Numerical Simulations for Liquefiable Sands

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ABSTRACT

The generalized plasticity model proposed by Zienkiewicz et al. (1985) with modifications (Pastor et al, 1990) was adopted as the base for building a numerical tool in simulating dynamic behavior of earth structures. The implementation of the generalized plasticity model was made modular so it can easily be used with analysis codes. This study employed FLAC for the analysis. Numerical simulation of the laboratory tests carried out by Castro showed that this approach and the present implementation are capable of duplicating the most important features of soil behavior under both static and cyclic loading.

This study also tested an implementation of a hypoplasticity model in a very limited setting. This is part of an effort to have another tool for cross checking of analysis results in the future.

Key Words: Liquefaction, plasticity soil model, effective stress analysis.

液化砂土之數值模擬

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摘　要

本研究選擇 Zienkiewicz 等(1985)與 Pastor 等(1990)提出的「廣義塑性模式」作為建構數值分析工具的基礎，並進行該模式的程式撰寫。目前已針對於 FLAC 程式套用上完成此模式之程式化，程式之正確性並經以數值模擬 Castro 的試驗資料來驗證。本研究亦初步測試了王氏「限界降伏面模式」於 FLAC 程式中的套用情形，主要是期於提供數值模擬時得有多一重檢測的工具。本研究所完成的土壤組模程式測試結果顯示，本程式已能掌握土壤受反覆載重下最重要的反應行為。

關鍵詞： 液化、塑性土壤模式、有效應力分析。

1. Introduction

To better understand the behavior of earth structures under complex loading environment, be it static or dynamic, it is crucial to incorporate the essential soil characteristics into an analysis. This is particularly true for the ground that consists of liquefiable sands. Due to extensive numerical and experimental research over the years, significant progress has been made. Numerous soil models are now available that vary over a wide range in their sophistication. For a credible analysis it is crucial that the most important features of soils be represented such as pore pressure generation mechanism, stress-dilatancy, hysteretic loops for energy dispassion. Moreover, these characteristics should be a direct consequence of a unified framework. Practically all plasticity based soil models that profess to have such capability; the kinematic hardening rule is adopted through some use of the bounding surface model.

As an overall effort to develop a modern tool in conducting dynamic analysis of earth structures, this study reviewed incremental plasticity based soil models, and selected the general plasticity model (Zienkiewicz et al., 1985; Pastor et. al, 1990) as the base for implementation. The major considerations were that the generalized plasticity model had a good application track-record, that the model did not have to check the location of yielding surface, and that few parameters are needed for calibration. The implementation of the model, although modular, was targeted at the present time to be used with a commercial code, FLAC. The implementation was verified by numerical simulation of laboratory tests carried out by Castro.

This study also tested an implementation of a hypoplasticity model developed by Dr. Wang (1990) using FLAC's User Defined Model (UDM) and dynamic linked library (DLL). This provides a basis for future cross checking of simulation results.

As illustrated in this paper, the implementation completed in the study appears to capture that the most important features of soil behavior during cyclic loading, such as progressive stiffness softening of soil with increasing pore pressure, accumulation of deformation, tress-dilatancy and hysteretic loops. This research thus provides a suitable starting point for future study. The formulations of the generalized plasticity model and the bounding surface hypoplasticity model are in shown in Lin et al. (2003) in details.

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2. Simulation using the generalized Plasticity model

In his ground breaking work, Castro(1969) had conducted many undrained tests, both monotonic and cyclic, on sands that helped clarify the behavior of sands, namely: liquefaction failure, limited liquefaction and dilative response. These results have since become a de facto standard for checking the validity of constitutive laws of sands. They were also employed for the verification in this study.

To test not only the implementation, but also the coupling analysis capability of FLAC, this study conducted undrained analysis using the effective stress approach. Both strain and stress controlled tests were carried out using one axi-symmetric saturated element. The generalized plastic soil model parameters are taken from Pastor et al. (1990). They are listed in Table 1. The simulation results as shown in Figure 1 agree well with the test results obtained by Castro(1969) for monotonic undrained triaxial tests.

Two types of cyclic tests were conducted by Castro, one without and the other with extension. A cyclic test without extension is a stress controlled test in which a deviatoric compression is repeatedly applied and removed. The simulation results are shown in Figure 2.

The results of simulation for the second type of cycle test, i.e., full-cycle stress controlled cyclic test, are shown in Figure 3. The sample failed during the fourth cycle of the loading. The general trend in the simulation results is fairly consistent with that of the physical test.

Table 1 The generalized plastic soil model parameters

Test	a	b	c
K_o (kPa)	35000	35000	35000
G_o (kPa)	52500	52500	52500
M_f	0.40	0.545	0.570
M_g	1.50	1.32	1.12
b_o	4.2	4.2	4.2
b_1	0.2	0.2	0.2
g	1	1	1
g_u	2	2	2
H_o	350	350	350
H_{uo} (kPa)	60000	60000	60000
P'_o (kPa)	400	400	400
a	0.45	0.45	0.45

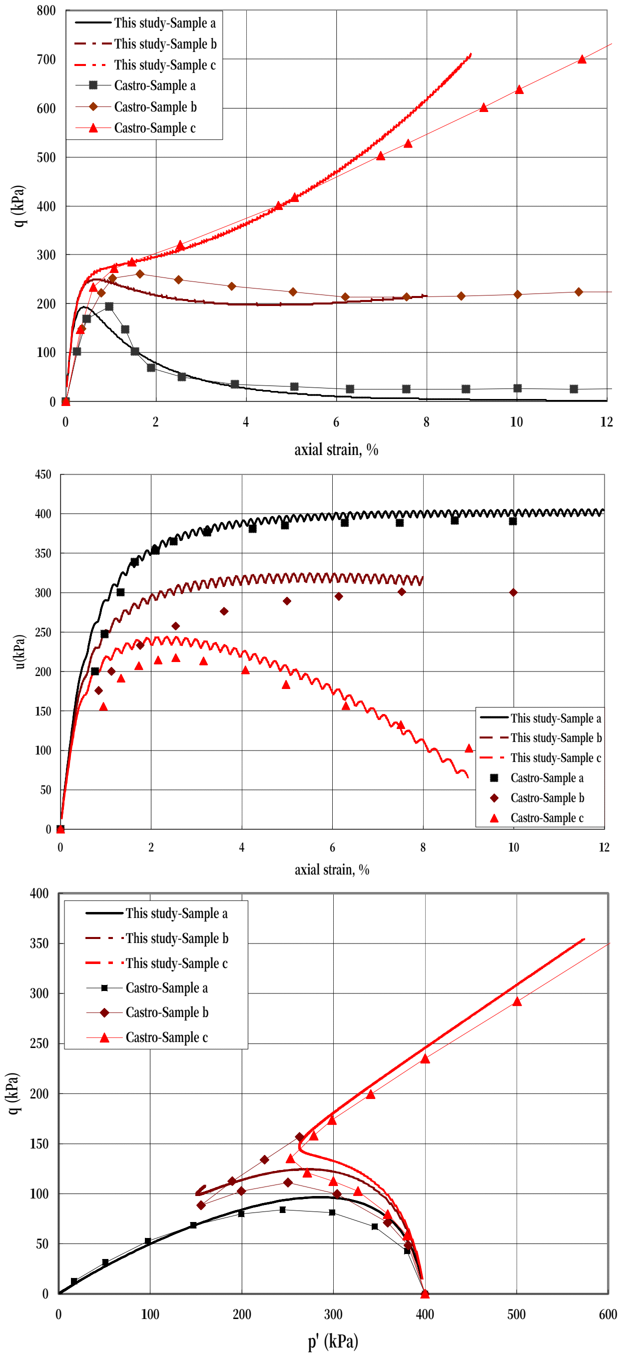

Figure 1 Numerical simulations of Castro's monotonic undrained triaxial tests - (a) q vs. axial strain; (b) u vs. axial strain; (c) q vs. p'

3. Preliminary Results of Bounding Surface Hypoplasticity Model

When dealing with a problem that has either a complicated configuration or a complex loading setup, or both, it may be prudent to have additional tool for cross checking analysis results. Toward this goal, another implementation based upon a bounding surface hypoplastic model by Wang et al.(1990) was also studied.

A hypoplasticity material is defined by Dafalias as a material for which the plastic flow is also affected by the stress gradient direction. Wang et al. adopted two yielding mechanisms. In the principal stress space one yield surface is a cone, the other a flat cap. This study did limited numbers of simulations using an implementation by Wang and HCItasca (2003) in FLAC. The Wang 's model is written in C++ by Wang and HCItasca and compiled into a dynamic linked library (DLL) file. The DLL version user-defined model could run 100% faster than a FISH version model in FLAC. The procedures in applying Wang's model are detailed in Lin et al. (2003).

Figure 4 shows the simulation results for a stress-controlled simple shear test in FLAC. It can be observed that after four cycles, the soil element starts to experience stress dilatancy after large deformation. The effective confining stress, p', decreases during the cyclic loading due to pore

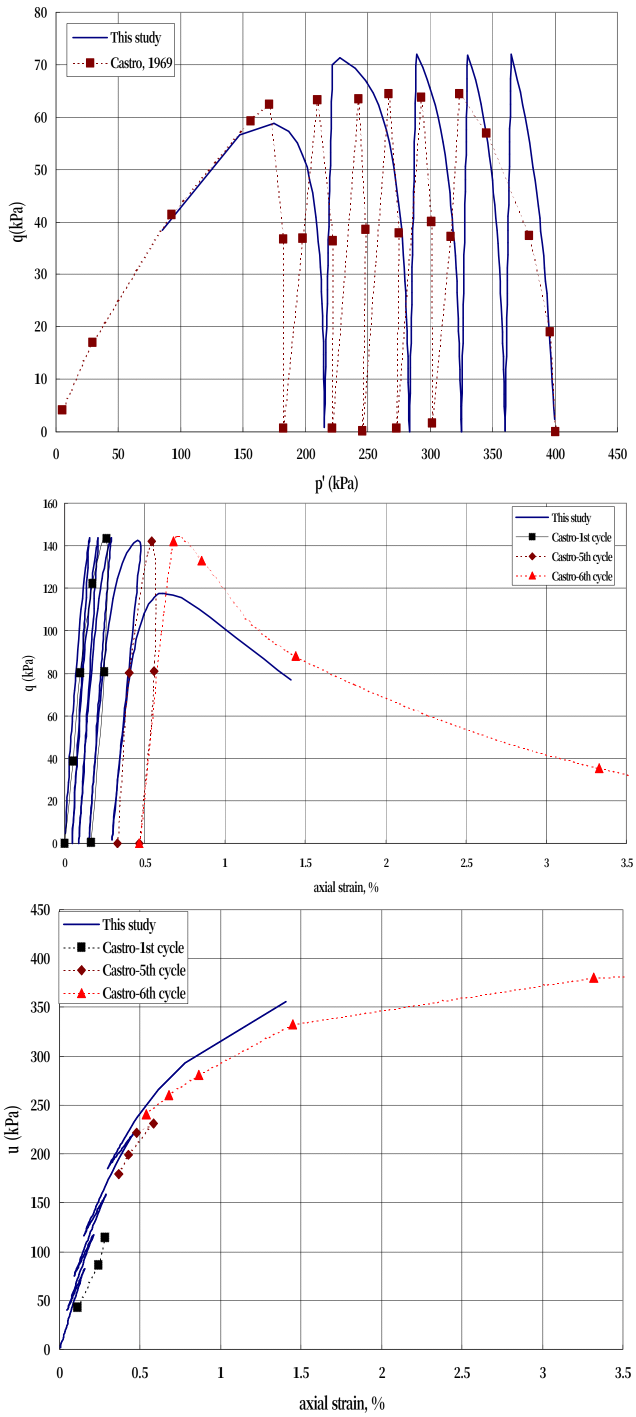

Figure 2 Numerical simulation of half –cycle stress controlled cyclic test (Dr=27%) - (a) q vs. p'; (2) q vs. axial strain; (3) u vs. axial strain

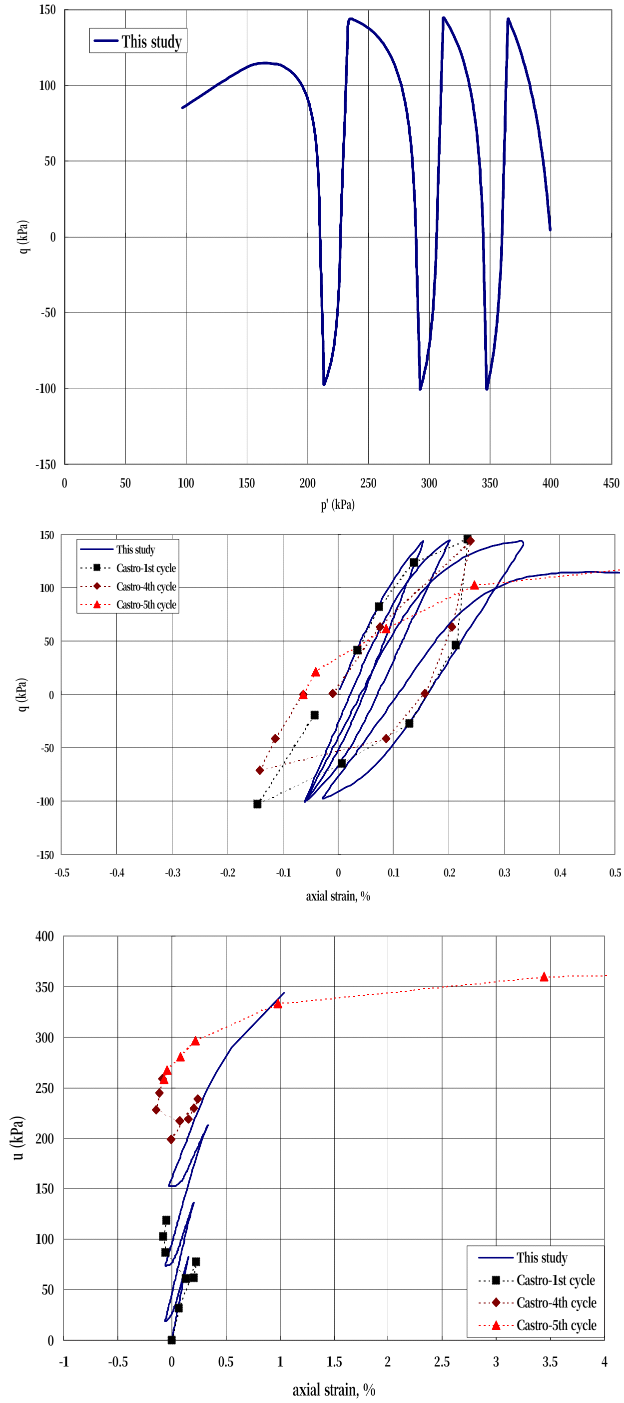

Figure 3 Numerical simulation of full-cycle stress controlled cyclic test (Dr=27%) - (a) q vs. p'; (2) q vs. axial strain; (3) u vs. axial strain

pressure build up. Figure 5 presents the results of a strain-controlled cyclic simple shear tests. The stiffness of the sample reduced dramatically due to the quick pore pressure buildup. That leads to the effective confining pressure to be close to zero and the sample liquefied. The present simulations results compared well with an independent implementation by Li using SUMEDES(Lin et al., 2003).

4. Conclusions

1.This study selected the generalized plasticity model as a core for forming an analysis tool because the model is simple and yet is capable of duplicate essential soil behavior. This study showed that the implementation within FLAC did successfully simulate the classic laboratory monotonic and cyclic tests conducted by Castro. The simulation carried out did capture the crucial features of soil behavior during cyclic loading, such as progressive softening of soil stiffness with increasing pore pressure, stress-dilatancy during shear, critical state deformation for very loose sand, hysteretic loops for energy dispassion, just to name a few. This provides credence for employing this approach for further applications.

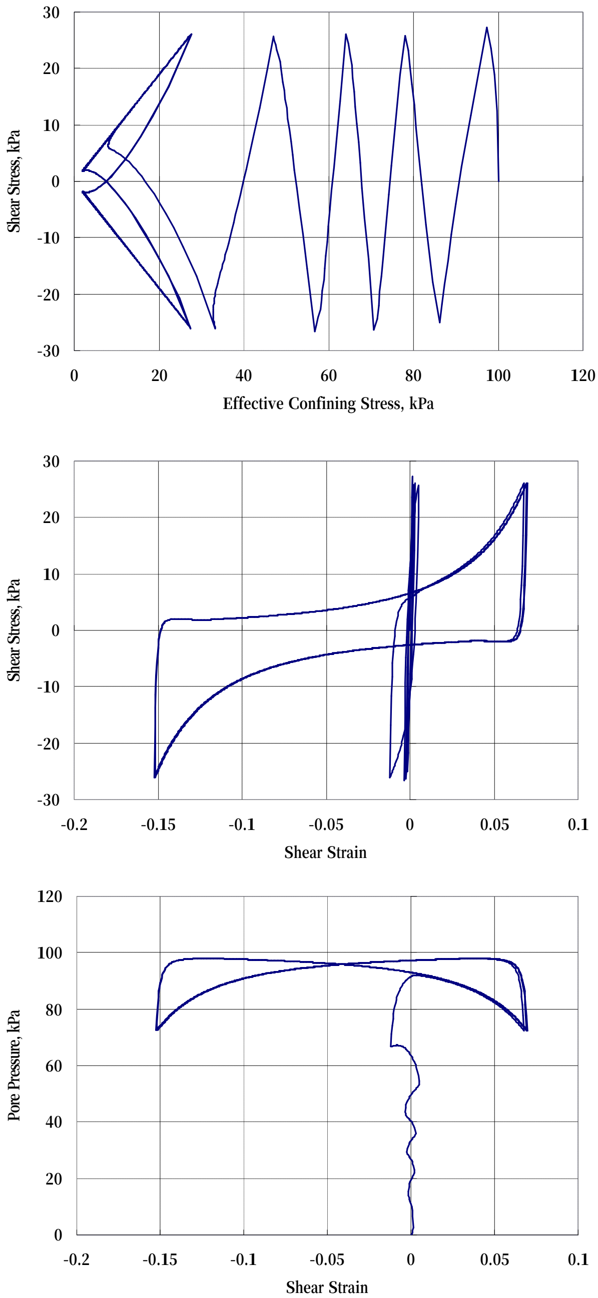

Figure 4 Simulation of simple shear with stress control using FLAC

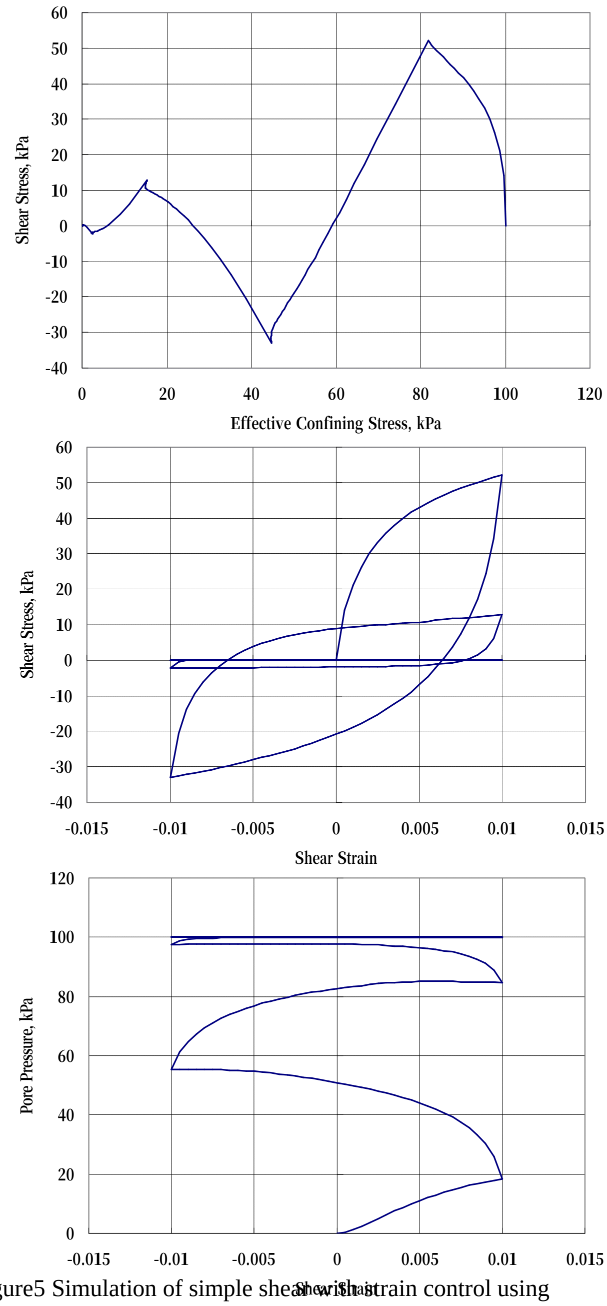

Figure5 Simulation of simple shear with strain control using FLAC

2.Limited simulation was also carried out in FLAC using hypoplasticity bounding surface model developed by Wang (1990). It appears that the implementation also generates essential soil characteristics, although verification against laboratory test data is yet to be carried out.

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