VELACS Project: A SUMMARY OF ACHIEVEMENTS

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ABSTRACT

In a collaborative and unprecedented effort, seven major universities from United States and England studied the liquefaction phenomena and its consequences by conducting extensive centrifuge tests on nine carefully selected centrifuge models. In addition, more than 20 groups of researchers from all over the world participated in a Class-A prediction exercise to predict the response of centrifuge models before they were conducted. This paper summarizes the lessons learned from the VELACS project in relation to repeatability of centrifuge models and performance of the existing numerical procedures in analyzing soil liquefaction and its consequences.

INTRODUCTION

The VELACS project (VErification of Liquefaction Analysis using Centrifuge Studies) was a collaborative effort among seven universities: University of California, Davis; California Institute of Technology; Cambridge University; University of Colorado, Boulder; Massachusetts Institute of Technology; Princeton University; and Rensselaer Polytechnic University. The project was the most extensive effort ever undertaken to determine the mechanisms involved in liquefaction, and to evaluate the consequences of soil liquefaction. Nine significant boundary value problems were modeled and tested at different centrifuge facilities, including uniform level ground, stratified layers, heterogeneous embankments, waterfront structures, and a soil structure interaction problem. More than twenty groups from different parts of the world, including USA, England, France, and Japan participated in the Class A prediction exercise which "predicted" the responses of the centrifuge models. The results of experimental studies as well as the Class A predictions are reported in the first volume of the Proceedings of the VELACS International Conference held from October 17 to October 20, 1993 at the University of California, Davis. In addition, an extensive series of overview papers, discussing different aspects of the centrifuge tests and the Class A predictions, was presented in the VELACS conference. A Second Volume of conference proceedings containing these papers will be published in September of 1994.

ACHIEVEMENTS OF THE VELACS PROJECT

Some of the primary technical conclusions of the VELACS project are summarized below.

1. Centrifuge modeling was found to be a reliable tool for studying the mechanisms of soil behavior in boundary value problems. It can produce repeatable results in different facilities provided that the centrifuge modelers follow a unified method of model preparation, and that the centrifuge facilities are capable of producing simulated earthquake motions consisting of a wide range of frequencies (See for example the results of Models 1, 2, 4a and 4b in the VELACS proceedings, Vol. 1, edited by Arulanandan and Scott, 1993; Also see Figures 1 to 5 which show the model configuration, planned base motion, and partial results for model 4-a). However, the effect of the frequency characteristics of the shaker, the boundary effects of the model container, and the minimization of undesirable effects such as unwanted vertical base motions should be thoroughly studied in future applications of centrifuge modeling. Figures 7 to 9 show the model configuration, and difficulties in achieving repeatable results in model 7 of the VELACS project

2. The existing numerical procedures for soil liquefaction analysis are generally effective in simulating the onset of liquefaction in contractive cohesionless soils. However, a wide range of differences exist in the predictions of liquefaction induced deformations made by different procedures. (See for example the lateral displacements predicted by different groups for Model #2. It ranges from less than 10 cm to more than 80 cm, while the measurements showed a maximum of 40 cm - see VELACS Proceedings, Vol. 1, 1993) Comparison of the results reported by different predictors with the experimental results shows that fully coupled effective stress based procedures which utilize plasticity based constitutive model are more promising for the prediction of deformation than partially coupled procedures or total stress based procedures which utilized empirical relationships to correlate pore pressure generation with the volumetric soil strain (see for example the predictions reported in pages 153-168 of the VELACS proceedings, Vol. 1). The VELACS Class A predictions revealed that the latter procedures may also produce unrealistic trends of deformation for contractive soils during the shaking phase (See for example Figs. 25-30, pp. 243--245 and Figs. 16-20, pp. 407-410, VELACS Proceedings, Vol. 1, 1993; Also see Figures 10 to 12 which show the model configuration, planned base motion, the recorded acceleration and pore pressure time histories, and the predicted time histories of the vertical settlement in model no. 1 of the VELACS project.

3. All the available numerical procedures are generally deficient and inadequate in simulating the behavior of dilative soils. A close examination of the Class A predictions reported by four different groups of predictors for the VELACS Model #6 (a heterogeneous embankment consisting of a relatively dense sand core overlain by a silt layer) reveals that predictions of pore water generation in the sand core generally do not agree with the experimental results (see predictions reported in pp. 773 and 779 compared to those reported in pp. 741-742 of the VELACS proceedings, Vol. 1, 1993). Such a discrepancy between numerical simulations and experimental results is expected since the existing constitutive models used to simulate the cyclic behavior of dense sands are inadequate.

4. One of the major lessons learned form the VELACS project is in any effective stress based procedure, the constitutive model plays a key role in the analysis of soil liquefaction and deformation. A comparison of the different predictions made by effective stress based procedures in the VELACS Class A prediction exercise shows significant differences in the predictions made with only slightly different u-p or u-U formulations. (See for example, the predictions reported in pp. 745-765 compared to the predictions reported in pp. 777-779, VELACS Proceedings, Vol. 1, 1993). These differences may have been caused by many factors, including

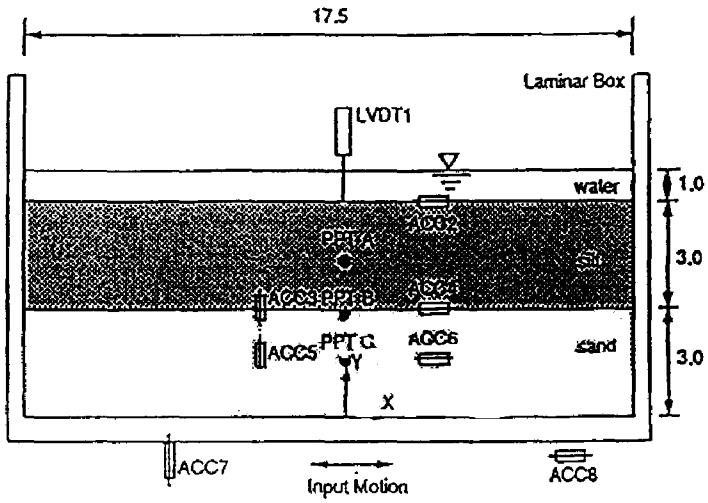
a) The inability of existing models to simulate the stress-strain response of non-cohesive soils for different stress (or strain) paths using a unique set of parameters. In most of the models, a compromise is made in choosing an average set of parameters which should most closely represent the stress path in the boundary value problem. When using this calibration procedure, considerable engineering judgement is required. In general, predictors try to get the best fit to laboratory tests. However, the lack of a standardized procedure for achieving the "best fit" results in various sets of material parameters, even for those using the same constitutive model to predict the same problem. (See for example the calibrated parameters for one of the constitutive models used by two different groups in the VELACS Class A predictions; pp. 187 and 248 in the VELACS proceedings, Vol. 1). The major reason for the use of different calibration procedures is that the models are not capable of producing reasonable simulations for different stress paths and different relative densities in non-cohesive soils. Therefore, predictors try to get the best out of a deficient model by using their previous experience in the application of the model to other boundary value problems. Evidently, difference in experiences will result in differences in calibrated parameters.

b) Different methods have been used to implement the plasticity based models in the computer codes. The accuracy and stability of these methods has not been thoroughly studied. A close examination of the published materials on the constitutive models used in the VELACS project reveals that most of the constitutive equations are integrated using conventional integration procedures for general plasticity models. In most cases, the special features of the constitutive models used for non-cohesive soils such as the pressure-dependent moduli have not been adequately accounted for in the integration procedure. Recent studies (Borja, 1991) show that even in the case of the simplest soil plasticity model (modified cam clay) special treatments are necessary if accurate and reliable results are to be obtained.

REFERENCES

Arulanandan, K. and Scott, R. F. (1993), "Verification of Numerical Procedures for the Analysis of Soil Liquefaction Problems." Proceedings of the International Conference on the Verification of Numerical Procedures for the Analysis of Soil Liquefaction Problems, held at the University of California, Davis on October 17 to 21, 1993. Balkema Press, Rotterdam.

Borja (1991), "Cam Clay Plasticity. 2., Implicit Integration of Constitutive Equation Based on a Nonlinear Elastic Stress Predictor." Computer Methods in Applied Mechanics and Engineering, Vol. 88, No 2, pp. 225-240, July.



Coordinates of transducers unit: m							
transducer	X	Y	Z	transducer	X	Y	Z
ACC2	2.54	6.00	0.00	ACC8	6.35	-0.63	0.00
ACC3	-2.54	3.00	0.00	PPT A	0.00	4.50	0.00
ACC4	2.54	3.00	0.00	PPT B	0.00	2.90	0.00
ACC5	-2.54	1.50	0.00	PPT C	0.00	1.50	0.00
ACC6	2.54	1.50	0.00	LVDT1	0.00	5.00	3.00
ACC7	-6.35	-0.63	0.00				

Fig. 1 Cross-sectional view of the centrifuge model no. 4a of the VELACS project.

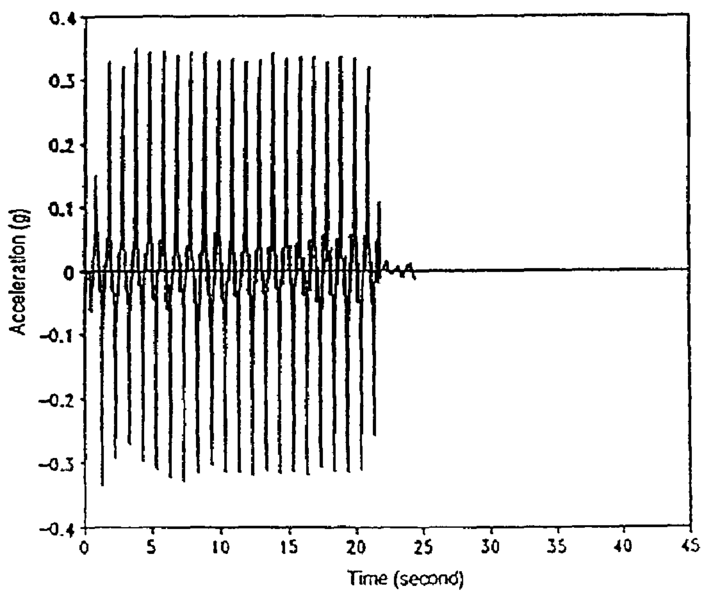


Fig. 2 Planned horizontal input motion for model no. 4a of the VELACS project

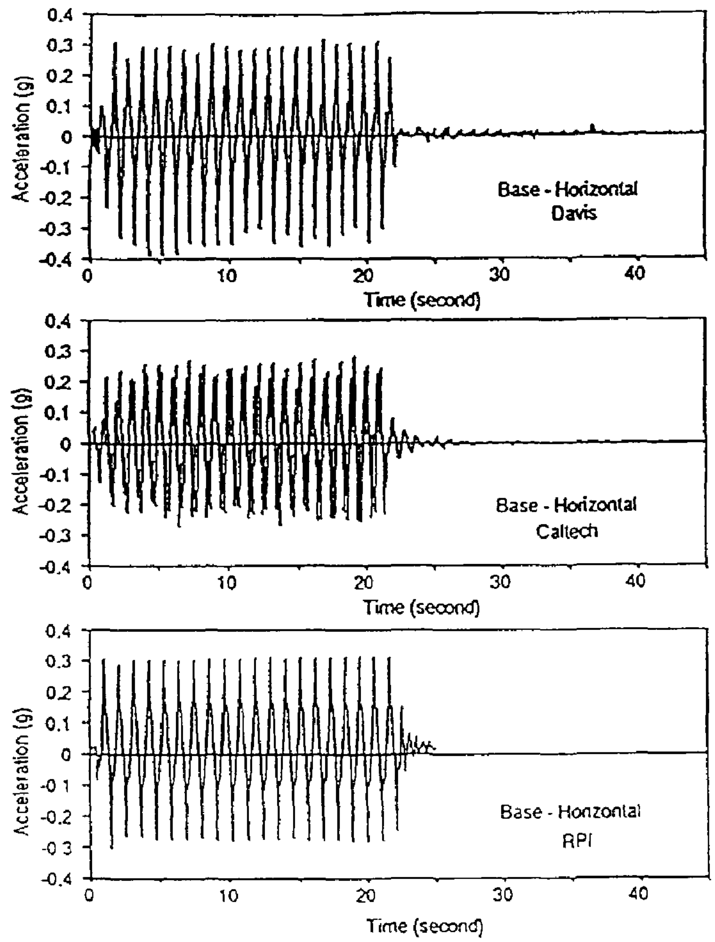


Fig. 3 Horizontal achieved input motion of model no. 4a of the VELACS project.

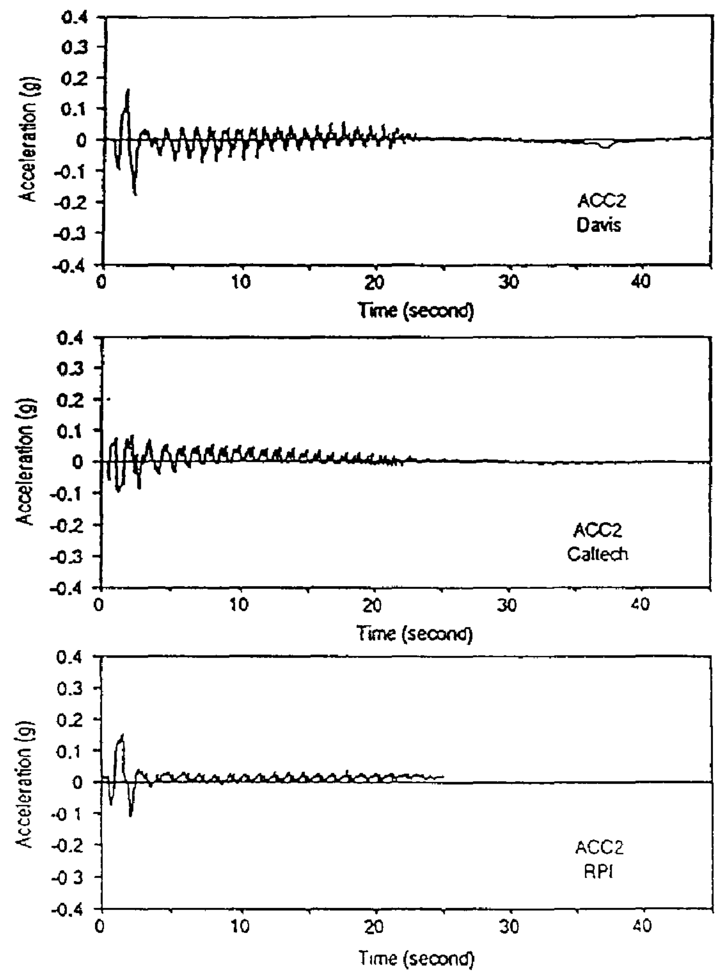


Fig. 4 Horizontal acceleration recorded at the surface, model 4a of the VELACS project

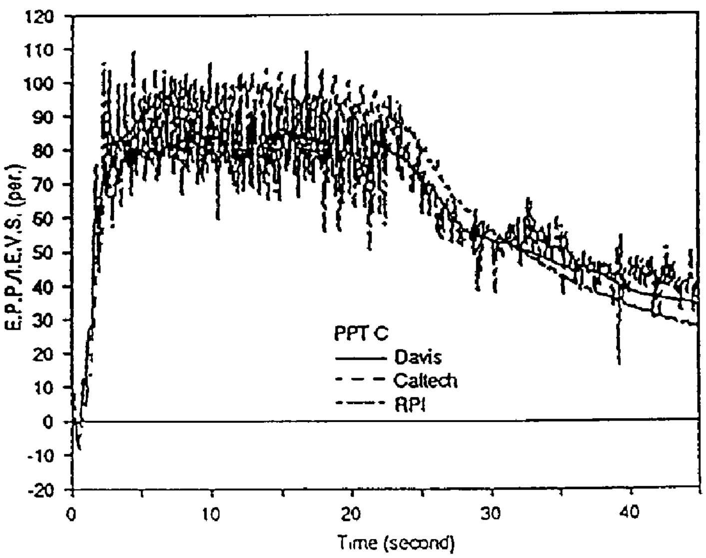


Fig. 5 Excess pore pressure measured at mid-depth of sand layer, model 4a of the VELACS project.

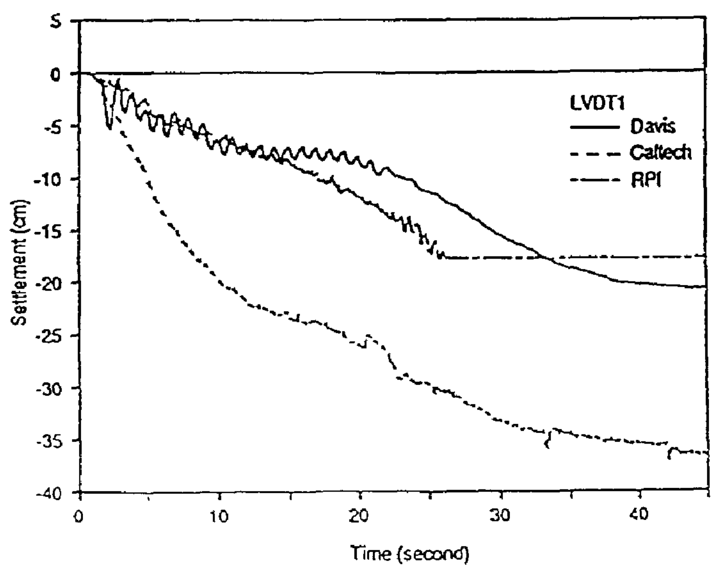
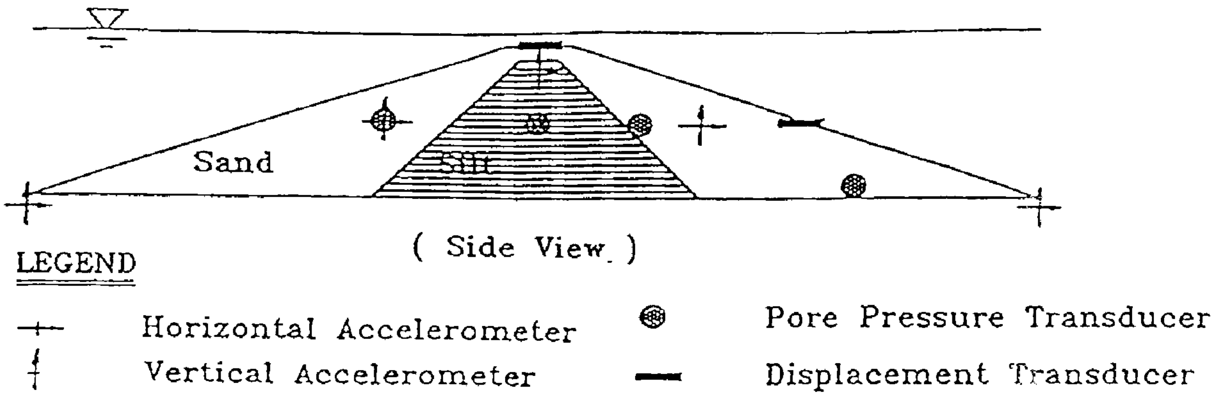
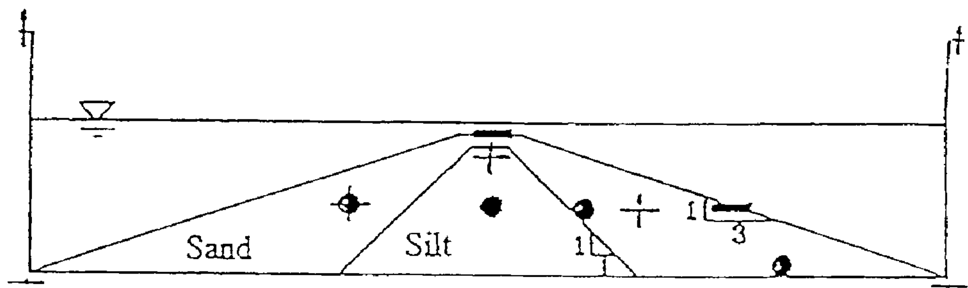


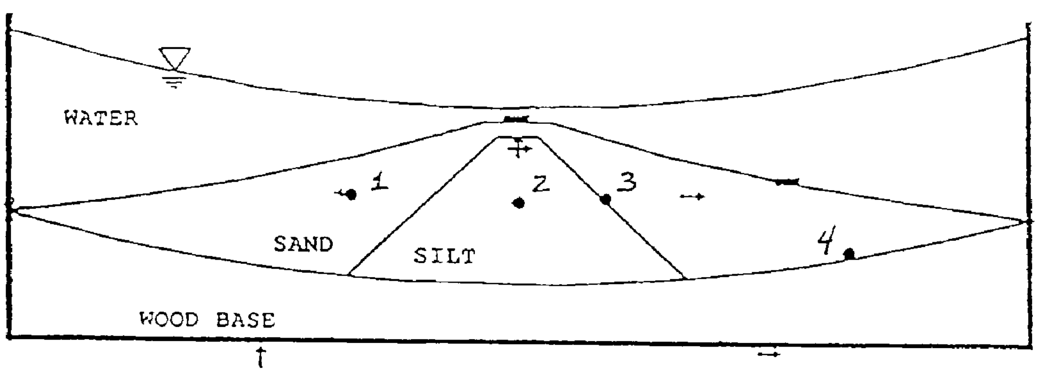
Fig. 6 Settlement of the silt surface, model 4a of the VELACS project



a: Model #7 configuration at CU
(from Astaneh et al. (1993))



b: Model #7 configuration at RPI
(from Adalier et al. (1993))



c Model #7 configuration at UCD

Fig. 7 Cross-sectional view of the centrifuge model no. 7 as constructed at different facilities in the VELACS project

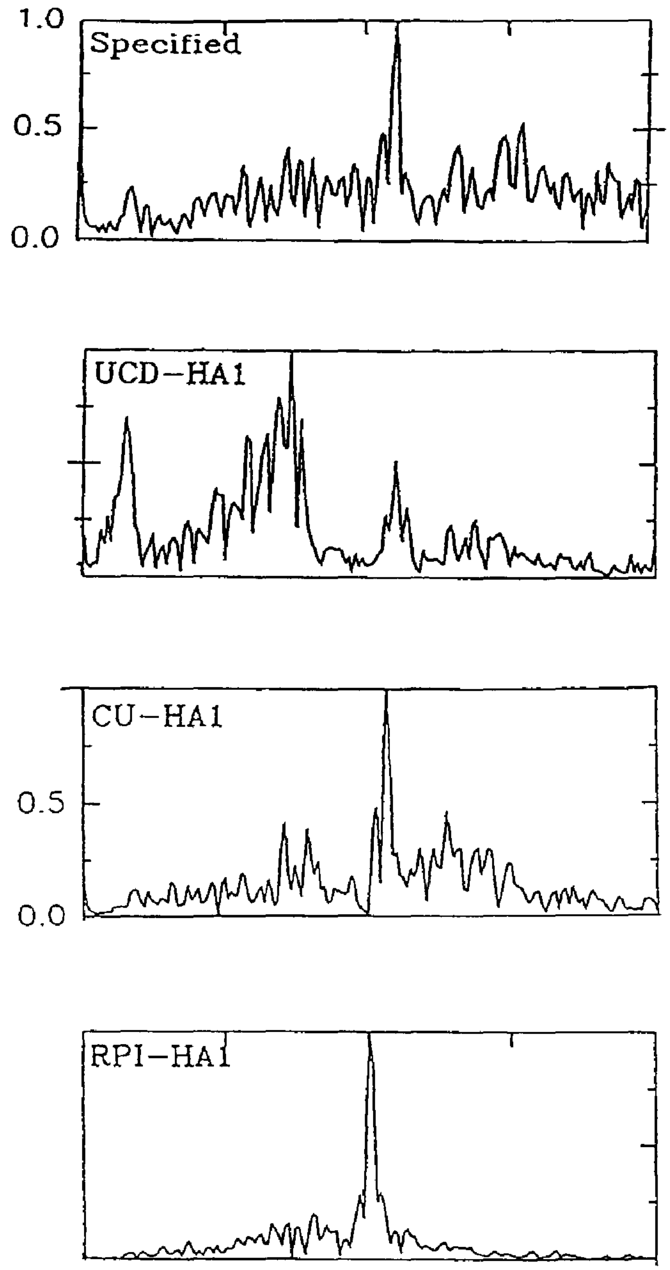


Fig. 8 Fourier spectrums of the achieved base motion at different facilities for model no. 7 of the VELACS project.

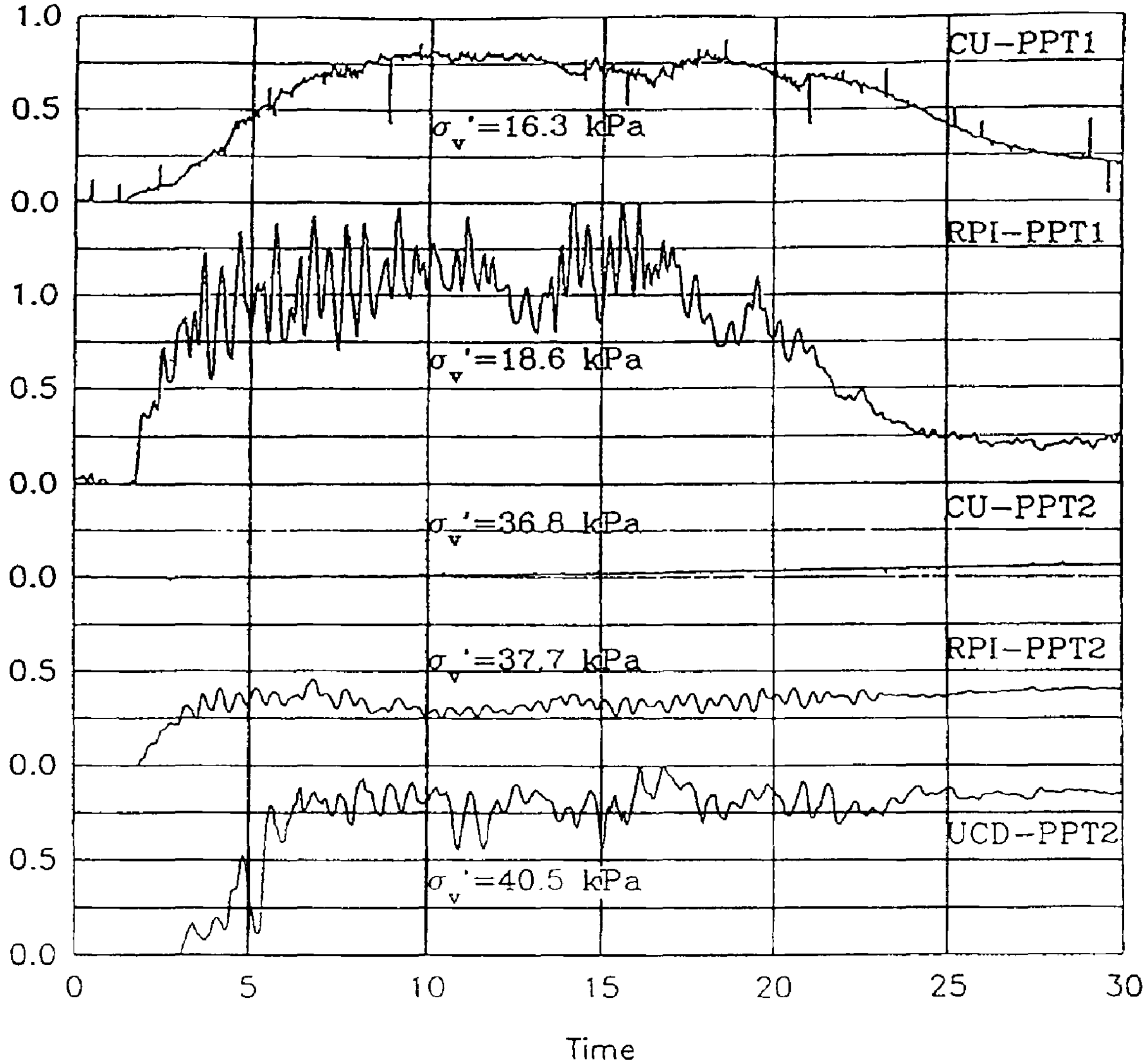
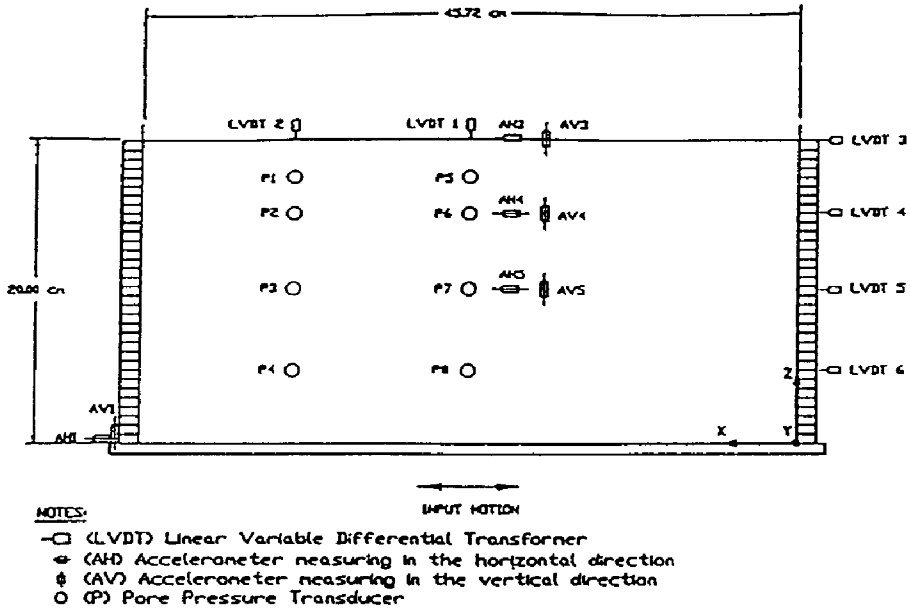
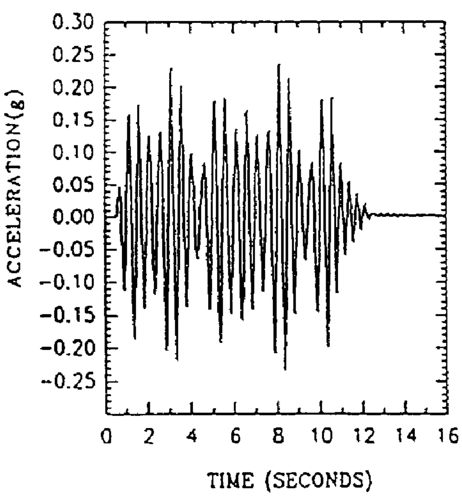


Fig. 9 Normalized excess pore pressure measured at different centrifuge facilities for model no. 7 of the VELACS project.

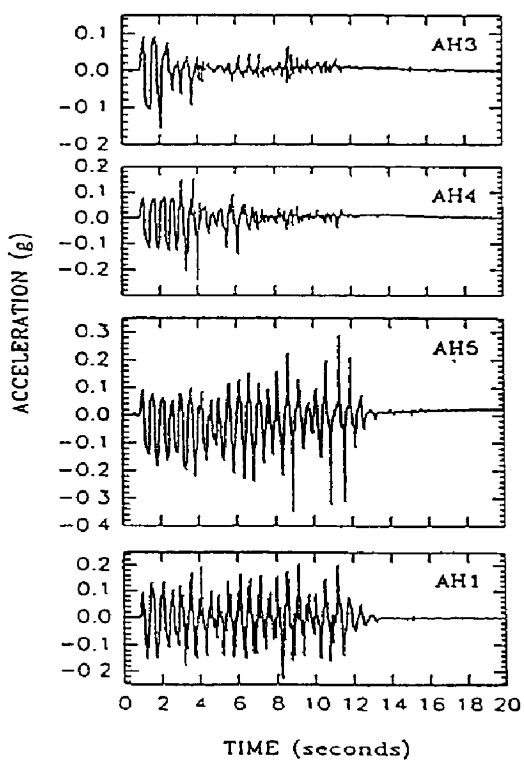


SIDE VIEW OF MODEL No. 1

R.P.I. Laminar Box and Model No. 1.

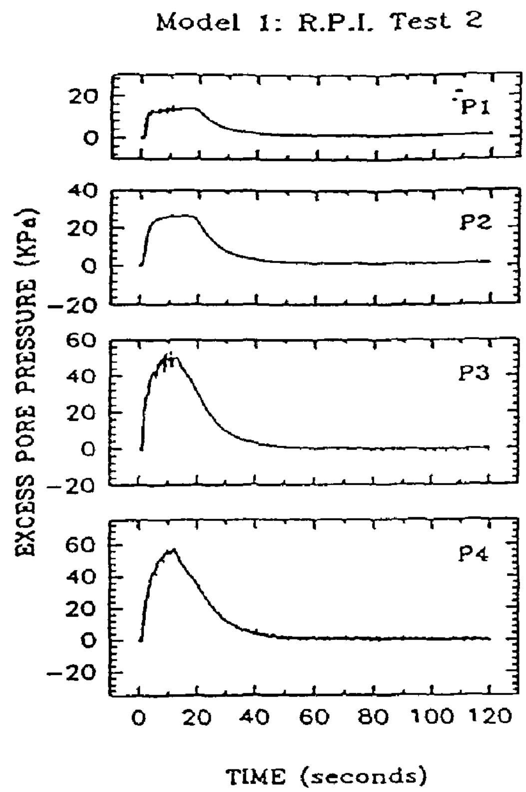


Prototype Horizontal Input Acceleration Proposed for Model No.1.

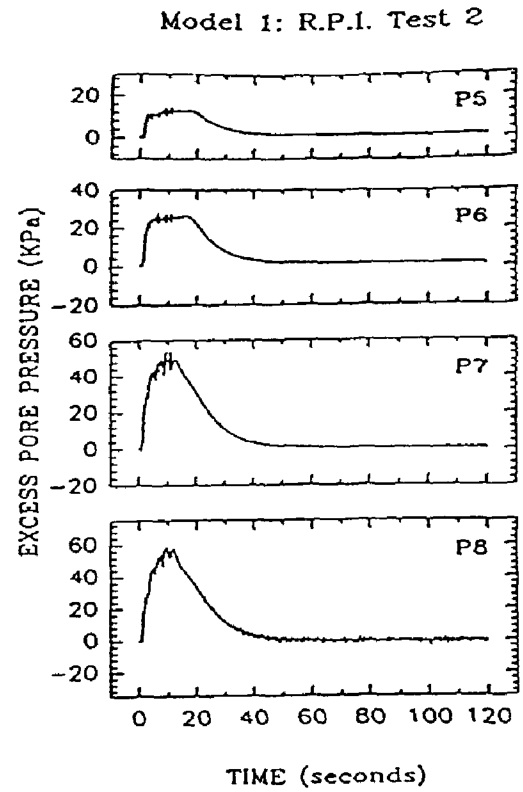


Plot Group 4, Horizontal Accelerations AH1-AH5.

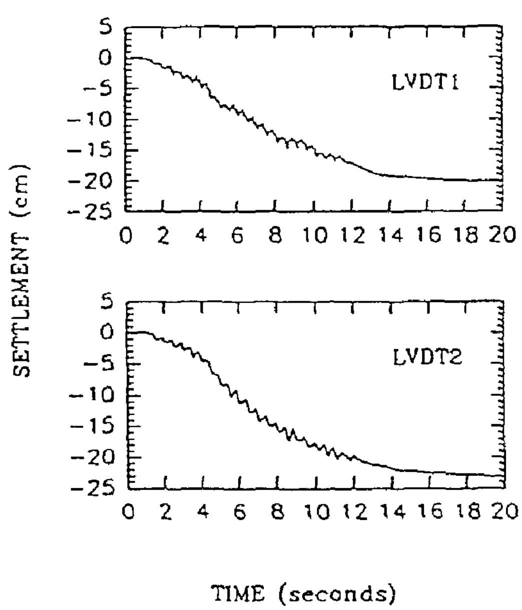
Fig. 10 Model Configuration, planned base motion, and some measured acceleration time histories for model #1 of the VELACS project.



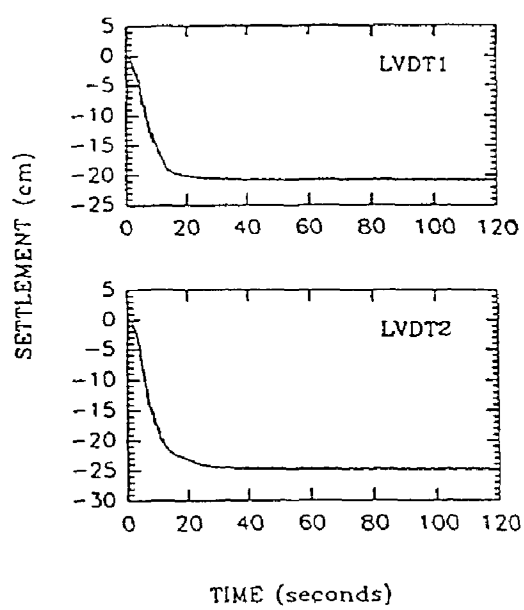
Plot Group 1, Long Term Excess Pore Pressure Histories of P1-P4.



Plot Group 1, Long Term Excess Pore Pressure Histories of P5-P8.

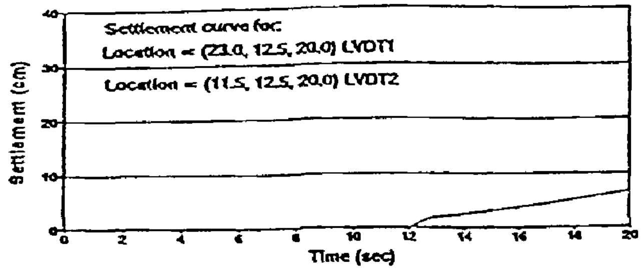


Plot Group 5, Short Term Vertical Settlements of Ground Surface.

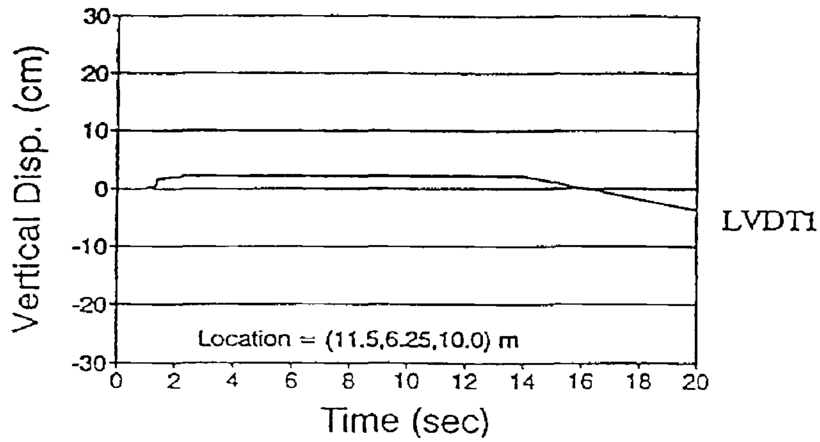


Plot Group 6, Long Term Vertical Settlements of Ground Surface.

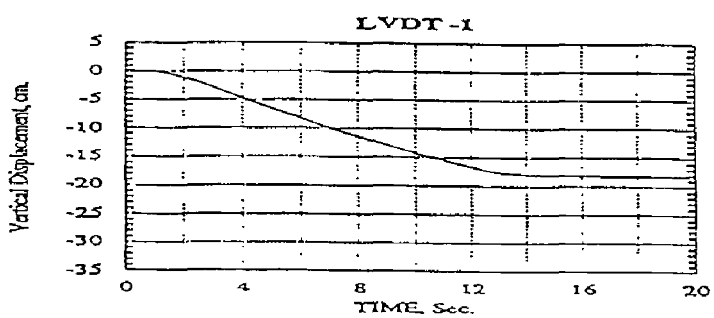
Fig. 11 Pore pressure time histories and vertical displacement time histories for model no. 1 at RPI.



Total Stress or Uncoupled Results:



Partially Coupled Results:



Fully Coupled Results:

Fig. 12 Predictions for contractive soils (Model no. 1 of the VELACS project)