A Simple Experimental Model of Cyclic Stress-Dilatancy for Sand

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Introduction

Several Stress-dilatancy equations, which relate the ratio of plastic strain increments to the stress ratio, have been proposed for drained monotonic loading. However there is a few studies on the stress-dilatancy of sand for drained cyclic loading (Pradhan and Tatsuoka, 1989)

In this paper experimental cyclic stress-dilatancy graphs of sand were used to make an experimental simple stress-dilatancy model. In this simple model the dilatancy ratio of sand is connected to stress ratio by some parameters, which are determined based on the geometry of experimental stress-dilatancy graphs.

This simple model can be used to estimate sand volume change under drained cyclic shear or pore water pressure buildup due to undrained loading.

Summary of experimental results

Results of a series of hollow torsional cyclic simple shear tests on Japanese Toyoura sand were used in this study (Shahnazari and Towhata, 2000).

Figure 1 shows the stress-dilatancy graph for a loose specimen under cyclic shear with constant strain amplitude of three percent. Figures 2a and 2b show the stress-dilatancy and volume change graphs for dense sand under irregular cyclic loading.

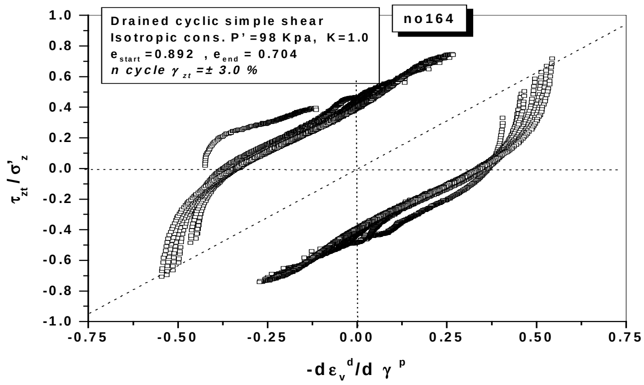

Figure. 1. Cyclic stress-dilatancy relation for loose sand

From these Figures and other test results the following conclusions can be drawn:

1. By loading reversal, the stress dilatancy rate ($-d\varepsilon_v^d/d\gamma^p$) changes discontinuously and after this sudden change, the graphs start from a diagonal line which passes through the center of coordinates.

2. For different strain amplitudes or different stress ratios the stress-dilatancy graph will change mostly after reversal of loading. When the graphs move to dilative direction, direction of all the curves passes through a specific point.

3. Density of sand has a greater effect on stress-dilatancy of virgin loading but the effect of this parameter on stress-dilatancy graphs of the following cycles is smaller. However loose sand shows more volume change compare to dense sand in these cycles.

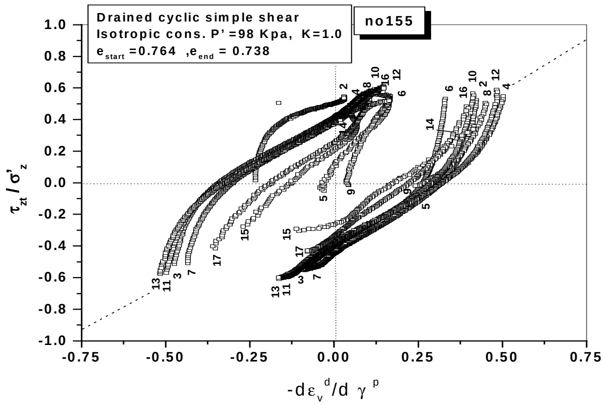

Fig. 2.a. Stress-dilatancy relation for dense sand under irregular cyclic loading

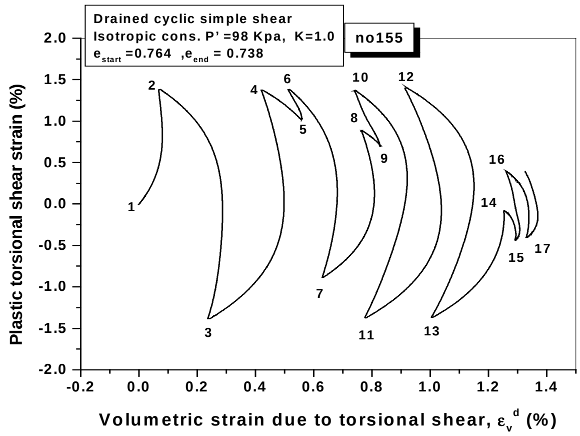

Fig. 2.b. Volumetric strain of dense sand due to irregular cyclic loading

Description of the model

A simple geometrical model of stress dilatancy was made using some specific points and a diagonal line. These points and diagonal line are shown in Figure 3. Coordinate of these points and slope of diagonal line can be determined by using the experimental stress-dilatancy graphs. Point A is the starting point of stress-dilatancy for virgin loading. Symmetric Points B and B' are the points, which the stress-dilatancy curves move toward them in dilative zone. After change of loading direction, curves start from diagonal line z-z with the slope of 1/ac. Points B and B' are the limit points with the maximum stress ratio of one.

When loading starts, the stress–dilatancy graph starts from point A with dilatancy ratio of $Y_A = (-d\varepsilon_v^d/d\gamma^p)_A$ and $R_A = 0$, and moves toward point B with dilatancy ratio of $Y_B = (-d\varepsilon_v^d/d\gamma^p)_B$ by the equation (1)

$$-d\varepsilon_v^d/d\gamma^p = (Y_B - Y_A) * R^n + Y_A \qquad (1)$$

Power n changes by change of density, confining pressure or initial anisotropic consolidation factor at

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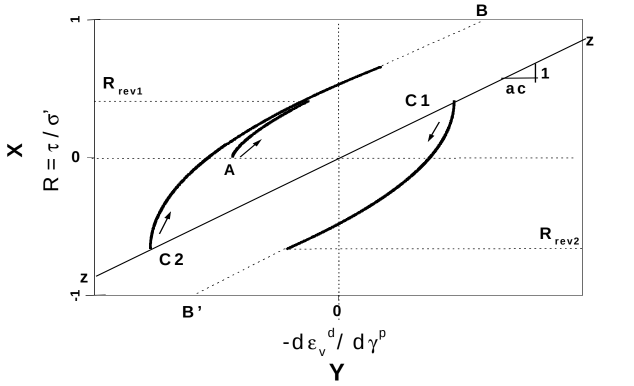

Figure 3. Geometrical description of stress-dilatancy model

the start of shearing.

When loading reversal happens at R= R_{rev1}, dilatancy ratio changes discontinuously and graph starts from diagonal line z-z from point C1 with R=R $_{rev}$ and Yc1= ac$*$ R_{rev1}. Then the stress-dilatancy curve moves toward B', with equation (2)

$$-d\varepsilon_v^d / d\gamma^p = (-Y_B - Y_{c1}) / (-1-R_{rev1})^2 * (R-R_{rev1})^2 + Y_{c1} \qquad (2)$$

When reversal happens again in point C2, the equation of stress-dilatancy curve from C2 toward B will be:

$$-d\varepsilon_v^d / d\gamma^p = (Y_B - Y_{c2}) / (1-R_{rev2})^2 * (R-R_{rev2})^2 + Y_{c2} \qquad (3)$$

By using this simple method the stress-dilatancy graph can be modeled for irregular cyclic loading.

Model results and discussion

Calculated stress-dilatancy graphs by using the presented model under four cycles of three percent constant single strain amplitude are shown in Figure 4.

Figures 5a shows the stress-dilatancy and volumetric strain of dense sand under irregular cyclic shearing. Volumetric strain was calculated by integration of stress-dilatancy ratio with respect to the stress ratio R, and is shown in Figure 5b. Recorded experimental volumetric strain of sand is also projected on this figure by dotted curves.

Comparison of experimental and model results shows that calculated stress-dilatancy relations by model are very similar to experimental stress-dilatancy graphs.

Figure 5b shows that the predicted volume change in first cycle is almost the same as recorded value but in the following cycles, model predicts greater volume change.

For calculation of stress-dilatancy relation and volumetric strain in this model, constant values of parameters (Y_B and ac) were used.

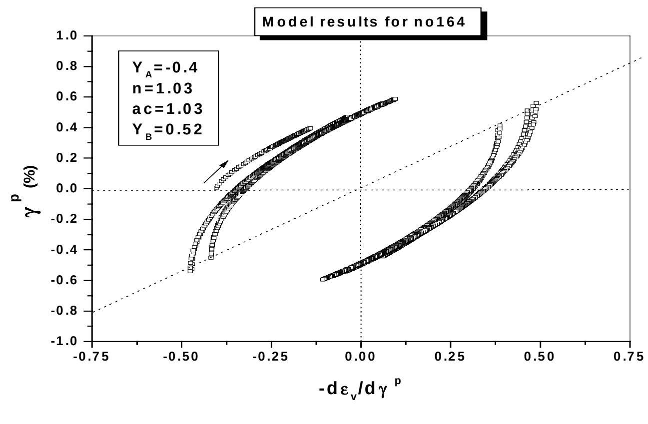

Figure 4. Calculated cyclic stress-dilatancy relations by model for loose sand

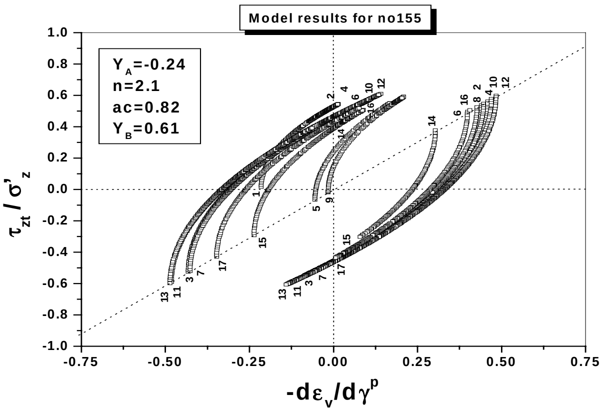

Figure 5a. Calculated stress-dilatancy relations by model for dense sand under irregular cyclic loading

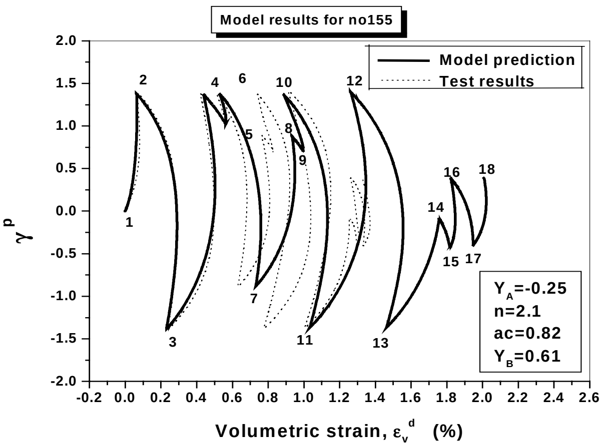

Figure 5b. Calculated volumetric strain of dense sand under irregular cyclic loading.

Although the stress-dilatancy graph has a minor change due to change of density and effect of previous cycles, but this minor change causes a remarkable effect on volume change.

It seems that the effects of void ratio and previous cycles on stress-dilatancy relations and volumetric strain of sand are very important. For evaluation of volumetric strain, effect of void ratio and previous cycles must be considered on stress-dilatancy graph and the parameters of the model.

References

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