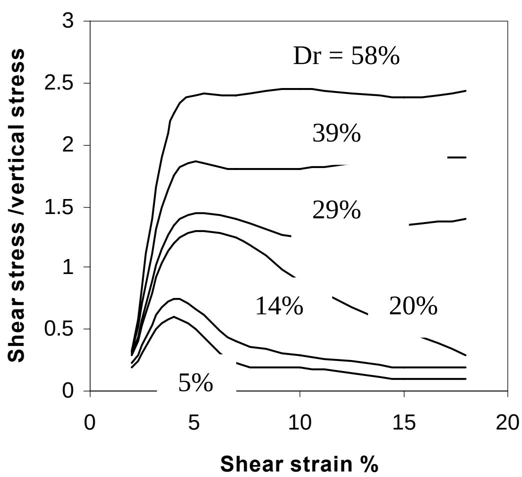

Figure 8 Torsional shear test on sand 2

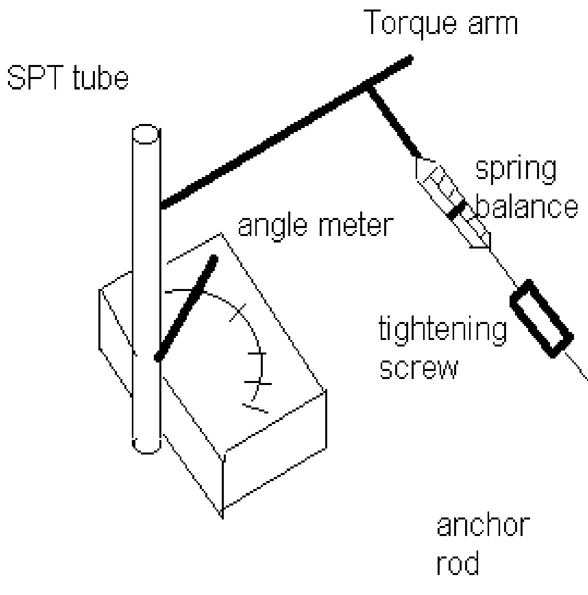

Figure 9 Torsional shear field test

4 TORSIONAL SHEAR TEST, FIELD TESTING

The field tests were carried out in southern part of Iran in Hormozgan University extension land. The area is covered by loose saturated sand up to the depth of 10 meters and is known to have liquefiable sand layers. Two boreholes were tested. After boring to the required depth and installing casing and filling the hole up with bentonite, Standard Penetration Test was carried out at the given depth. After SPT test, the torsional field shear was carried out. The schematic test setup is shown in Figure 9.

The test unit consists of the following parts:

A. A platform of 50 centimeter high and surface area of 100 centimeter by 150 centimeter with a 10 centimeter diameter hole in the middle to let the SPT sampler and tube pass from it.
B. A plate for measuring angles of rotation with graduation in degrees on it with 100centimeter diameter and 10 centimeter hole in the middle.
C. Steel arms of 100 and 50 centimeter lengths attached to the SPT tube for applying the torque to the SPT sampler.
D. Two spring balances of 30 and 50 kilogram range for measuring the force applied to the arm to create the torque on the SPT sampler.
E. A pointer attached to the tube to help in measuring the rotation angle.
F. An anchor rod inserted in the ground to be a fixed support for applying the force through the tightening screw attached to the spring balance.

The torsional shear was done in the following manner:

The platform was installed and the plate for angle measurement was fixed on it. The hole in the plate and the platform was centered with the SPT tube. Then the arm was fixed to the SPT tube at one meter high above the ground with the help of grippers. A vertical pointer was also applied to the arm to point to the graduations on the angel measurement plate. Another pointer was also applied to the tube at the level of the graduation plate. These tow pointers should measure the same angle during the application of the torque if there is no tilt in the tube. Then the spring balance was hooked to the torque arm and through the tightening screws to the anchor rod. By tightening the screw, a force was gradually applied to the torque arm. The spring balance measured the force and this force multiplied by the arm would give the magnitude of the torque. The rotation angle was measured by the pointer taking care during the test to have the two pointers pointing to the same rotation angle. It should be mentioned that the periphery of the SPT sampler was roughened to prevent slippage between the sampler and the sand and to introduce the shear in the sand. . After carrying the torsional shear test, the boring was continued to another depth and the procedure was repeated, thus doing SPT test first and torsional shear test afterwards at the same depth. The schematic test setup is shown on Figure 9.

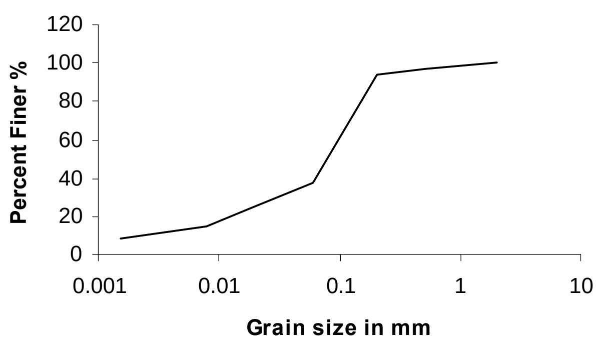

Figure 10 Grain size at depth 1.5m B.H.1

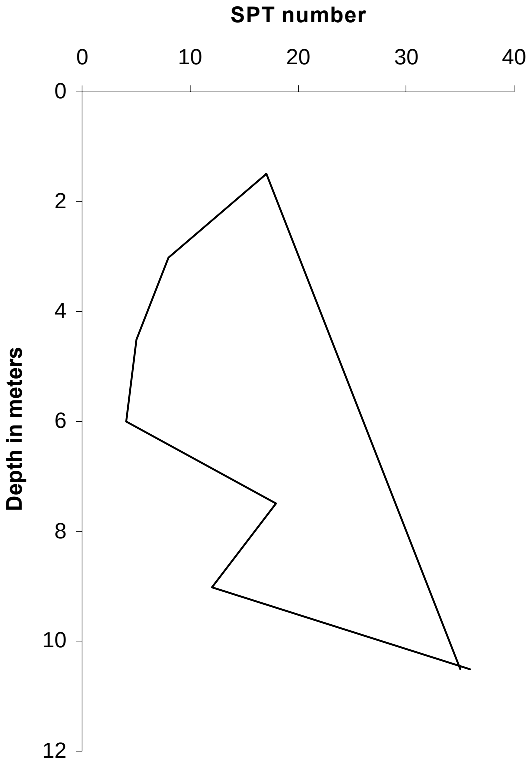

Figure 11 SPT variation with depth

This simple setup was chosen to be easily applicable to SPT test without major modification of the SPT test setup. The only modification was roughening the sides of the SPT cylinder to prevent slippage.

A sample grain size distribution of the sand in the field is shown in Figure 10 The variation of SPT with depth is shown on Figure 11 for both boreholes.

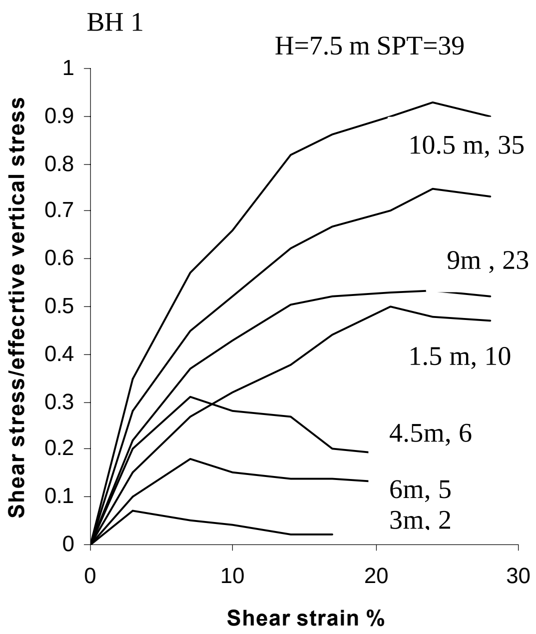

Figure 12 Torsional field test B.H No. 1

The torque measured during the torsional shear test was converted to shear stress and the rotation angle converted to shear strain. The shear stress in the soil at contact with SPT Sampler was made non dimensional by dividing it with respect to vertical effective stress. The results for Bore Hole No. 1 is shown in Figure 12 and for Bore Hole No. 2 is shown in Figure 13.

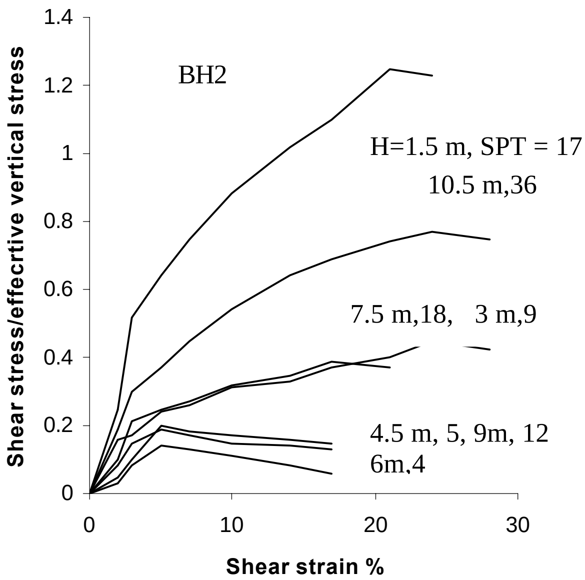

Figure 13 Torsional field test B.H No. 2

5 DISCUSSION OF RESULTS

The results of laboratory and field torsional shear tests were presented in Figures 7,8,12,13..

It is clear from laboratory tests that higher relative densities have dilative effect, this means that with the increase of shear strain, the shear stress is increased and up to large shear strains this trend is evident. At low relative densities, the contractive effect is evident and the shear stress reaches a maximum and it then declines with the increase of shear strain.

Also the results of field torsional shear tests indicate that at higher SPT values, the dilative behavior is also present in the field test and shear stress keeps increasing up to large shear strains. However at low SPT values, the contractive behavior is present and shear stress reaches a maximum and then declines with the increase of shear strain. It is also interesting to notice that at the same SPT , the shallower samples show more dilative behavior.

Thus torsional field shear test is another signature for the sandy soils after SPT for prediction of liquefaction potential.

7 CONCLUSIONS

Considering the theoretical development and the results of the laboratory and field torsional shear tests, it is concluded that

1. The torsional shear test is capable of predicting the contractive and the dilative behavior of the sand adjacent to the SPT sampler.

At the dilative behavior, the shear stress increases continuously up to large shear strains. When the behavior is contractive, the shear stress reaches a maximum and then decreases with the increase of the shear strain. At low relative densities or at low SPT values, the shear stress may reduce to almost zero.

2. It is possible after SPT test, with simple modification of test technique, to run torsional shear test in the field, thus giving another signature of the soil behavior to be used in liquefaction potential evaluation.

3. The predicted theoretical pattern of shear stress versus shear strain is followed both at laboratory torsional shear tests and at the filed torsional shear test.

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