CONSTRUCTION OF STRESS-STRAIN HISTORIES FROM RECORDED DYNAMIC RESPONSE

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ABSTRACT

Instrumented centrifuge laminated box experiments generate acceleration and LVDT displacement histories along the model height. These histories are employed to directly construct the associated dynamic stress-strain histories. Soil shear response at different elevations is explored. Soil strength during liquefaction and lateral spreading is revealed at different elevations along the model height.

INTRODUCTION

Centrifuge dynamic testing offers a highly controlled laboratory environment for exploring soil response. In a laminated soil container, histories of acceleration, LVDT displacements, and pore-pressures are conveniently recorded along the model height. These records constitute the dynamic response of a one-dimensional (1D) shear beam. Through this shear beam idealization, the associated stress-strain histories can be directly constructed from the recorded acceleration and displacement histories. The involved procedure is described below. This procedure was originally developed (Elgamal and Zeghal 1992, Zeghal and Elgamal 1993, 1994a, 1994b, Elgamal *et al.* 1994) to analyze downhole records at Lotung, Taiwan; at Wildlife refuge site, CA (Figure 1); and for VELACS (Arulanandan and Scott 1993) centrifuge experiments (Taboada and Dobry 1993a, 1993b).

TEST SETUP

An instrumented laminar box is shown in Figure 2 (Gutierrez *et al.* 1994). As shown, the histories of displacement are recorded along the outer side of laminates. In this test, a loose saturated layered soil stratum was built of silty sand (7 % silt). Each layer was constructed by pluviation under water, and consolidated before building the next (hydraulic fill method with water employed as pore fluid). The test was conducted at a centrifugal acceleration of 50 gravities. Before shaking, the model was tilted by about 0.2° to the horizontal in order to simulate the response of a mildly sloping infinite slope. Histories of recorded acceleration and displacement are shown in Figures 3 and 4.

CONSTRUCTION OF SHEAR STRESSES AND STRAINS

Displacement histories yield shear strains through the simple expression

$$\gamma_i(t) = \frac{d_i(t) - d_j(t)}{h_{ij}} \tag{1}$$

where $\gamma_i(t)$ is average shear strain history within the layer bound by LVDTs i and j, $d_i(t)$ is displacement history at station i, and h_{ij} is spacing between stations i and j. Strains derived from accelerations (i.e., using d_i obtained by double integration of acceleration a_i) were superposed on lateral permanent drift traces recorded by the LVDTs at each elevation of interest. The corresponding stress history at any elevation is obtained by (Elgamal *et al.* 1994, Zeghal and Elgamal 1994b): *i*) integrating the acceleration records along the height from the surface downwards, up to the desired elevation, and *ii*) multiplying by the soil mass density.

RESULTS

The stress-strain histories constructed from Figures 3 and 4 are shown in Figure 5. Inspection of these histories reveals:

1- The soil liquefied, and the upper layers became progressively isolated from additional dynamic excitation.

2- Lateral strains are observed to gradually accumulate in the downslope direction during each additional loading cycle. Permanent strains were concentrated within the elevation range of 7 m- 9.5 m below ground surface.

2- Upon liquefaction, and before isolation, a level of strength associated with yielding may be inferred from cyclic loading during the time frame 1 s-2 s. These strength values are listed in Table 1 for selected elevations along the height.

SUMMARY AND CONCLUSIONS

A laminated container testing technique combined with a simple methodology for constructing the involved stress-strain histories was presented. Valuable information is directly extracted concerning soil stiffness and strength during liquefaction along the soil layer height. This information is of direct practical importance, and is also particularly valuable for validating simplified as well as elaborate computational procedures. Finally, the reported testing and analysis techniques constitute a basic methodology for evaluation of cyclic soil response; and offer a compliment to conventional shear and triaxial testing. The involved effort and expense is similar to that involved in these conventional tests.

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Table 1: Variation of yield strength with depth.

Depth (m)	σ'_v (kPa)	τ_{yield} (kPa)	τ_{yield}/σ'_v
1.625	18.03	1.0	0.055
3.625	37.70	2.0	0.053
5.125	50.50	2.1	0.042
6.375	62.85	4.0	0.064
8.125	79.63	12.0	0.151
9.250	89.00	22.0	0.247

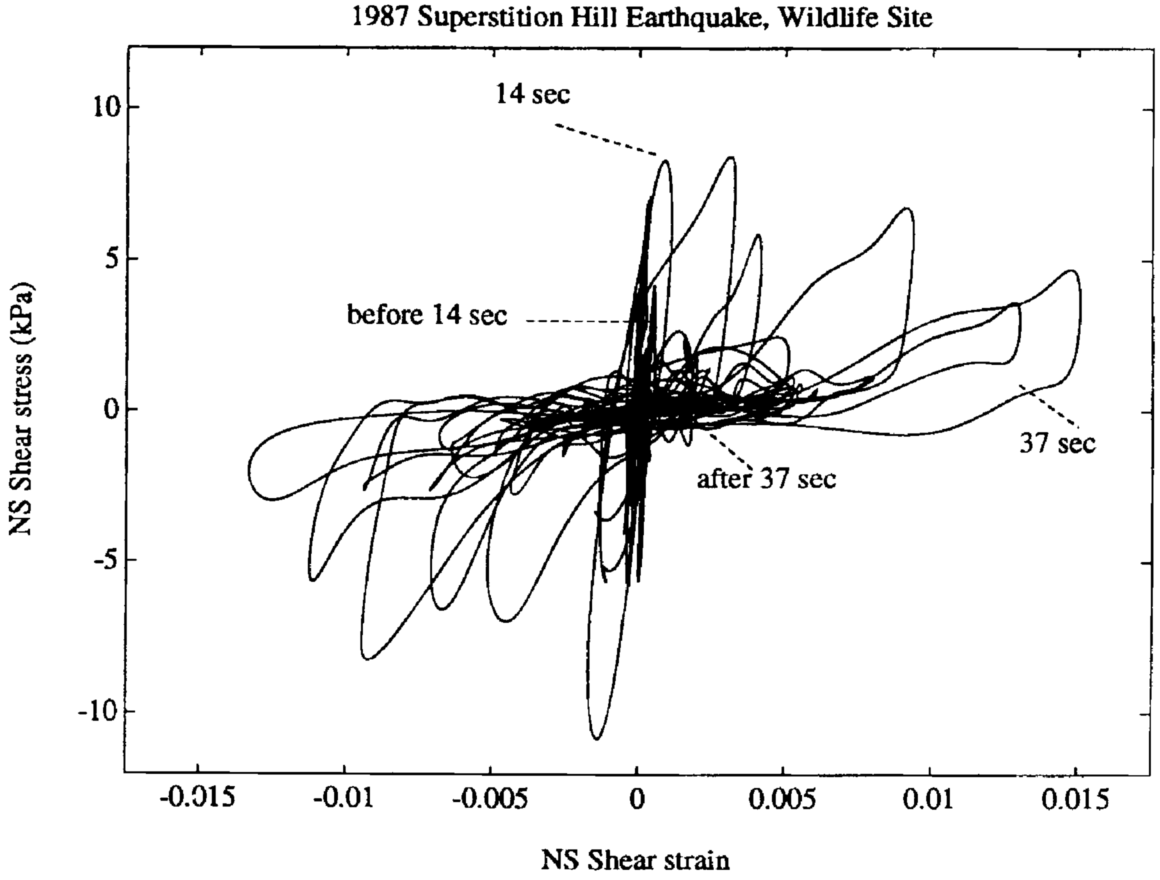

Figure 1: Shear stress strain history at the Wildlife refuge site during liquefaction (Elgamal and Zeghal 1992, Zeghal and Elgamal 1994).

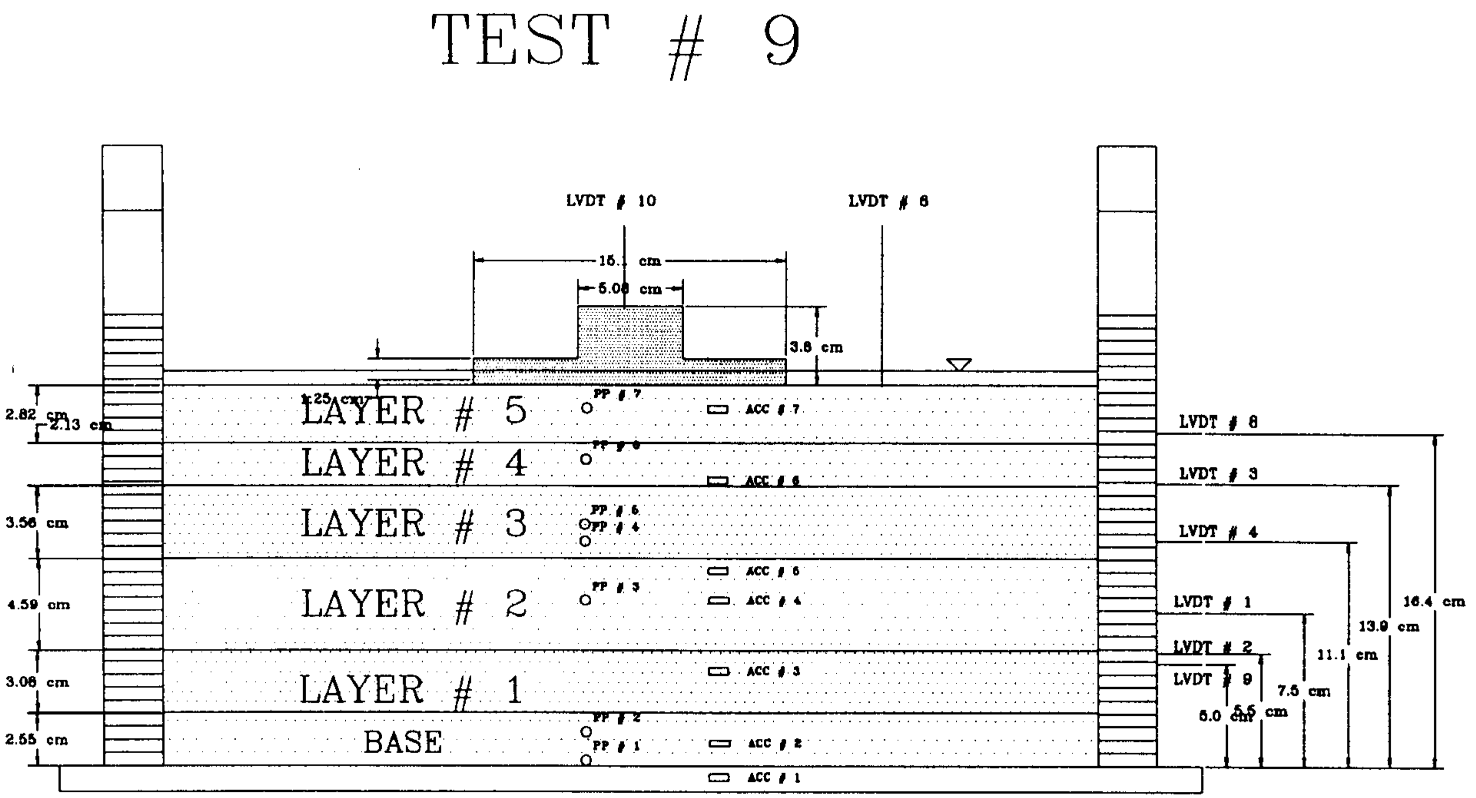

Figure 2: Test setup: soil profile and instrumentation (dimensions given in model scale).

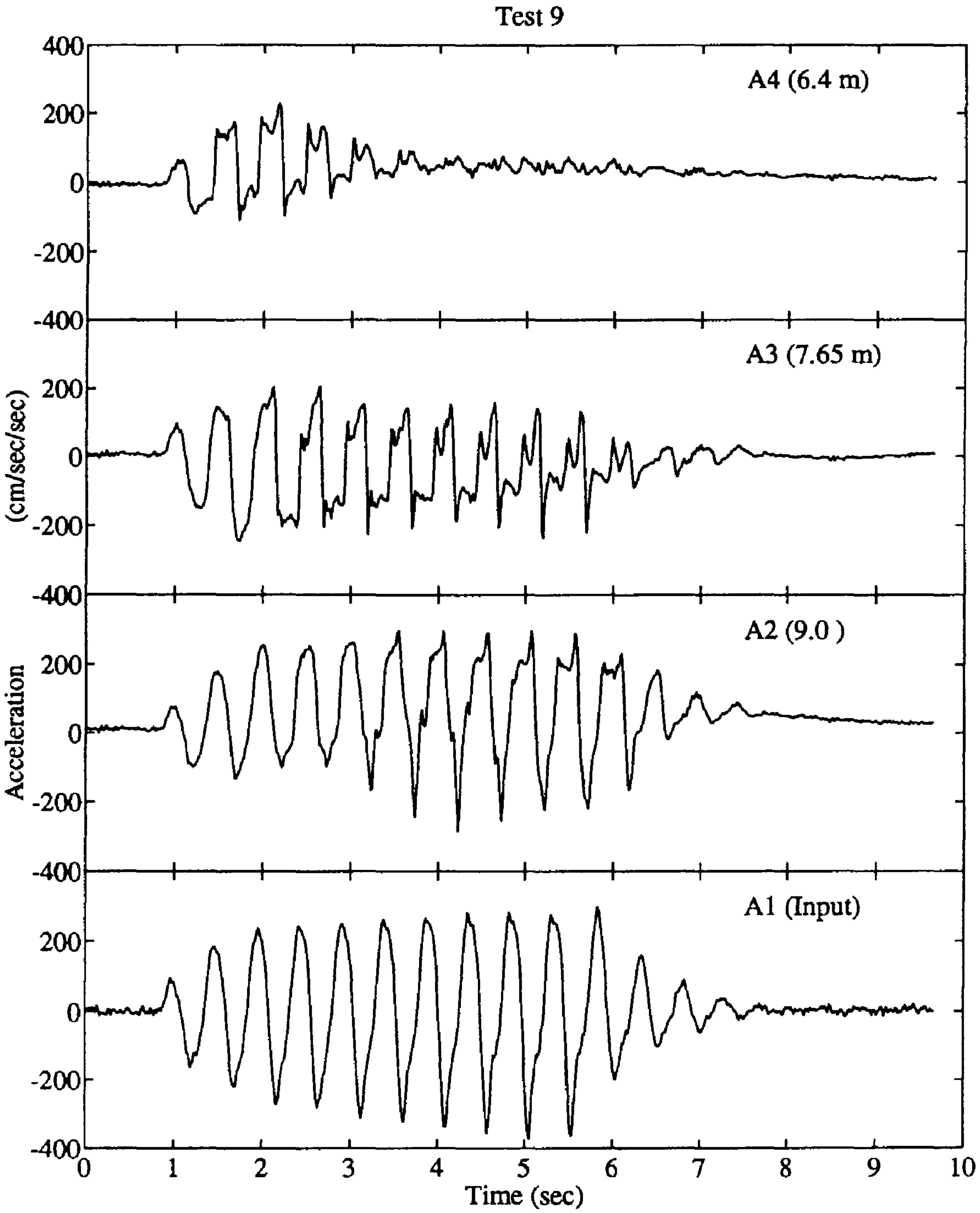

Figure 3: Acceleration histories at 6.4 m depth, 7.65 m depth, 9.0 m depth, and input acceleration history (prototype scale).

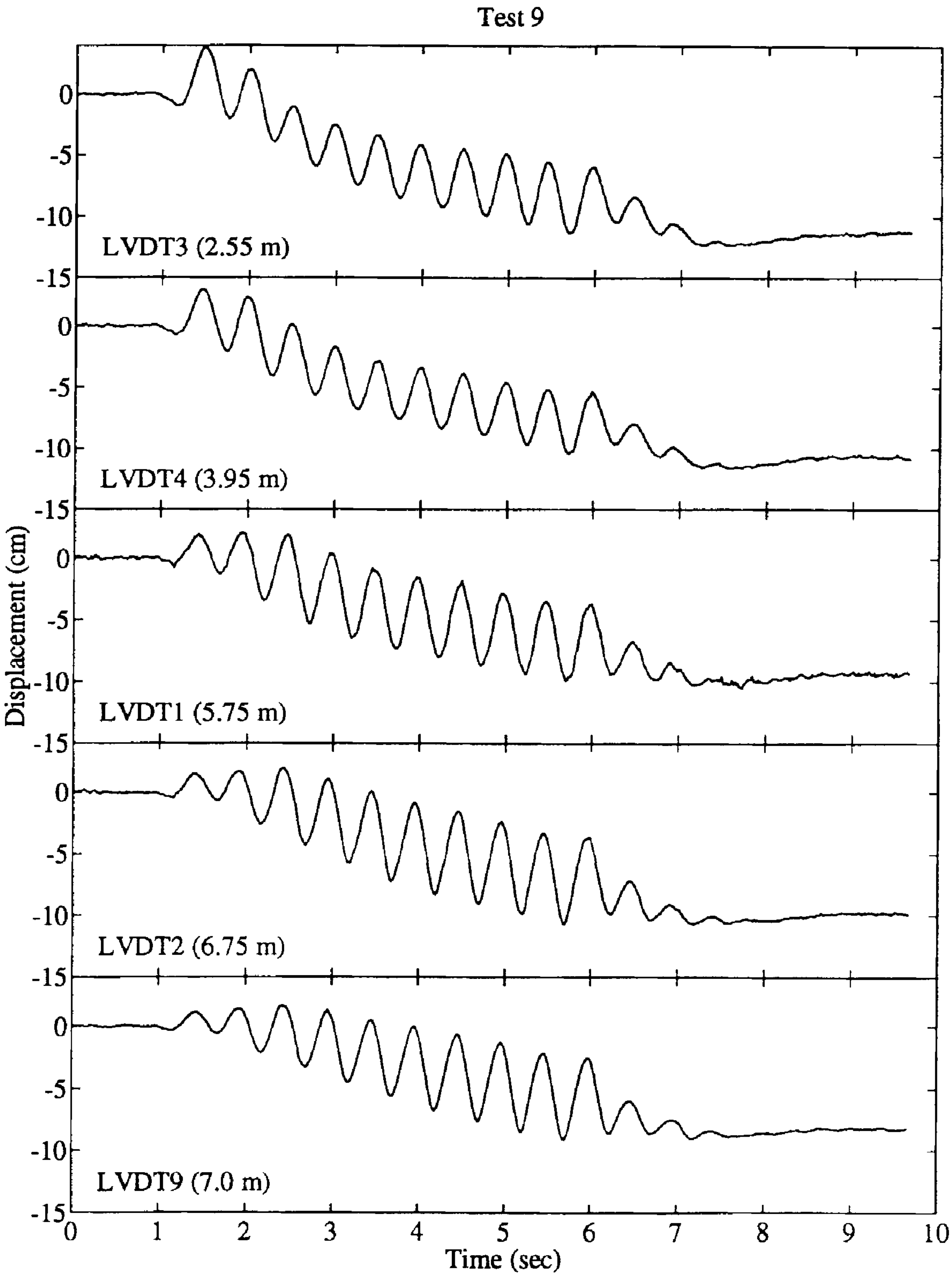

Figure 4: Displacement histories at 2.55 m depth (LVDT3), 3.95 m depth (LVDT4), 5.75 m depth (LVDT1), 6.75 m depth (LVDT2), and 7.0 m depth (LVDT9); prototype scale.

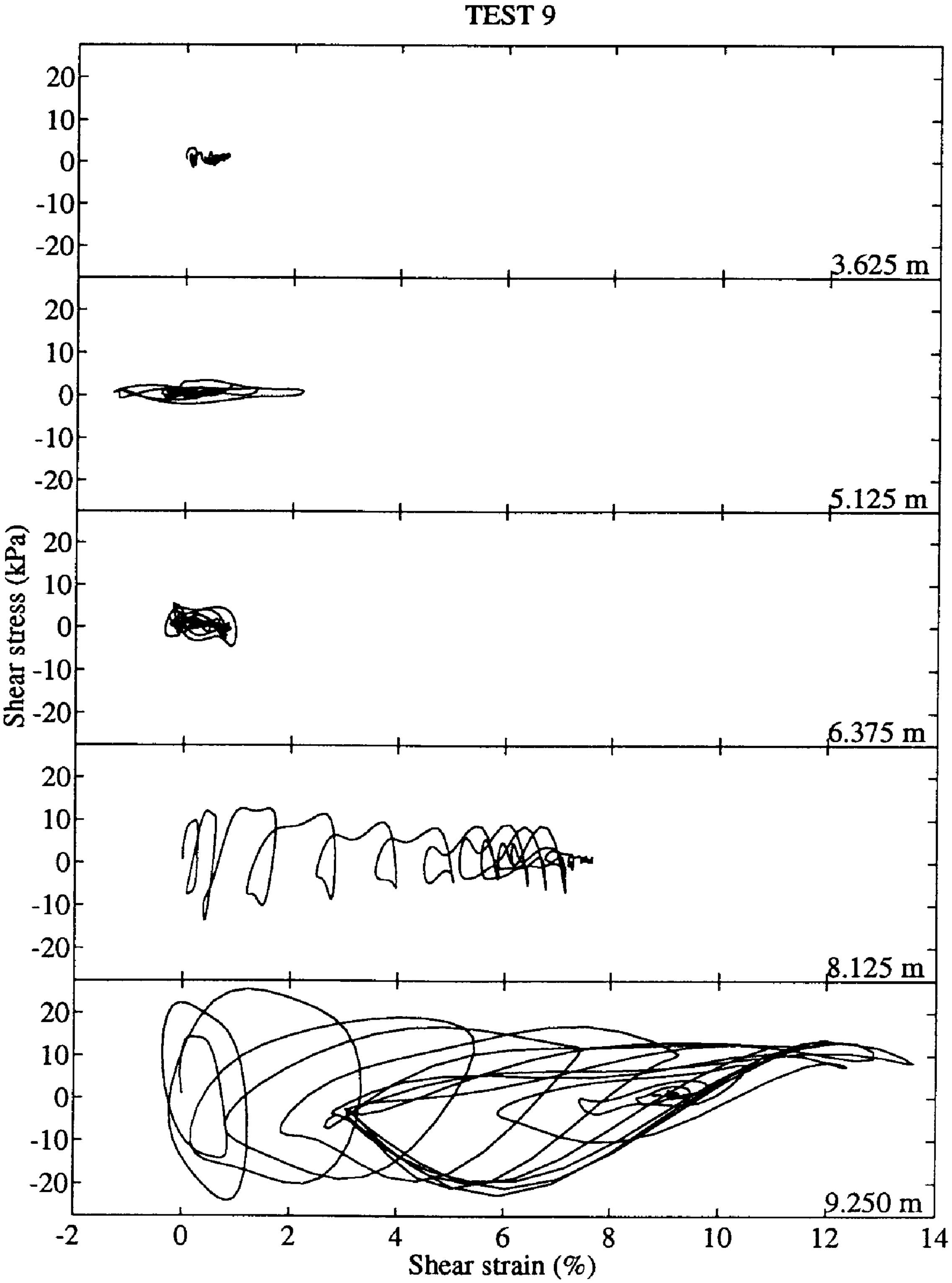

Figure 5: Shear stress-strain histories at 3.625 m depth, 5.125 m depth, 6.375 m depth, 8.125 m depth, and 9.250 m depth (prototype scale).