CONSTRUCTION RELATED VIBRATIONS

by

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16. Abstract
The objective of this research project was to develop a procedure for evaluating soil response to construction induced vibrations. The settlement potential of 33 specimens of residual soil obtained from 8 different sites was evaluated by resonant column and torsional shear tests. These tests included an evaluation of the effect of confining pressure from 25 kPa to 100 kPa, shear strain amplitude from $1 \times 10^{-4}\%$ to $1 \times 10^{-1}\%$, frequency of vibration from 0.2 to 10 Hz and number of cycles up to 1 million on the dynamic densification of residual soils. This research also studied the influence of confining pressure, shear strain amplitude, and number of cycles on the shear modulus and damping ratio of residual soil specimens. The dynamic settlement of the residual soils tested was observed to be small, especially in comparison to that reported in the literature for sands. The following general trends were observed:

(a) Dynamic settlement was greatest for the most granular specimen with decreasing settlement associated with increasing fines content;
(b) Dynamic settlement decreased with increasing confining pressure; and,
(c) Dynamic densification of residual soils increased with increasing shear strain amplitude. Further, the results of the cyclic torsional shear test on residual soils tested showed that the threshold shear strain, that value below which there is essentially no volume change, is in the range of 0.005% to 0.01%.

The dynamic settlement was found to increase monotonically with increasing number of loading cycles. An analytical model has been proposed to predict the ground settlement due to construction induced vibrations on the basis of the results of this research and previous work reported in the literature.

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ABSTRACT

The objective of this research project was to develop a procedure for evaluating soil response to construction induced vibrations. The settlement potential of various types of residual soil was evaluated by resonant column and torsional shear tests on a total of 33 specimens obtained from 8 sites. These tests included an evaluation of the of effect of confining pressure from 25 kPa to 100 kPa, shear strain amplitude from 1 x 10^{-4} % to 1 x 10^{-1} %, frequency of vibration from 0.2 to 10 Hz, and number of cycles up to 1 million on the dynamic densification of residual soils. This research also studied the influence of confining pressure, shear strain amplitude, and number of cycles on the shear modulus and damping ratio of residual soil specimens. The dynamic settlement of the residual soils tested was observed to be small, especially in comparison to that reported in the literature for sands. The following general trends were observed:

(a) Dynamic settlement was greatest for the most granular specimen with decreasing settlement associated with increasing fines content;

(b) Dynamic settlement decreased with increasing confining pressures;

(c) Dynamic densification of residual soils increased with increasing shear strain amplitude. Further, the results of the cyclic torsional shear test on residual soils tested showed that the threshold shear strain, that value below which there is essentially no volume change, is in the range of 0.005% to 0.01%.

(d) The dynamic settlement was found to increase monotonically with increasing number of loading cycles.

An analytical model has been proposed to predict ground settlement due to construction induced vibrations on the basis of the results of this research and previous work reported in the literature.

CHAPTER 1

INTRODUCTION

The objective of this research project was to develop a procedure for evaluating soil response to construction induced vibrations. The settlement potential of various types of residual soil was evaluated by resonant column and torsional shear tests. This included the study of effect of confining pressure, shear strain amplitude, frequency of vibrations, and number of cycles on the dynamic densification of residual soils. This research also studied the influence of confining pressure, shear strain amplitude, and number of cycles on the shear modulus and damping ratio of residual soil specimens. An analytical model has been proposed to predict ground surface settlement due to construction induced vibrations on the basis of the results of this research.

Chapter 2 of this report includes a detailed literature review on the characteristics of construction vibrations sources and wave attenuation with distance from source. It reviews methods for estimating ground settlement for dry sand during earthquakes. It also includes the testing techniques and methods for evaluating dynamic soil behavior. The factors affecting shear modulus and damping ratio of soils have also been discussed in this chapter.

Chapter 3 gives the site details, basic engineering properties, USCS classification and test conditions for each of the specimens tested. It also includes a detailed description of the tests conducted, experimental procedures followed, and the equipment (Stokoe cell) used to conduct the resonant column and torsional shear tests.

Chapter 4 provides the results of all the laboratory tests conducted during this research project. The influence of confining pressure, shear strain amplitude, cyclic frequency, and number of cycles on the shear modulus, damping ratio, and the dynamic densification of various residual soils tested has been discussed in detail in this chapter.

Chapter 5 analyzes the Rayleigh wave attenuation with respect to depth and distance in the soil profile. It proposes a simple method to estimate the equivalent number of cycles for construction induced vibrations. An analytical model has been provided to evaluate the dynamic settlement of residual soils under cyclic shear strain. The relation between the shear modulus and shear strain amplitude has also been modeled based on data generated from laboratory tests. This chapter also includes the procedure developed (along with example problems) to estimate dynamic settlement due to construction vibrations. The computer program developed - "Construction Vibration Induced Settlement (CVIS)" has been discussed in this chapter. Finally, Chapter 6 summarizes the major observations and conclusions.

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND

2.1 Introduction

Construction related vibrations are important primarily because of their potential to cause complaints of discomfort and/or cause damage to adjacent buildings and infrastructure systems. To evaluate the settlement caused by construction induced vibrations requires quantification of factors related to the vibration source, wave attenuation through the soil profile and soil behavior under dynamic excitation. The following discussion cites significant background in each of these important areas..

2.2 Source of Construction Vibrations

Construction vibrations are of three different types: (1) transient or impact vibrations; (2) steady-state or continuous vibrations; and (3) pseudo-steady-state vibrations. Examples of transient construction vibrations are those that occur from blasting with explosives, impact pile driving, demolition and wrecking balls. Steady-state vibrations may be generated by vibratory pile drivers, large pumps used in jacking underground pipes and compressors. Pseudo-steady-state vibrations are so called because they are of a random nature or a series of impact vibrations that are at short enough intervals to approach essentially a steady-state condition. Examples of these are jackhammers, pavement breakers, trucks and scrapers. The relative intensities of construction vibration are shown in Fig. 2.1 (Wiss, 1981).

Some typical characteristics of vehicular induced ground motion were given by Barneich (1985) and Taniguchi and Sawada(1979). The vibration amplitude and

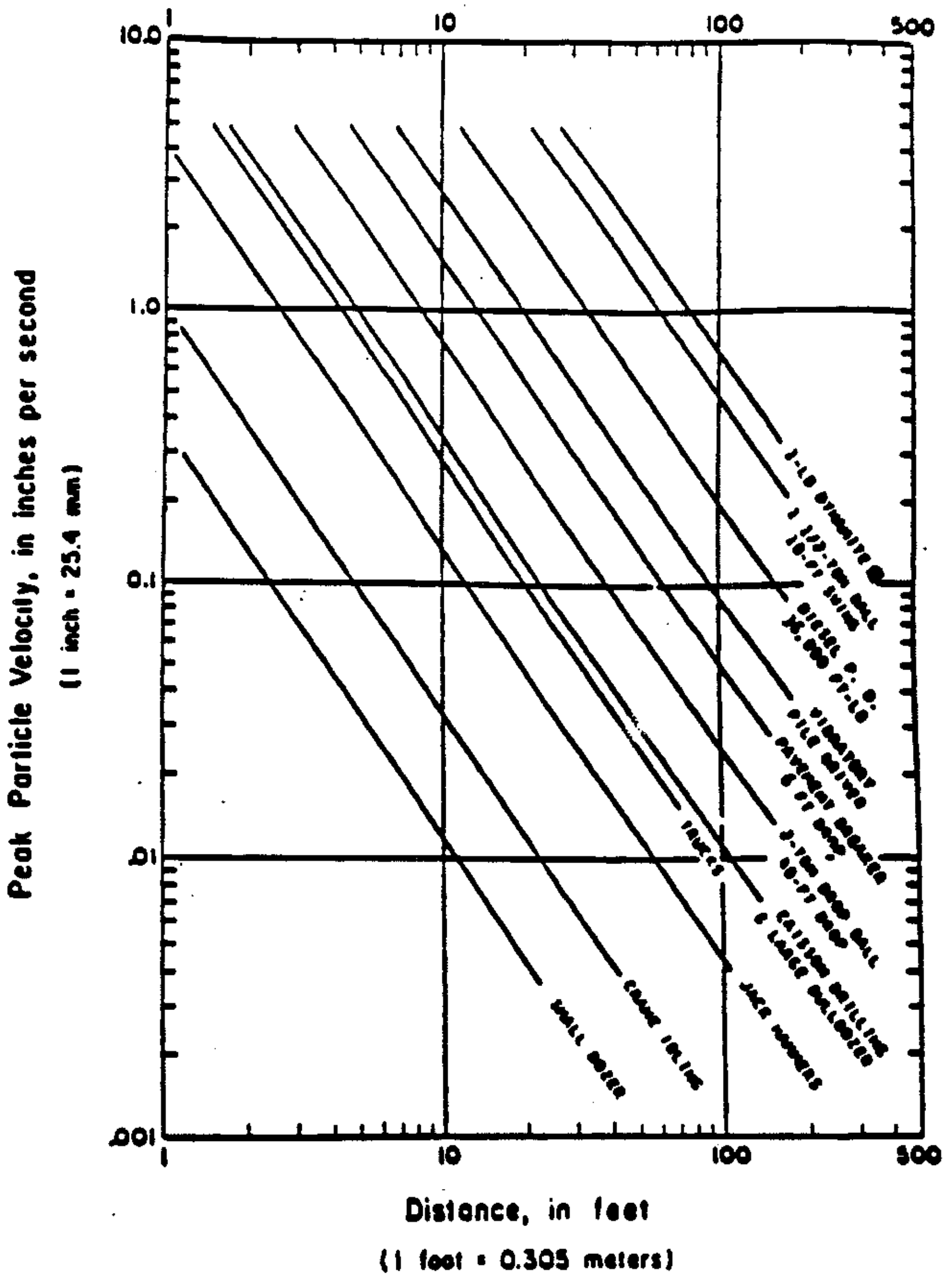


Figure 2.1 Relative Intensities of Construction Vibrations (Wiss, 1981)

frequency are dependent on wheel base, speed of vehicle and road roughness. Frequencies are generally in the 3 to 30 Hz range with most data in the range of 10 to 30 Hz. The time history and Fourier spectra of a truck induced vibration are shown in Figs. 2.2 and 2.3 respectively. Horizontal vibration amplitude is one-half to two-thirds of vertical amplitude in the same frequency range.

Dowding (1991) gave a comprehensive evaluation of pile driving vibrations. The dominant frequency of impact motion depends on driving conditions and the pile and hammer properties. For typical impact hammers, it ranges between 10 and 50 Hz. Vibratory hammers produce ground motions at the hammer frequency, which are typically in the range of 15 to 30 Hz. Dowding suggested that unlike blasting, which requires at most some 400 to 800 individual blasts, pile driving can involve up to some 200,000 impact blows for the installation of typical pipe piles and some 800 to 1000 run-ups during vibration of sheet piles.

The properties of ground motion caused by blasting are described by Siskind et al. (1981) in "Report of Investigation 8507" for the US Bureau of Mines. They studied blast-induced ground vibration from surface mining to assess its damage and annoyance potential, and to determine safe levels and appropriate measurement techniques.

In the study of granular soil settlement, it becomes necessary to determine the equivalent number of significant uniform stress or strain cycles for construction vibrations that have an irregular time history. The effect of the stress or strain history on a given soil deposit should be the same as the equivalent number of uniform cycles. The basic procedure included in developing the equivalent stress cycle method has been described by Seed et al.(1975, 1976, 1979) and Valera and Donovan (1977) from the point of view of soil liquefaction during earthquakes. Figure 2.4 was generated using the results of the soil liquefaction study using simple shear tests.

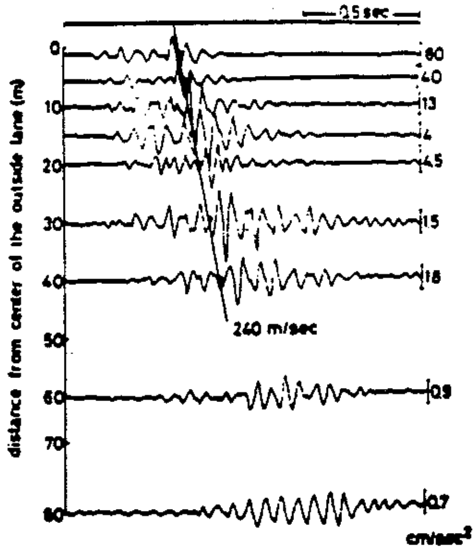


Figure 2.2 Wave Motion Record (10 Mg Truck, Speed 60 km/hour, 18 mm Bump, Vertical Component) (Taniguchi and Sawada, 1979)

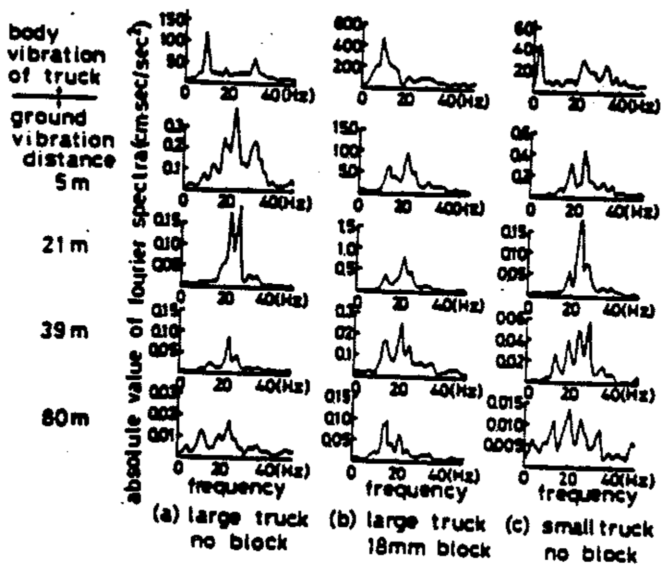


Figure 2.3 Fourier Spectra (10 Mg Truck, Speed 60 km/hour, 18 mm Bump, Vertical Component) (Taniguchi and Sawada, 1979)

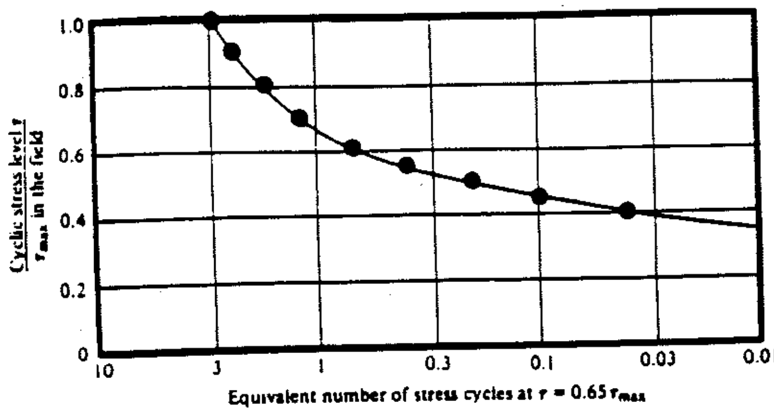


Figure 2.4 Plot of τ/τ_{max} vs N at τ=0.65 (Seed et al., 1975)

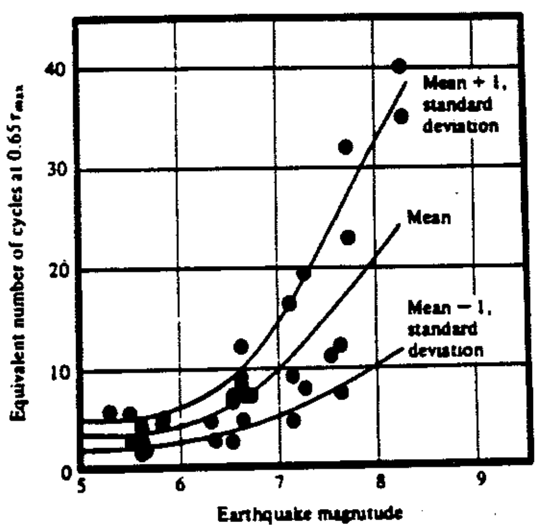


Figure 2.5 Equivalent Numbers of Uniform Stress Cycles Based on Strong Component of Ground Motion (Seed et al., 1975)

Equivalent numbers of uniform stress cycles for several earthquakes analyzed with magnitudes of 5.3-7.7 are shown in Fig. 2.5. Similar relationships need to be developed to evaluate construction induced vibrations at different energy levels as explained above.

2.3 Attenuation of Construction Related Vibrations

Vibrations lose energy during wave propagation through the ground. The decay of amplitude of vibrations with distance can be attributed to geometrical damping and material damping. From the evaluation of wave propagation theory and the field tests reported in the literature, it has been concluded that for surface impacts such as trucks, heavy equipment and dynamic compaction, Rayleigh waves dominate the energy transfer in the ground. For a point source, like pile driving near the ground surface, the surface vibration amplitude can be expressed as :

$$A = A_1\left(\frac{r_1}{r}\right)^{1/2} \exp\left[-\alpha\,(r - r_1)\right] \qquad (2.1)$$

where A is the amplitude of particle velocity at a distance r from the source, A_1 is the amplitude of particle velocity at a reference point, at a distance r_1 from the source, and α denotes the coefficient of material damping. The coefficient of material damping, α, can be obtained from field measurements or can be calculated by :

$$\alpha = \frac{2\pi f \eta}{V_R} \qquad (2.2)$$

where f is the vibration frequency, V_R is the Rayleigh wave velocity and η is the material damping ratio, which can be obtained from resonant column/torsional shear tests.

Frequency of traffic-induced vibrations is mainly determined by soil conditions. Published results suggest that vibrations produced by large trucks (mass about 20 Mg or 22 tons) have almost the same frequency as those produced by small trucks (mass about 10 Mg). The damping ratio, η, depends on the shear strain amplitude and soil type, as shown in Fig. 2.6(b).

Equation 2.1 is the wave attenuation expression for a point source. However, bulldozers, pans and trucks are finite line sources for which the point source equation is not strictly valid. For this case, no exact solutions are available. Prof. Wahls, Department of Civil Engineering, North Carolina State University, developed the following approximate analysis method in 1981 based on geometric damping and energy conservation theory :

$$A = A_1 \sqrt{\frac{\frac{L}{\pi} + r_1}{\frac{L}{\pi} + r}} \exp\left[-\alpha \left(r - r_1\right)\right] \tag{2.3}$$

where L is the length of the source. This method agrees very well with data obtained from field tests performed in Wilmington, NC in 1981, as shown in Fig. 2.7.

2.4 Dynamic Densification of Sands and Clays

In order to limit building damage and disturbance to residents from construction vibrations, the Siskind et al. (1971), and Edvards and Northwood (1960) recommended maximal peak particle velocities of 50.8 mm/sec (2.0 ips) for residential structures. This criterion focuses on residential-type buildings under transient vibrations caused by blasting. Only the vibration frequency, maximum particle velocity and condition

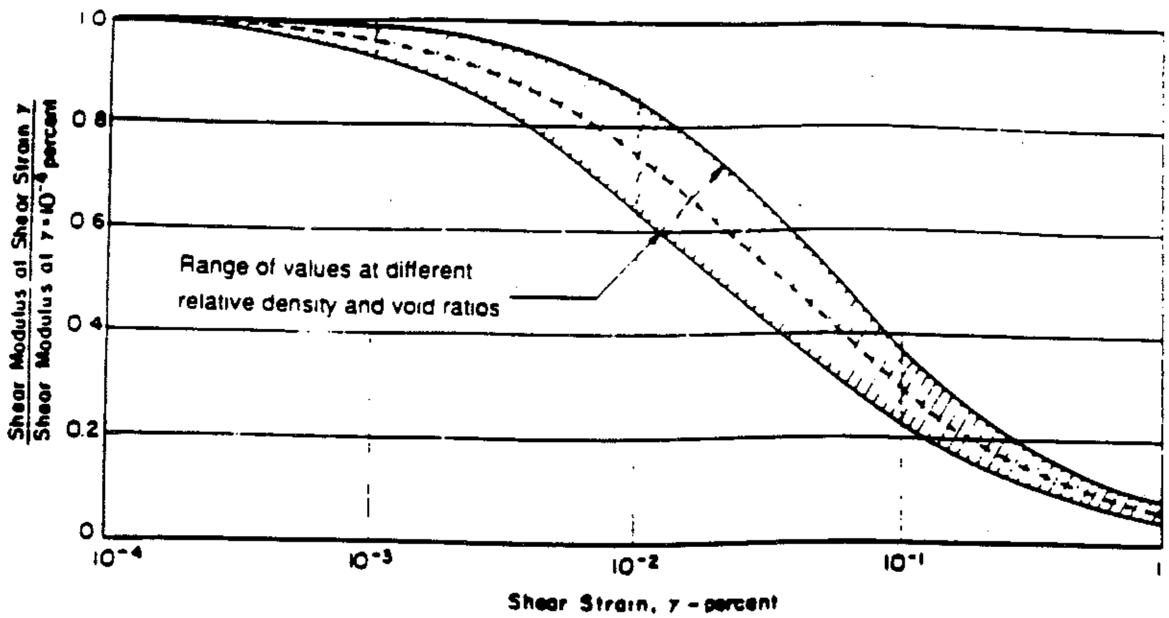


Figure 2.6(a) Variations of Shear Modulus with Shear Strains for Sand (Seed and Idriss, 1970)

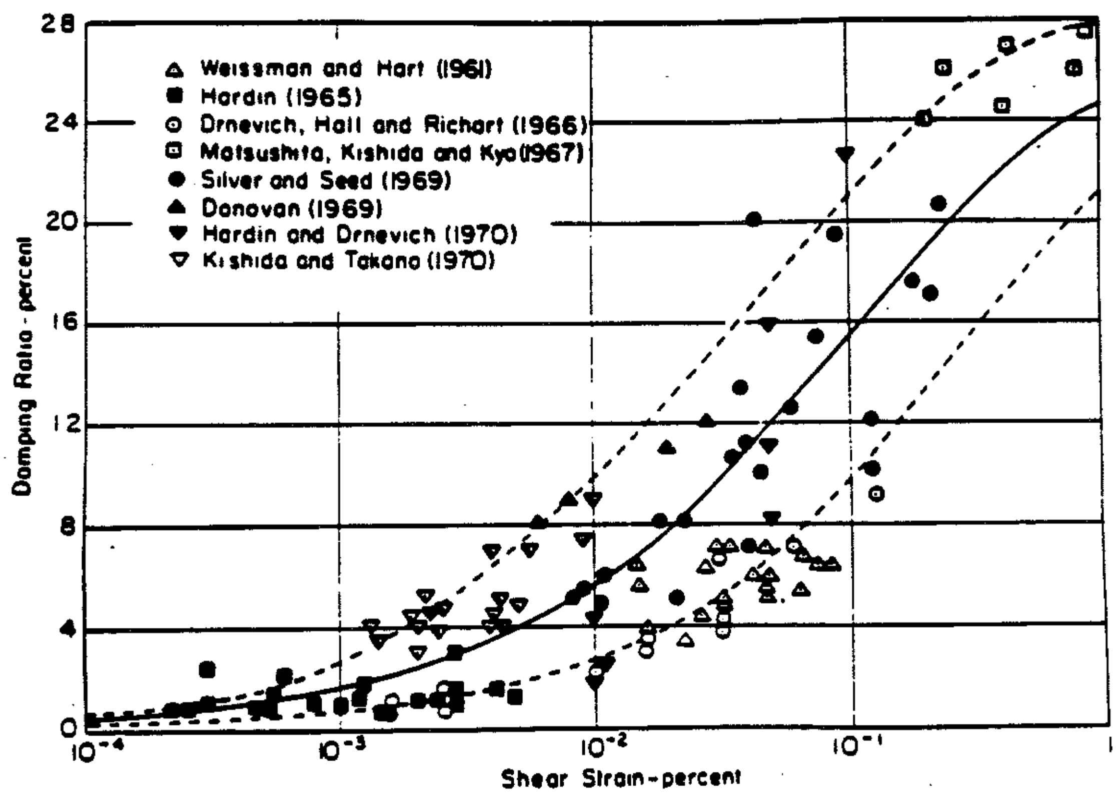


Figure 2.6(b) Damping Ratios for Sand (Seed and Idriss, 1970)

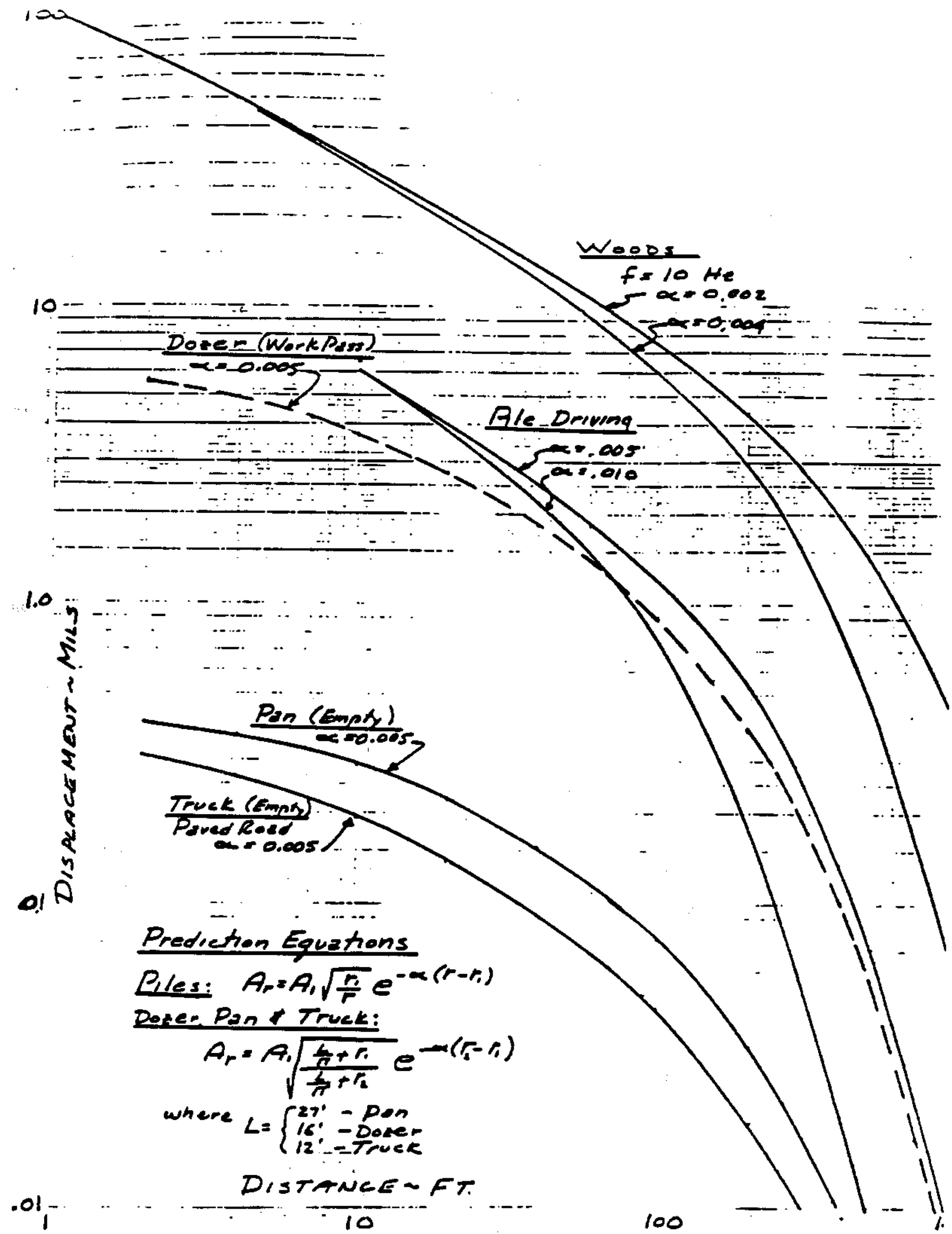


Figure 2.7 Attenuation of Line Source (Wahls, 1981)

of buildings were considered in this analysis. Very few studies have considered the criteria for damage caused by the deformation of soils due to construction related vibrations. Lacy and Gould (1985) showed that significant settlement and damage to adjacent buildings and infrastructure systems occurred due to pile driving with measured peak particle velocities ranging between 2.3 mm/sec and 10.2 mm/sec (0.09 and 0.4 ips), which are substantially less than the criteria recommended in practice.

As shown in Fig. 2.8, vibratory ground motion can be as high as 102 mm/sec (4 ips) within 1.5 m (5 ft) of the pile, but decreases rapidly to 25.4 mm/sec (1 ips) at 3 m (10 ft). Thus at 3m (10 ft) distance from pile driving, the amplitude of vibrations is lower than that generally thought necessary to induce direct structural damage. Also note that vibration amplitude is lower on buried pipe line than at ground surface. However, a large number of these vibrations may cause foundation settlement, which could induce structural damage. Dowding (1991) found that soil densification can extend approximately as far as the length of the pile, as suggested by the data in the following table :

Table 2.1 : Pile Length versus Distance of Influence in Sands (Dowding, 1991)

CASE	PILE LENGTH (m)	DISTANCE OF EFFECT (m)
Lacy & Gould (1985)		
A	30	45
D	40	37
Clough & Chameau(1980)	12	11 - 15
Linehan et al (1992)	< 23	18

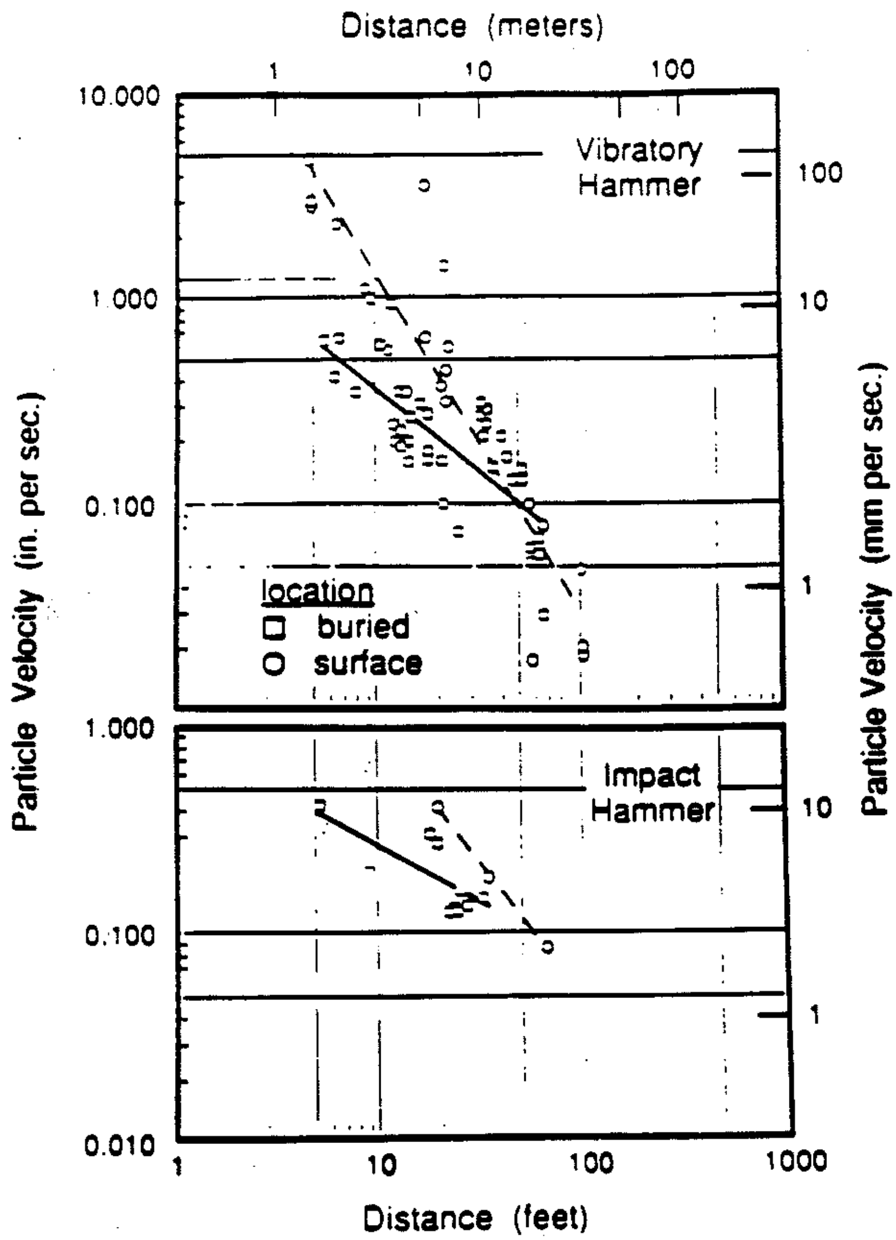


Figure 2.8 Comparison of Peak Particle Velocity at the Ground Surface and on a Buried Pipe Line (Dowding, 1991)

Dowding (1991) noted that densification, and thus settlement, results from a complex combination of vibration amplitude, number of repetitions, soil properties, and position of the water table. Dowding said, "the number of repetitions or pulses depends upon the number of piles, their length, and the number of blows or vibratory cycles required per unit penetration". Even though the magnitude of single or short-term vibration is not enough to result in a considerable settlement, long-term accumulative vibration effects may result in settlement causing damage to adjacent buildings and therefore must be investigated in order to establish safe design guidelines. In addition, the ground motion attenuates very rapidly with distance from the source. As a consequence, the differential settlement caused by differential ground motion is much more dangerous for buildings. It should be emphasized that all above cases concentrated on the settlement of sand under construction related vibrations. There is no report concerning the response of silty or sandy clay soils, residual soils or slightly cemented soils subject to construction vibrations.

In many of these cases the movements causing settlement are cyclic in nature, varying from many cycles of low strain amplitude in the case of construction vibrations to relatively few cycles of larger strain amplitude in the case of an earthquake. Of course, the energy of construction induced vibrations is much smaller than the energy released in an earthquake.

Several research programs concentrated on settlement of dry sand layers subjected to seismic vibrations (Seed and Silver, 1972; Pyke et al., 1975). Laboratory observations show that, when a sand layer is subjected to controlled vertical acceleration, considerable settlement does not occur up to a peak vertical acceleration of 1g. However, cyclic shear strains induced in these sand layers resulted in considerable settlement (Fig. 2.9). The

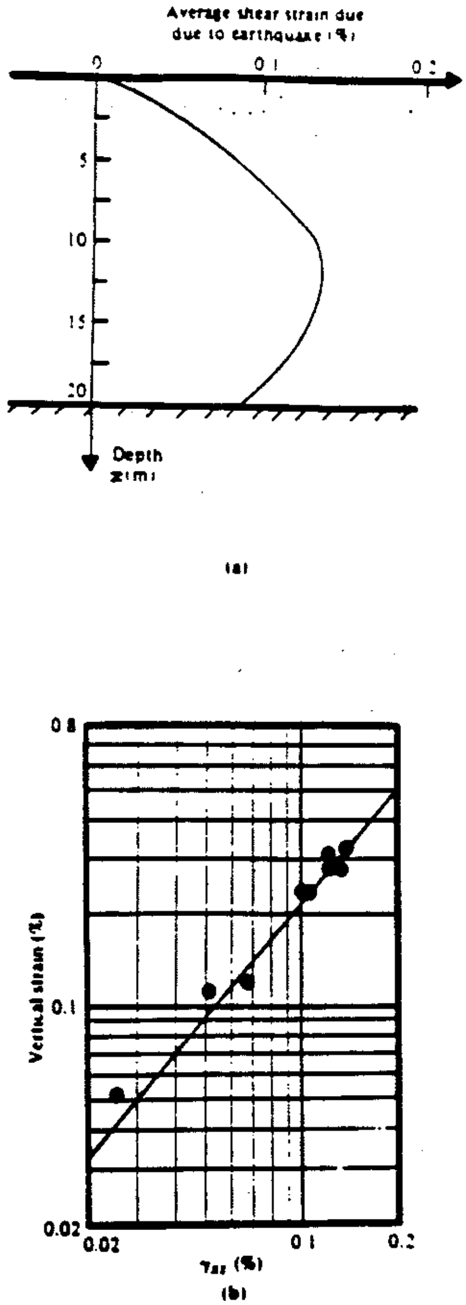


Figure 2.9 (a) Average Shear Strain due to the Earthquake for Sand : Unit Weight = 16.1 kN/m^3 and Relative Density = 50% (b) Laboratory Simple Shear Test Result for 10 Cycles (Das, 1983)

controlling parameters for settlement in dry sand due to cyclic shear strain have been studied in detail by Silver and Seed (1971). The following conclusions were advanced :

For a given normal stress and amplitude of shear strain, the vertical strain increases with the number of strain cycles as shown in Fig. 2.10. However, a large portion of the vertical strain occurs in the first few cycles. Silver and Seed (1971) noted that in some cases, "the vertical strain occurring in the first 10 cycles is approximately equal to or more than that occurring in the next 40-50 cycles". For a given value of vertical stress and number of cycles, the vertical strain increases with the increase of shear strain amplitude.

An increase in the relative density could markedly reduce the settlement of a given soil. Silver and Seed (1971) also noted that "at higher amplitudes of cyclic shear strain (greater than 0.05% for a given number of cycles), the vertical strain is not significantly affected by the magnitude of the vertical stress". This may not be true where the shear strain is less than 0.05%. Seed and Silver (1972) have suggested a procedure to evaluate the settlement of a sand layer subjected to seismic vibrations. This procedure divides soil profile into several sub-layers and calculates the settlement in each layer using equivalent number of cycles and shear strain amplitude.

Lacy and Gould (1985) described that in general, narrowly-graded, single sized clean sands with relative densities of 50 to 55%, are susceptible to vibratory densification. Figure 2.11 shows the grain size distribution for these sands. These sands fall within the bounds which define soils that are liquefiable.

Youd (1972) concluded that densification of Ottawa sand samples was independent of frequency in the range of 10 cycles/min to 115 cycles/min (Fig. 2.12).

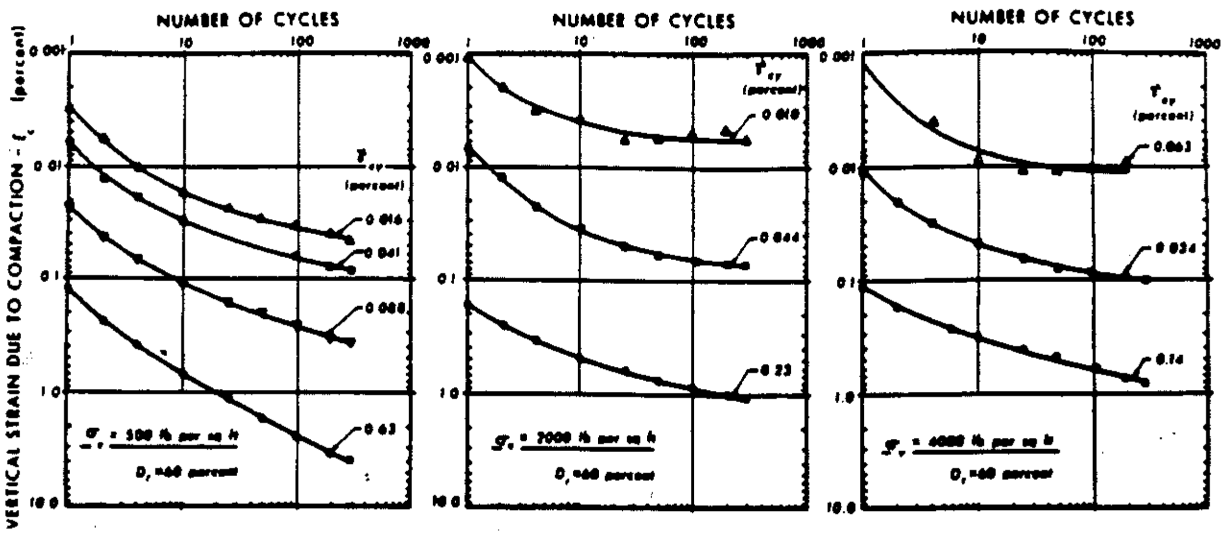


Figure 2.10 Relationship Between Vertical Settlement and Number of Cycles at Different Shear Strains for Medium Dense Sand (D_r=60%) (Seed et al., 1971)

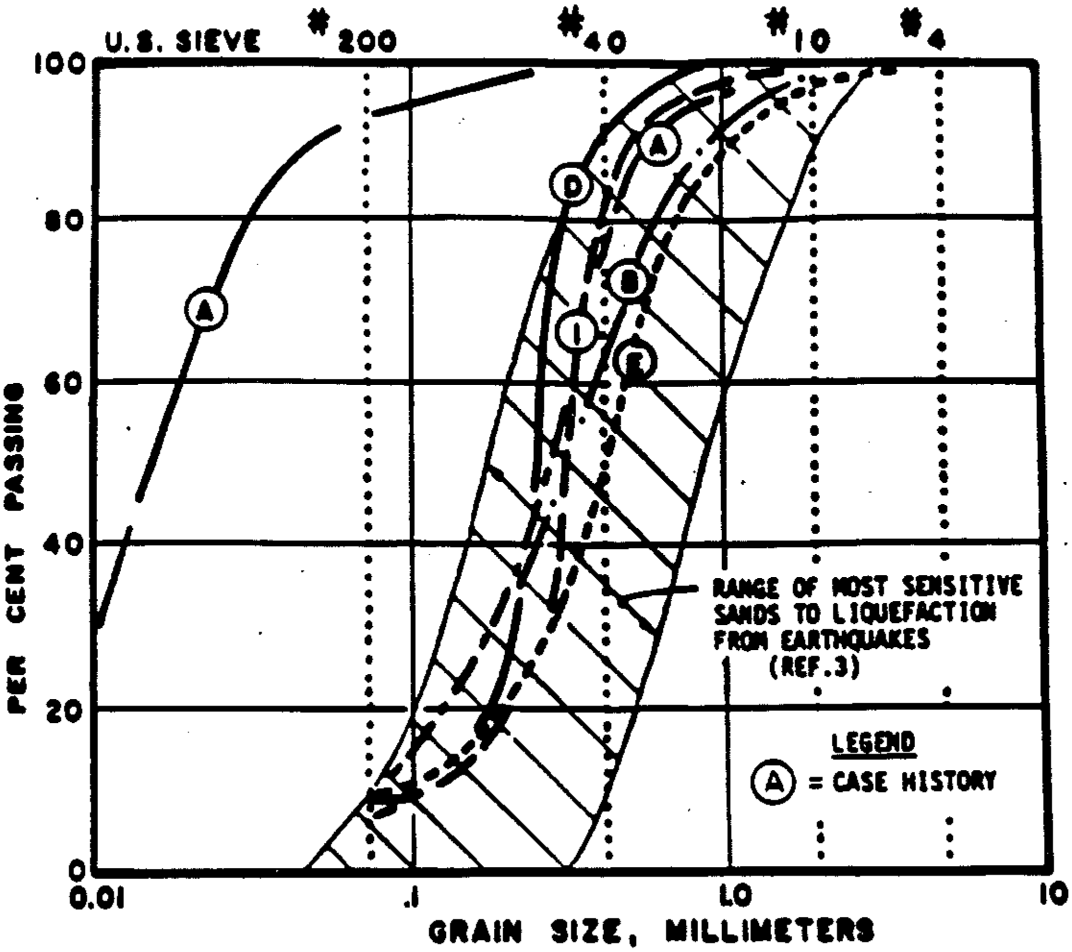


Figure 2.11 Grain Size Distribution Curves for Sands Susceptible to Liquefaction and Vibratory Densification (Lacy and Gould, 1985)

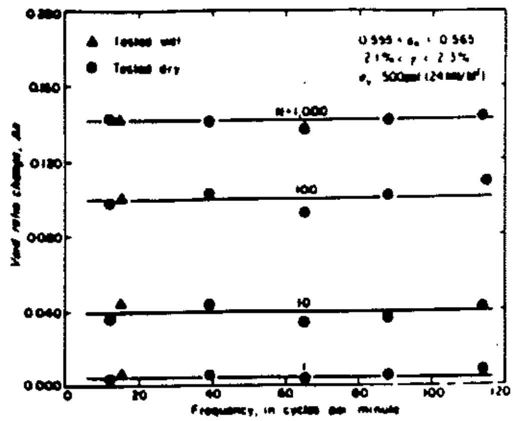


Figure 2.12 Nondependence of Density on Cyclic Frequency for Sand (Youd, 1972)

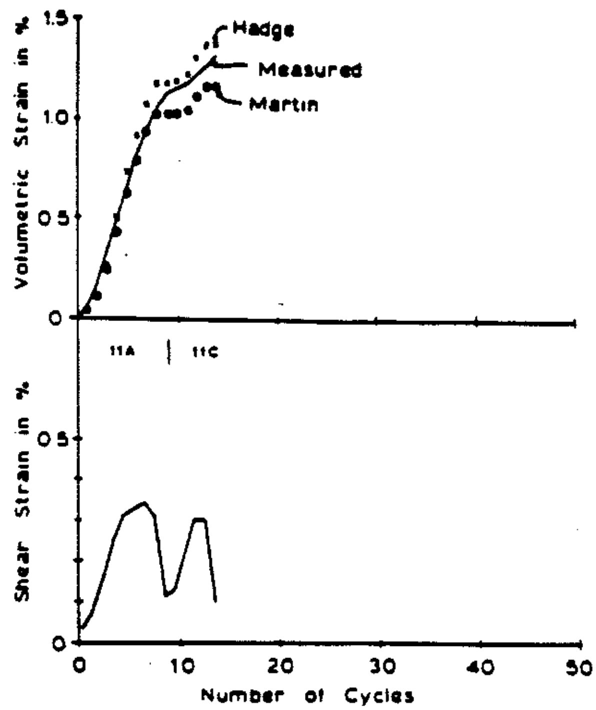


Figure 2.13 Comparison Between Calculated and Measured Densification (Lambe and Whitman, 1985)

Also, no significant behavioral differences were detected between samples tested dry and similar samples tested in a saturated, but completely drained, condition.

Pyke et al. (1975) conducted studies to calculate the settlement of a dry sand layer subjected to multi-directional shaking. It was pointed out that vertical acceleration up to about 1g acting alone without horizontal motion had practically no effect on settlement. However, when it acts in combination with the horizontal motion, it produces a marked increase in the total settlement.

The amount of densification occurring during one cycle of shear strain is governed by the amount of densification that has already occurred and the magnitude of cyclic shear strain. The rate of sand densification is governed by the character of the cyclic shear-strain time history. Two analytical models for the settlement of dry sand under seismic shaking were developed by Martin et al. (1975) and Hadge respectively and verified by Lambe and Whitman (1985) by means of dynamic centrifugal modeling. A comparison between computed and measured densification is shown in Fig. 2.13 (Lambe and Whitman, 1985).

Chu and Vucetic (1992) conducted settlement tests on compacted clay in a cyclic direct simple shear device. They used a Marshall Silver-type device, which is similar to the Norwegian Geotechnical Institute (NGI) type of short cylindrical specimen confined in a wire-reinforced rubber membrane. Three degrees of compaction were achieved below, at and above the optimum moisture content. All specimens were sheared under the same vertical consolidation stress. In each test the cyclic shear strain amplitude, γ_c, was controlled, ranging between 0.008 and 4.6%. They concluded, "the test results show a very constant behavior of the clay at all three moisture contents. At small cyclic shear strains below $\gamma_c \cong 0.1\%$, the stress-strain behavior is slightly nonlinear, i.e., close to linear elastic, and the vertical settlement is negligible. In some tests such non-destructive behavior was recorded up to $\gamma_c \equiv 0.2\%$. At γ_c larger than the threshold shear strain amplitude, the cyclic stress-strain behavior becomes non-linear and a continuous settlement with the number of cycles, N, occurs. The results do not show a clear relation between the rate of settlement with N and the degree of the compaction and moisture content. For different moisture contents, similar settlements were obtained for given γ_c and N". Some typical tests results are shown in Fig. 2.14.

Heartz and Lambe (1986) conducted research to measure the shear strength, compressibility, and permeability of Piedmont residual soil derived by weathering of gneiss and schist bedrock. This soil differs greatly from transported sands and clays because of its geologic origin. A typical soil profile is shown in Fig 2.15. Grain size distribution curves as a function of depth are shown in Fig 2.16. As the void ratio of residual soils is relatively high, it appears that these soils could be subject to dynamic densification. The relationship between axial strain and volumetric strain is quite scattered for specimens subject to isotropic consolidation (see Fig. 2.17). In general, the data supports a radial strain to volumetric strain ratio of 1:3, which means that for isotropic consolidation the radial strain is equal to the axial strain. In the interpretation of his test data, Isenhower (1979) assumed that the ratio of radial to vertical strain obtained from isotropic consolidation was valid for cyclic torsional shear tests.

2.5 Testing Methods and Equipment for Evaluating Dynamic Soil Behavior

The primary laboratory tests utilized in measuring dynamic soil properties are the resonant column, torsional shear, cyclic triaxial, cyclic simple shear, and the shaking table tests. Comparisons of these techniques are presented in Table 2.2 and Fig. 2.18.

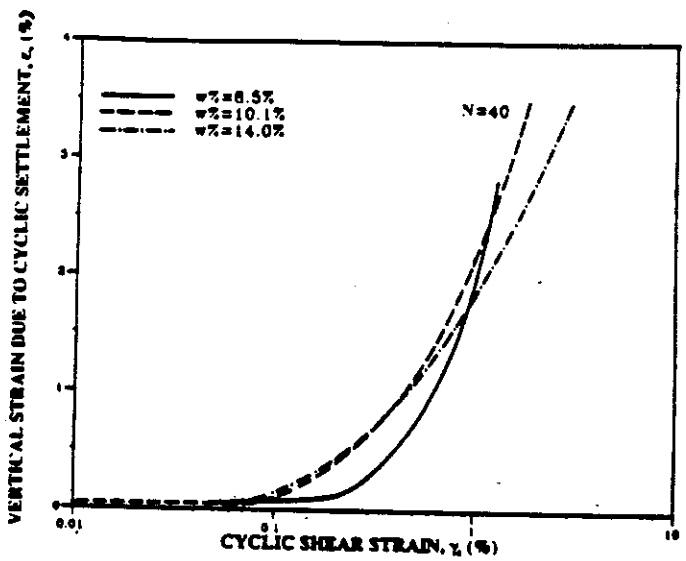


Figure 2.14 Dynamic Settlement of Compacted Clay at Different Water Contents (Chu and Vucetic, 1992)

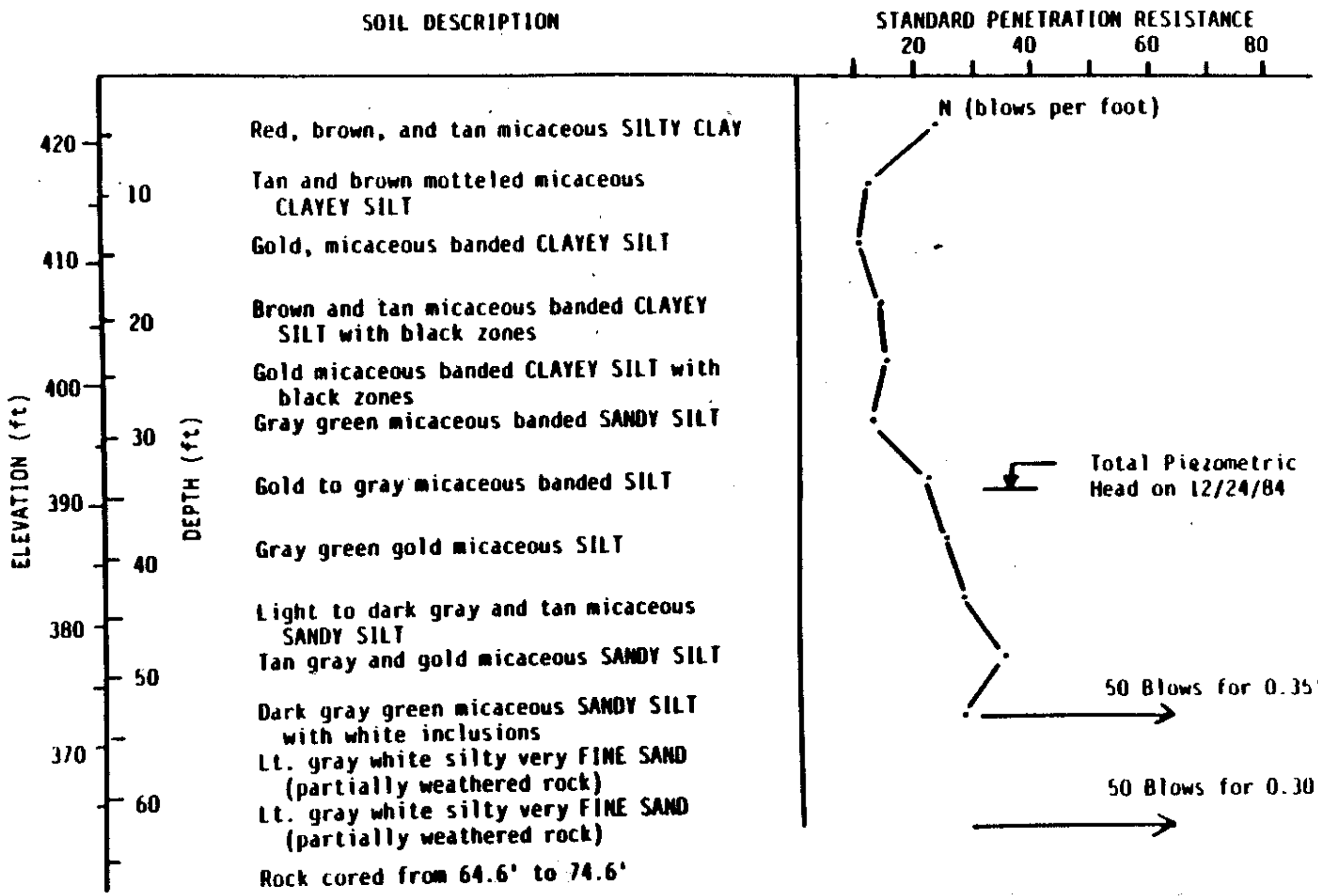


Figure 2.15 Boring Log and Visual Soil Description for Residual Soils in North Carolina (Heartz and Lambe, 1986)

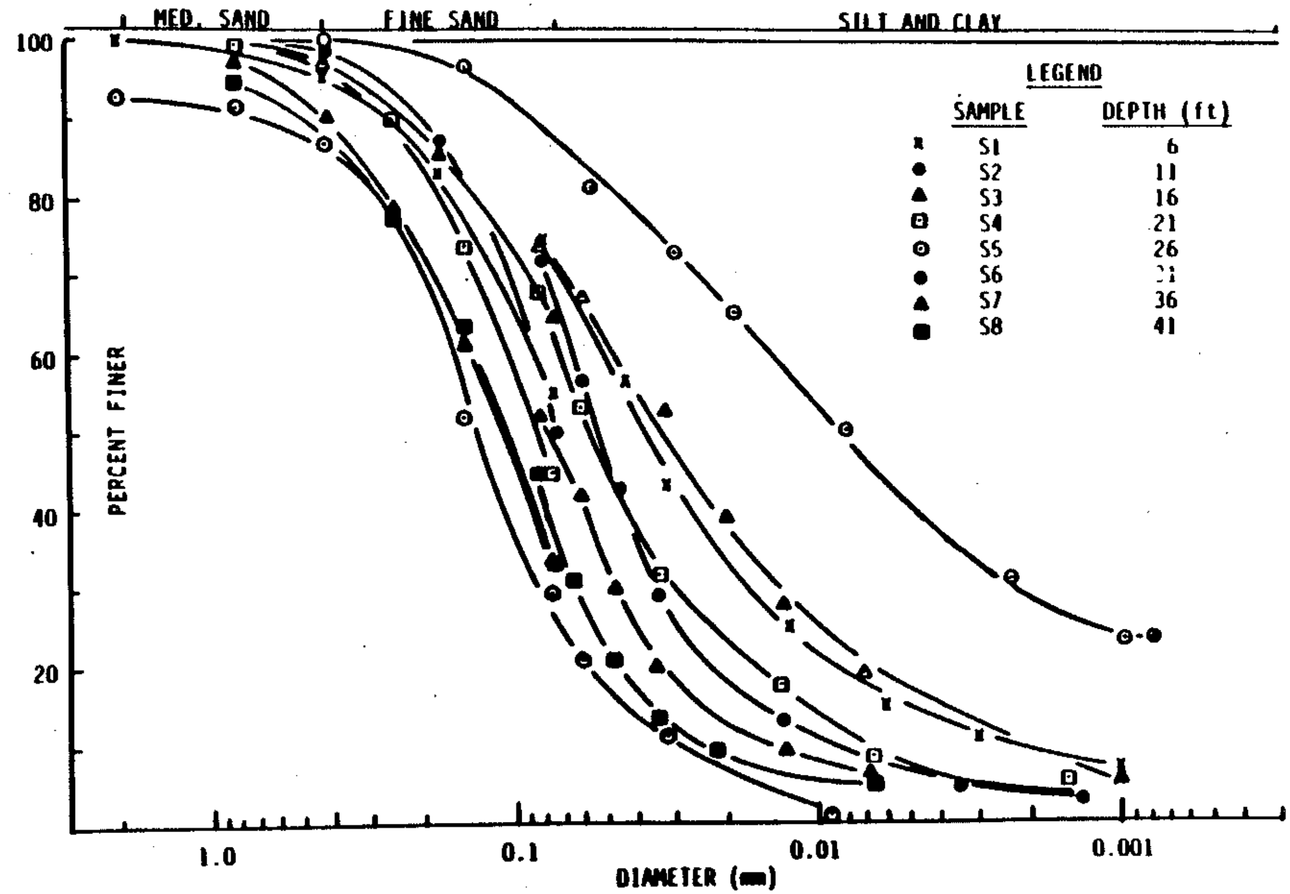


Figure 2.16 Grain Size Distribution Curves of Residual Soil Samples (Heartz and Lambe, 1986)

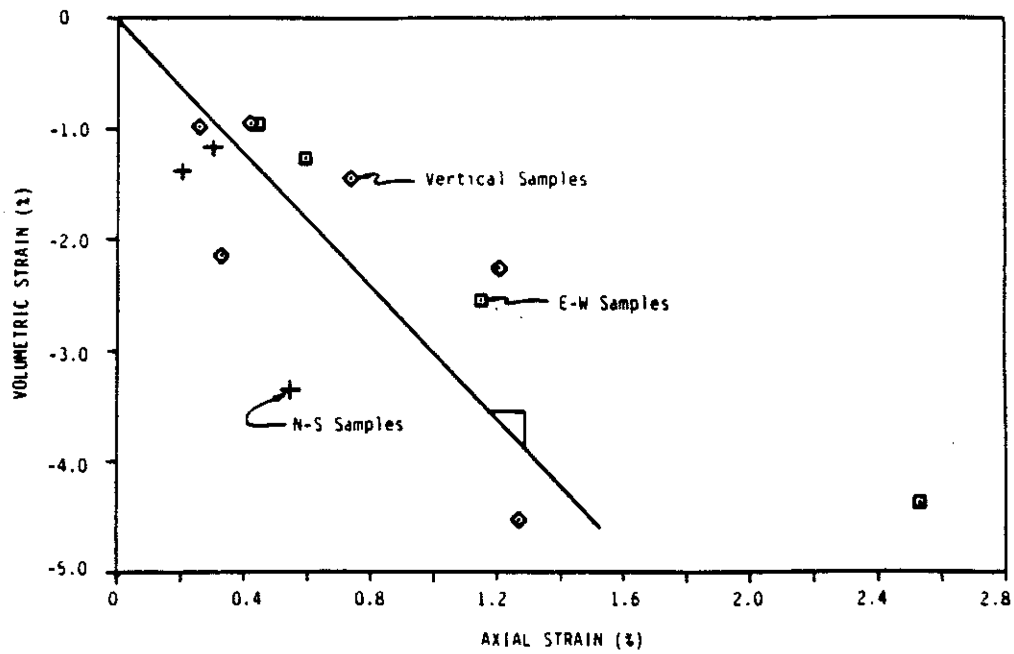


Figure 2.17 Comparison of Volumetric Strain and Axial Strain for Residual Soil Under Isotropic Consolidation (Heartz, and Lambe, 1986)

Table 2.2 Laboratory Techniques for Measuring Dynamic Soil Properties (Woods, 1978)

	Shear Modulus	Young's Modulus	Material Damping	Cyclic Stress Behavior	Attenuation
Resonant Column	X	X	X		
with adaptation					X
Ultrasonic Pulse	X	X			X
Cyclic Triaxial		X	X	X	
Cyclic Simple Shear	X		X	X	
Cyclic Torsional Shear	X		X	X	
Shake Table	X			X	

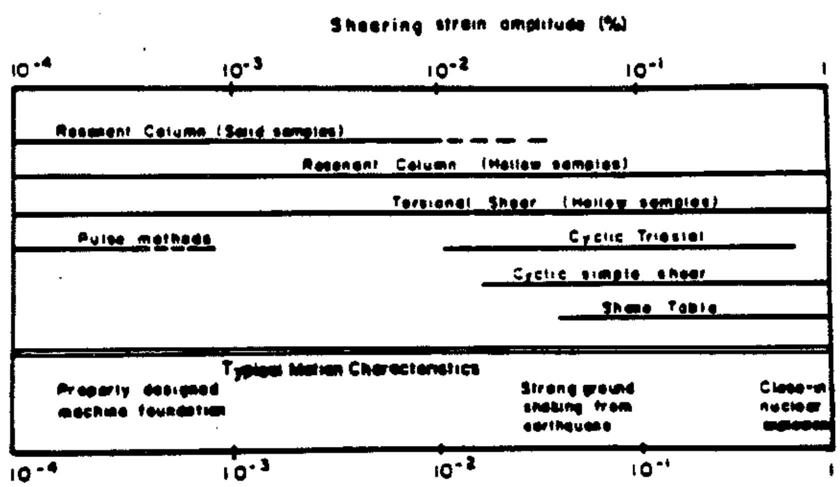


Figure 2.18 Shear Strain Capabilities of Laboratory Techniques (Woods, 1978)

2.5.1 Cyclic triaxial test

The cyclic triaxial test was developed in the 1960's to investigate liquefaction parameters in cohesionless soils (Seed and Lee, 1966). The basic idea behind this test is that once the specimen is consolidated under an isotropic confining pressure, the axial stress and confining pressure are increased and decreased, respectively, to develop a shearing stress on the 45° plane through the specimen. Next, the axial stress and confining pressure are reversed to change the direction of the shear stress on the same plane. For a saturated and undrained specimen the same test can be performed simply by cycling the axial stress alone.

While the cyclic triaxial test provides valid results for identifying the cyclic loading behavior of cohesionless soils up to strains of 5 to 20 percent (depending on specimen density) whereby liquefaction occurs, there are some drawbacks. First, measurements at shear strains below 0.01% are hard to obtain. Secondly, strain controlled tests tend not to produce symmetric hysteresis loops due to differences in the extension and compression portions of each cycle. Also, this same problem causes specimens to neck in stress-controlled tests. Third, as with other cyclic shear tests, there is a void ratio re-distribution within a specimen during testing. Fourth, stress concentrations have been a problem at the top and base caps of the specimens. Lastly, the major principle stress changes direction by 90° during the test.

2.5.2 Cyclic simple shear test

The cyclic simple shear test was developed to model the reversing shearing stresses of an earthquake produced vertical propagating shear wave. Two common types of devices used for this test are the Norwegian Geotechnical Institute (NGI) and

Cambridge University models shown in Fig. 2.19. Figure 2.20 shows how the specimens are sheared in a typical test with the hinged rigid wall Cambridge model.

Although "simple" is part of the title, the test produces nonuniform stress conditions due mainly to boundary conditions. This results in specimen failure at lower stresses than would occur in the field (Seed and Peacock, 1971).

2.5.3 Shake table test

The shake table test was developed in response to the difficulties of the cyclic simple shear test, namely nonuniform stress conditions, void ratio variations, and stress concentrations. DeAlba et al. (1976) and Seed et al. (1977) performed tests on 2.29m x 1.07m x 0.10m sand specimens to evaluate liquefaction parameters (shear strain, pore pressure, and acceleration). It is disputed whether this larger scale test reduces the problems inherent in the small scale cyclic simple shear test (Seed, 1976 and Finn, 1972).

2.5.4 Resonant column test

Resonant column analysis utilizes theories of elasticity and viscoelasticity to determine the shear modulus and damping properties of either a solid or hollow cylindrical soil specimen. Resonant column tests may be performed at shear strain amplitudes of 0.0001 to greater than 0.1 percent. Tests performed at shear strain amplitudes of 0.001 percent or less are referred to as low amplitude resonant column tests in that soils exhibit linear elastic behavior in this region. Tests performed above 0.001 percent are called high amplitude tests. In this region, the soil behavior becomes increasingly nonlinear.

The determination of shear wave velocity and consequently the shear modulus of the specimen is based on the theory of elasticity. During the resonant column test, the soil specimen is vibrated at its first mode of torsional vibration and values of resonant

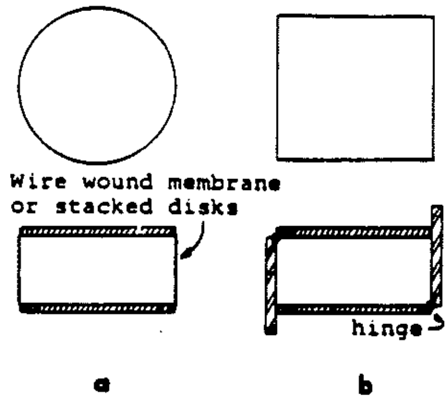


Figure 2.19 Schematic of (a) NGI and (b) Cambridge Simple Shear Devices (Prevost and Hoeg, 1976)

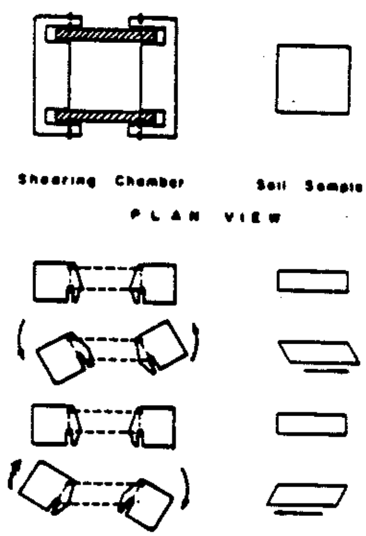


Figure 2.20 Schematic of Specimen Shearing During a Simple Shear Test (Prevost and Hoeg, 1976)

frequency, specimen weight, length, and diameter, and values of mass polar moment of inertia for both the specimen and the drive system are recorded. The data reduction is based on the wave equation in torsion. Isenhower (1979) provides a good derivation of this equation.

(a) Shear Wave Velocity and Shear Modulus

The necessary equations for the calculation of shear wave velocity and shear modulus are as follows :

The mass polar moment of inertia for a solid soil specimen can be calculated from :

$$I = \frac{md^2}{8} \tag{2.4}$$

where: m = mass of specimen (= weight/gravity) and

d = outside diameter of specimen.

The shear wave velocity (V_S) is found by solving :

$$\frac{I}{I_O} = \beta \tan\beta \tag{2.5}$$

where: I = mass polar moment of inertia of the soil specimen,

I_O = mass polar moment of inertia of drive system

$\beta = \frac{\omega l}{V_s}$

ω = natural circular frequency of specimen, and

l = specimen length.

Thus, the shear wave velocity can be calculated from :

$$V_s = \frac{\omega l}{\beta} = \frac{2\pi\, l}{\beta\, p} \quad (2.6)$$

where: p = resonant period (msec).

Lastly, the shear modulus is calculated from :

$$G = \rho V_s^2 \quad (2.7)$$

where: ρ = sample mass density.

(b) Viscous Damping

There are two techniques which may be used to determine the material damping characteristics of soils. These two techniques are hysteretic damping (discussed in Section 2.5.5), which is best determined at low frequencies (< 1 Hz) and viscous damping (defined here), which is determined in the resonant column test.

By taking records of the free vibration decay curves, viscous damping parameters can be determined. Because soil specimens in a resonant column analysis exhibit underdamped behavior as described by Richart (1970) and Isenhower (1979), the viscous damping ratio can be found by first determining the logarithmic decrement (δ) of the free vibration decay curve. Typically, three to six cycles of motion are used to obtain δ. The logarithmic decrement and the viscous damping ratio are then calculated from :

$$\delta = \frac{1}{n-1} \ln \frac{z_1}{z_n} \quad (2.8)$$

$$D = \sqrt{\frac{\delta^2}{4\pi^2 + \delta^2}} \quad (2.9)$$

where: n = number of cycles used to calculate δ and

z = amplitude of the cycle of interest (see Figure 2.21 where c = viscous damping coefficient, k = elastic spring constant, and m = mass).

The classic cases of overdamped, critically damped, and underdamped behavior in viscously damped systems can be seen in Fig. 2.21.

(c) Shearing Strain Amplitude

In both the resonant column and torsional shear tests, values for shear modulus and damping are determined as a function of the shearing strain amplitude. However, in observing Fig. 2.22 one can clearly see that the shearing strain amplitude varies across the radius of the specimen from a zero value along the central axis of rotation. At any radius r, the shearing strain value, γ, is calculated from :

$$\gamma = \frac{\alpha r}{l} \qquad (2.10)$$

where: α = angle of twist in radians.

From previous analytical studies of solid specimens at the University of Texas (SBEL manual), it has been suggested that the representative shear strain for a given specimen be taken as that strain at a radius C of approximately 0.8 times the specimen radius for shearing strains from below 0.001 percent to 0.1 percent.

In the resonant column test, a device called an accelerometer is mounted on the drive plate connected to the top of the specimen in order to enable the torsional displacements to be evaluated. By measuring the accelerometer output, the resonant period, specimen diameter and length, and finding the angle of twist of the drive plate, the single amplitude shearing strain can be determined. In taking these values into account, the shearing strain is calculated as follows for solid specimens :

$$\gamma = 1.1067 \times 10^{-9} a p^2 \frac{d_o}{l} \qquad (2.11)$$

where: a = accelerometer output (mV),

p = resonant period (msec), and

d_o = outside diameter of sample

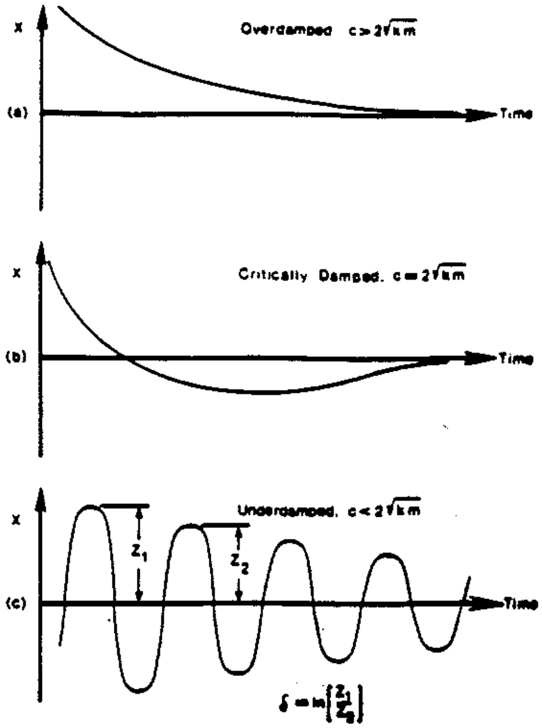


Figure 2.21 Free Vibrations of a Viscously Damped System

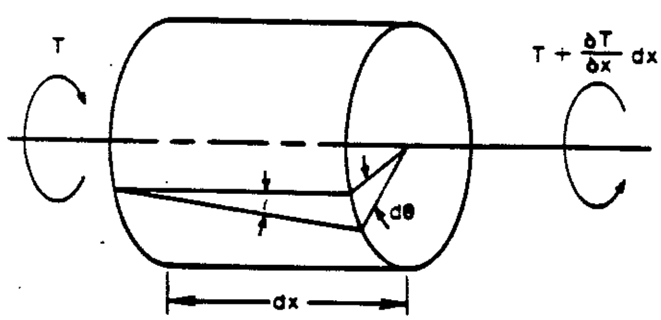


Figure 2.22 Torsion in a Circular Elastic Rod

These relationships can be shown simply on a log-log plot of resonant period versus accelerometer output for a given specimen length and diameter, as in Fig. 2.23 for a solid specimen with a diameter to length ratio of 1:2.

2.5.5 Torsional shear test

Like the resonant column analysis, torsional shear analysis uses the theories of elasticity and viscoelasticity to determine the shear modulus and damping properties of either solid or hollow cylindrical soil specimens. Torsional shear tests may be performed at shear strain amplitudes of 0.0001 to greater than 0.1 percent.

In contrast to resonant column tests, torsional shear tests are generally conducted at frequencies of less than 2 Hz. In these tests, the dynamic response of the specimen is evaluated using torque-twist curves, referred to as hysteresis loops, which in this research were recorded on an X-Y plotter, as well as saved as a file in the computer's disk. From these curves, the shear modulus and hysteretic damping ratio can be determined. The torsional shear test is valuable in that it allows the effect of the number of loading cycles on the specimen response to be shown.

(a) Shearing Stress-Strain

Shearing stress is calculated based on the theory of elasticity for circular bars in pure torsion. Shearing stress at any radius may be calculated from :

$$\tau = \frac{rT}{J_p} \qquad (2.12)$$

where: r = radius at which τ is calculated,

T = applied torque, and

J_p = area polar moment of inertia $(= \frac{\pi r^4}{2})$.

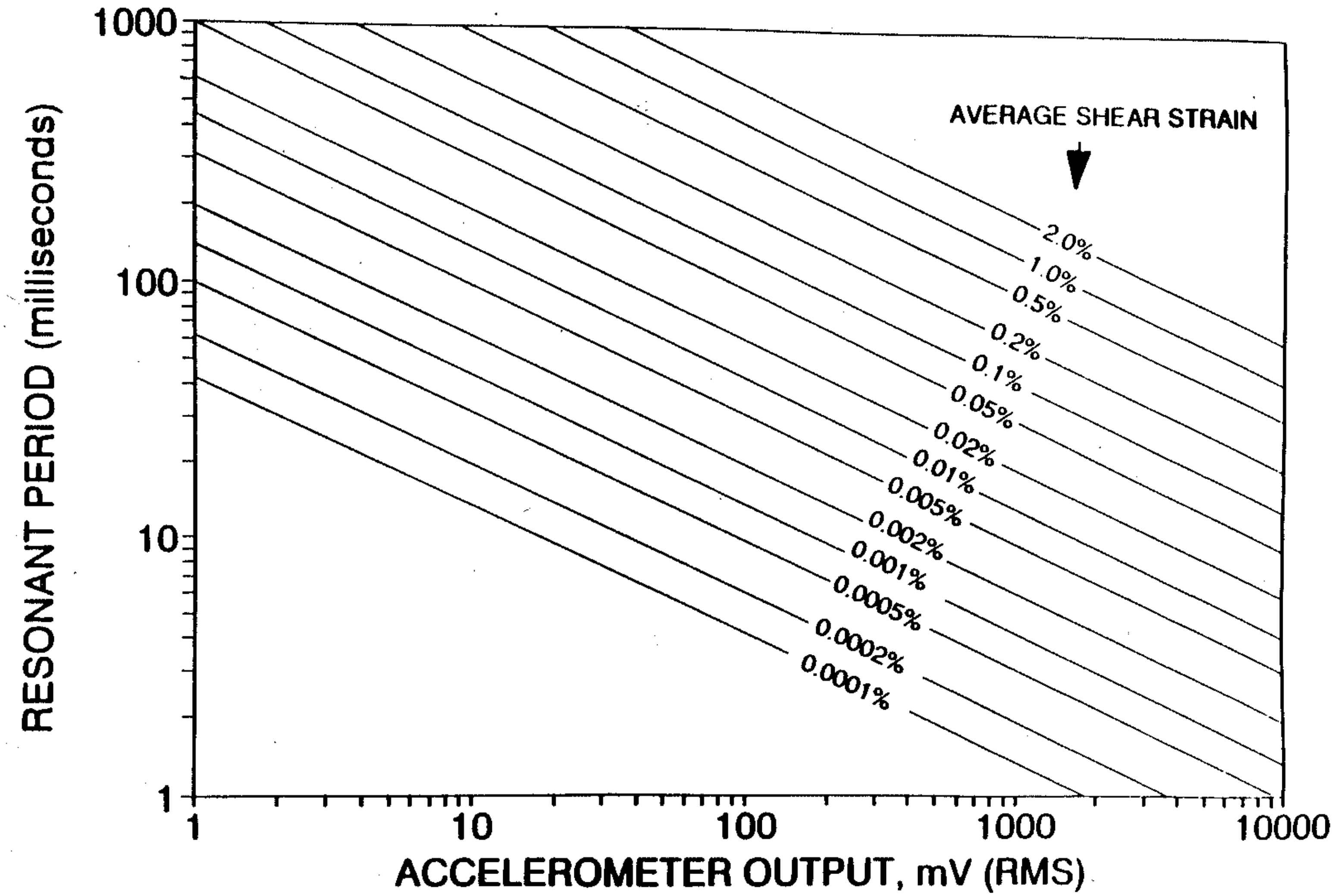


Figure 2.23 Relationship Between Accelerometer Output, Resonant Period, and Shear Strain Amplitude for a 2:1 Solid Specimen

As explained in Section 2.5.4(c), the value of r used is 0.8 times the specimen radius for solid specimens and the average value of inside and outside radii for hollow specimens. The value of applied torque is calculated from :

$$T = V_T K_T \tag{2.13}$$

where: V_T = input voltage to the torsional drive system and

K_T = torque output calibration factor (= torque/volt).

In order to calculate the shearing strain, the angle of twist must first be calculated from :

$$\alpha = K_p V_p \tag{2.14}$$

where: α = angle of twist (radians),

K_p = proximitor calibration factor (= radians/volt), and

V_p = proximitor output voltage.

As in the resonant column test, the shearing strain amplitude is calculated as :

$$\gamma = \frac{\alpha C}{l} \tag{2.15}$$

where: C = 0.8 times the specimen radius

(b) Shear Modulus

The shear modulus value in the torsional shear analysis is simply the slope of the hysteresis loop as shown in Fig. 2.24. Thus, shear modulus is calculated from :

$$G = \frac{\tau}{\gamma} \tag{2.16}$$

(c) Hysteretic Damping Ratio

In addition to viscous damping, determined in the resonant column test, the second technique for determining soil damping is calculating the hysteretic damping ratio. The

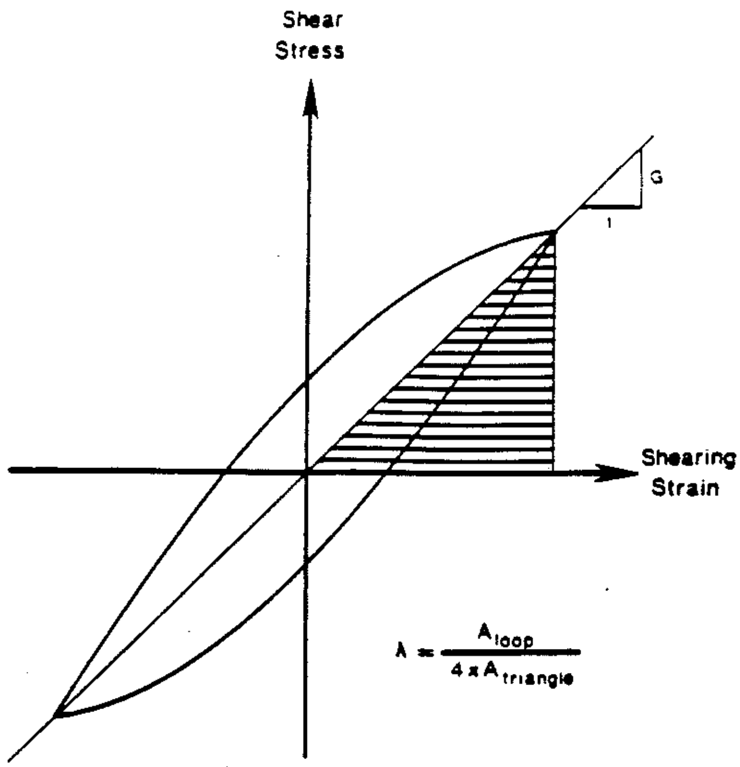


Figure 2.24 Definition of Secant Shear Modulus, G, and Hysteretic Damping Ratio, λ

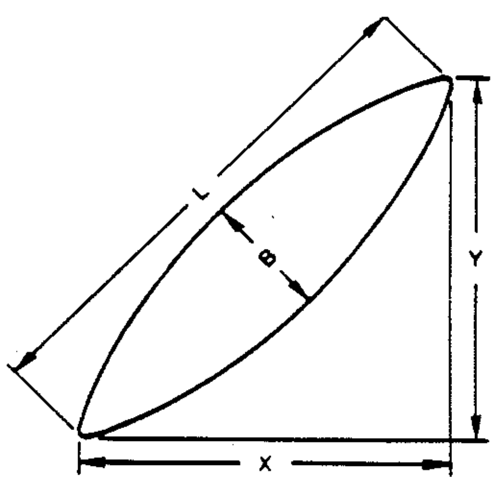


Figure 2.25 Hystersis Loop Measurements

amount of energy absorbed during one loading cycle and the peak strain energy in the soil specimen during this cycle are used to calculate the hysteretic damping ratio. The energy absorbed can be measured by determining the area of the hysteresis loop. The peak strain energy is measured by finding the area under the secant modulus line from zero to the peak strain value (see shaded area on Fig. 2.24).

The area of the hysteresis loop can be approximated by thinking of it as an ellipse and using :

$$\text{Area of Loop} = \frac{\pi}{4} LB \qquad (2.17)$$

where L and B are the length and width of the ellipse as shown in Fig. 2.25. Thus, the equation for calculating the hysteretic damping ratio is :

$$\lambda = \frac{A_{loop}}{4\pi A_{triangle}} \qquad (2.18)$$

2.6 Factors Affecting Shear Modulus and Damping Ratio

Hardin and Black (1968) have suggested that a large number of factors contribute to the shear modulus of soils. Among these factors, the soil type, density or void ratio, e, average effective confining pressure, $\bar{\sigma}_0$, and amplitude of strain have most significant influence on shear modulus.

Shear modulus decreases as the shear strain amplitude increases. The shear modulus reaches its peak value at low shear strain amplitude. For sands at shear strain less than 0.0001 percent, the most important of the above parameters are $\bar{\sigma}_0$ and e. Hardin and Black (1968) proposed the following equations for sands under low amplitudes of vibration :

$$G_{max} = 8481 \frac{[2.17-e]^2}{1+e} \bar{\sigma}_0^{\,1/2} \quad \text{(kPa)} \qquad (2.20)$$

for round grained sands, and :

$$G_{max} = 8481 \frac{[2.97-e]^2}{1+e} \overline{\sigma}_o^{1/2} \qquad \text{(kPa)} \qquad (2.21)$$

for angular grained sands.

Once G_{max} has been estimated for low strain amplitudes, the shear modulus for higher strain amplitudes must be estimated by accounting for the natural degradation which takes place at higher strains. Seed and Idriss (1970) developed a simplified equation for sands and gravely soils as follows :

$$G = 1000 K_2 [\overline{\sigma}_o]^{1/2} \qquad (2.25)$$

where: K_2 = a constant determined from Fig. 2.26.

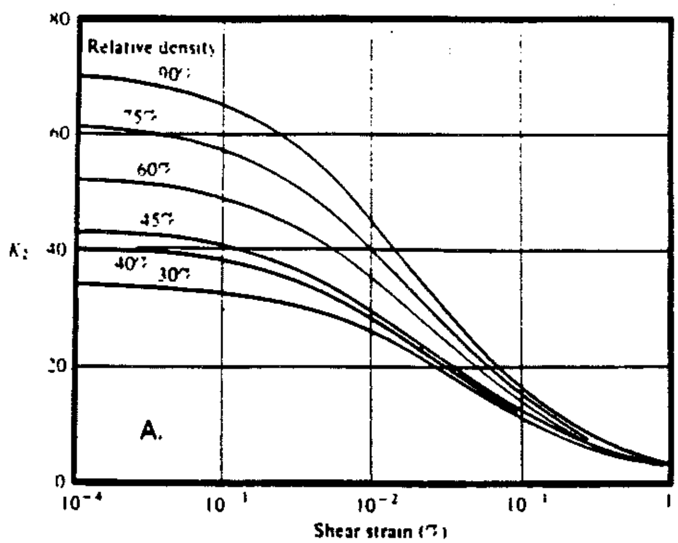
As seen in Fig. 2.26, both the shear modulus at any desired strain amplitude and the maximum shear modulus can be estimated from this equation.

Seed and Idriss (1970) also found a relationship between in situ shear modulus and undrained shear strength (c_u) for saturated clays, as shown in Fig. 2.27. This relationship was developed by collecting experimental results from several sources.

Basically, material damping values (viscous or hysteretic) are affected by the same parameters that influence shear modulus. However, as shear modulus increases, damping is decreased and vice versa. Ideally, the maximum damping value would occur at G = 0. Seed and Idriss (1970) analyzed damping ratio data for sands and saturated clays as related to shear strain amplitude. The results of this study are shown in Figs. 2.28 and 2.29.

2.7 Summary

This chapter has addressed the properties of construction related vibrations, their attenuation in the ground, dynamic densification of sands and clays, shear modulus and damping ratio, as well as experimental techniques for determining soil dynamic properties.



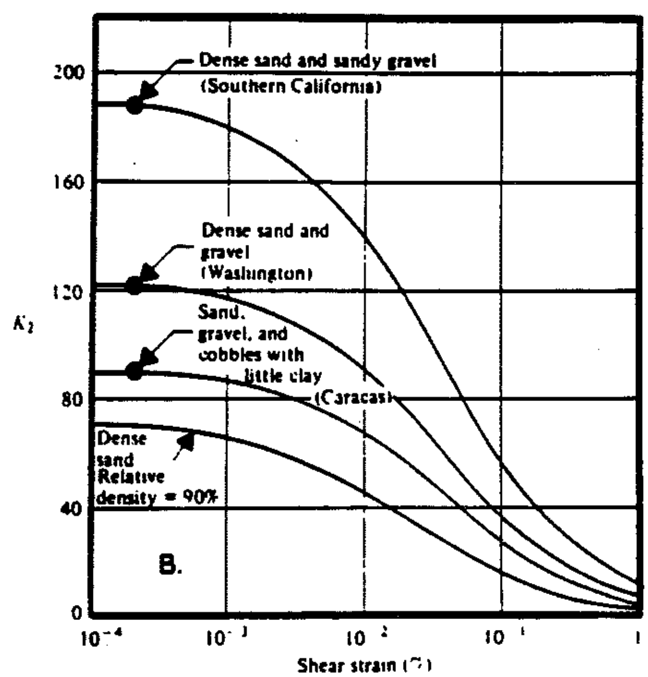


Figure 2.26 Values of K_2 for (a) Sand and (b) Gravely Soils (Seed and Idriss, 1970)

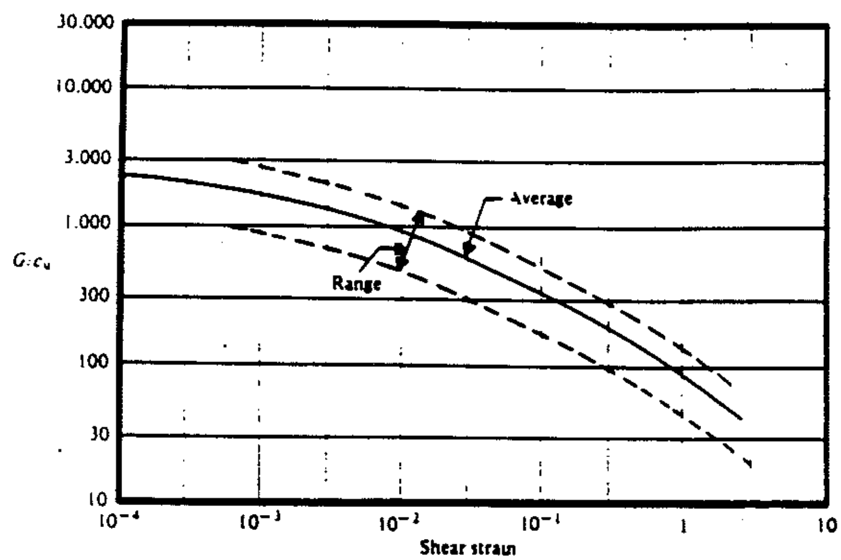


Figure 2.27 **In Situ Shear Modulus for Saturated Clays (Seed and Idriss, 1970)**

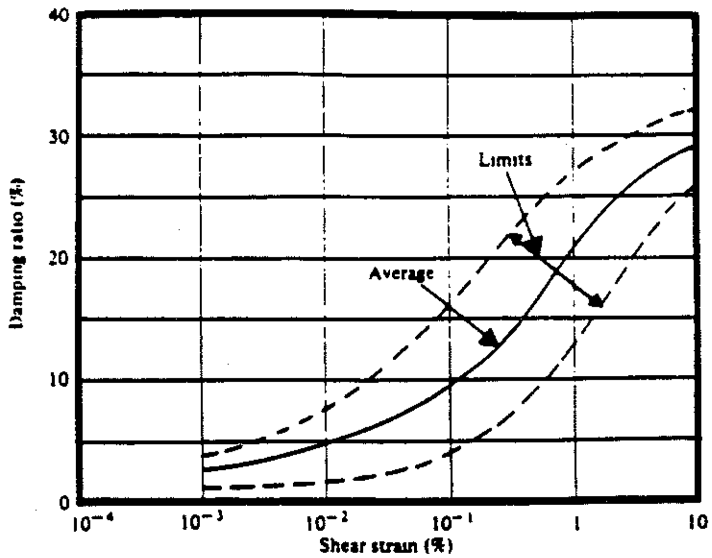


Figure 2.28 Damping Ratios for Sand (Seed and Idriss, 1970)

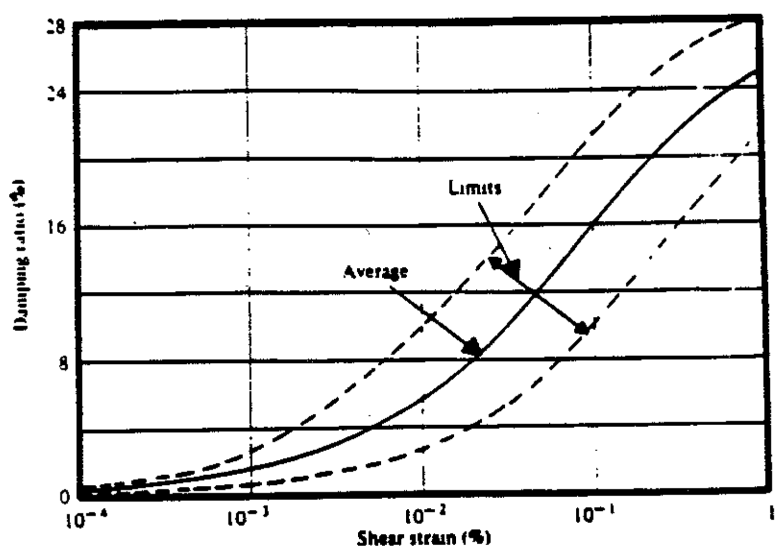


Figure 2.29 Damping Ratios for Clays (Seed and Idriss, 1970)

The last portion of this chapter was dedicated to discussing some of the factors which affect the shear modulus and material damping values, and displaying some typical data for sands and clays. The attenuation of construction induced vibrations is controlled by these soil characteristics.

In conclusion, significant research has been conducted on the dynamic response of granular materials subject to vibrations. This work has resulted in models capable of predicting settlement in dry and saturated sands under earthquake loading. However, this work has not yet been extended to include silty and clayey sand materials that are typical of residual soils and coastal plain deposits in North Carolina. This research program was formulated to focus on these materials.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 Introduction

This chapter describes the major aspects of the experimental program conducted during this project. It provides the site details, basic properties of the specimens tested, details of the tests conducted on each specimen, parameters varied during these tests, and detailed experimental procedures.

3.2 Site Details

Residual soil samples were collected from ***eight*** different sites in North Carolina. The Shelby tube samples from these sites were supplied by NCDOT. Maps showing the location of each of these sites are presented in Appendix 5.

The experimental program was carried out in two Phases. Shelby-tube samples were collected from ***three*** sites in Phase I and resonant column and torsional shear tests were performed on the specimens. The main objective of these tests was to evaluate the shear modulus and the damping characteristics of the residual soil specimens at different shear strain amplitudes. The specimens tested in this phase were identified as RC-n or TS-n where RC or TS represents the type of the test conducted on the specimen and "n" the number of the specimen tested.

In Phase II, Shelby-tube samples were collected from ***five*** more sites and torsional shear tests were performed on the specimens. The prime objective in this phase was to study the influence of confining pressure, shear strain amplitude, cyclic frequency, and number of cycles on the change in vertical and radial (horizontal) dimensions of the specimens during dynamic testing. The specimens tested in Phase II were identified as mST#n where "m" represents the site number and "n" the number of the Shelby tube (from site "m") from which this specimen was obtained. So, 3ST#10 refers to the specimen trimmed out of the 10th Shelby tube from site # 3. (Note that the numbering is discontinuous because no specimens could be trimmed from some of the Shelby tubes).

The site details of each of the specimen tested are presented in Table 3.1.

3.3 Engineering Characteristics

The engineering properties observed for each specimen were initial water content, void ratio, degree of saturation, and specimen dimensions, as shown in Table 3.2. These values are those that were observed before the test at atmospheric pressure. After the tests were performed on a specimen, specific gravity and grain size analyses were made. Table 3.3 gives the percentage of gravel, sand, silt, and clay size particles, the Atterberg limits, and the USCS soil classification for each of the specimen tested. The grain size distribution curve for each specimen is presented in Appendix 3.1.

3.4 Parameters Investigated

A number of parameters influence the densification of soil due to construction vibrations. The influencing parameters that were investigated in this research project are confining pressure, shear strain amplitude, cyclic frequency, and number of cycles.

Shear strain amplitudes were varied from 0.001% to 0.1%. Vibrations due to construction activities that are a cause of concern, typically produce shear strains within this range. Besides this, due to certain equipment limitations, the maximum shear strain was limited to 0.1%. Specimens were tested at three confining pressures -- 25, 50, and 100 kPa. These pressures relate to in-situ pressures for soils less than 20 feet deep in ground - the region that was of concern in this study. A frequency of 0.2 Hz was used for

Table 3.1 Site Details of the Specimens Tested

Site No.	County	NCDOT Project No.	Specimen No.	Station	Depth (ft)	GWT (ft)	SPT (N)
Phase I							
I-1	Franklin/ Vance	6.399001T	RC-1	344+00 105' RT	2.7 - 4.2	Dry	-
			RC-2	344+00 105' RT	2.7 - 4.2	Dry	-
I-2	Franklin/ Vance	6.399001T	RC-3	330+00 163' RT	3.0 - 5.0	Dry	-
			RC-4	330+00 163' RT	3.0 - 5.0	Dry	-
			RC-5	330+00 163' RT	3.0 - 5.0	Dry	-
I-3	Guilford	8.1570601	TS-1	320+00 140' LT	9.0 - 11.2	27	-
			TS-2	320+00 140' LT	9.0 - 11.2	27	-
			TS-3	320+00 140' LT	9.0 - 11.2	27	-
Phase II							
II-1	Rockhingham	5.5151	1ST#4	13+90 -L- 31' LT	13.3 - 15.3	Dry	6
II-2	Wake	4.6321302 (M - 220)	2ST#1	22+92 - L- 31'LT	3.0 - 5.0	N/A	10
			2ST#2	22+95 - L- 31' LT	3.0 - 5.0	N/A	10
			2ST#3	22+95 - L- 31' LT	3.0 - 5.0	N/A	10
			2ST#5	81+00 -L- C. L.	5.0 - 7.0	N/A	15
			2ST#7	81+00 -L- C. L.	5.0 - 7.0	N/A	15
			2ST#8	81+00 -L- C. L.	7.0 - 9.0	N/A	15
			2ST#9	22+95 - L- 32' LT	3.0 - 5.0	N/A	10
			2ST#10	22+95 - L- 32' LT	3.0 - 5.0	N/A	10
			2ST#11	22+95 - L- 31' LT	3.0 - 5.0	N/A	10
II-3	Wake	6.409003T	3ST#2	4+50 72' LT	4.1 - 6.1	N/A	14
			3ST#2L	4+50 72' LT	4.1 - 6.1	N/A	14
			3ST#3	4+50 72' LT	7.7 - 9.0	N/A	14
			3ST#4	4+50 75' LT	4.8 - 6.8	N/A	14
			3ST#5L	4+00 60' LT	4.0 - 6.0	N/A	11
			3ST#6	4+00 60' LT	6.0 - 8.0	N/A	12
			3ST#8	4+00	4.1 - 6.0	N/A	11
			3ST#9	4+00	2.9 - 4.9	N/A	-
			3ST#10L	4+00	3.3 - 5.3	N/A	-
			3ST#11A	4+00	5.8 - 7.8	N/A	-
			3ST#11B	4+00	5.8 - 7.8	N/A	-
			3ST#12	4+00	3.8 - 5.8	N/A	-
II-4	Wake	8.T401704	4ST#1	143+00 250'LT	13.2 - 15.2	11	9
			4ST#4	143+00 250'LT	15.4 - 17.4	11	9
II-5	Wake	8.U401710	5ST#2	627+00 C. L.	11.0 - 13.0	1.0	5

Table 3.2 Engineering Properties of the Specimens Tested

Specimen No.	Water Content (%)	Initial Void Ratio	Specific Gravity	Saturation (%)	Initial Length (in)	Initial Diameter (in)
RC-1	24.6	0.89	2.74	75	5.81	2.87
RC-2	30.5	1.00	2.74	84	5.88	2.87
RC-3	39.2	1.25	2.81	88	5.96	2.87
RC-4	40.7	1.31	2.81	87	5.91	2.87
RC-5	41.9	1.35	2.81	87	5.83	2.87
TS-1	37.8	1.50	2.69	68	5.99	2.85
TS-2	36.8	1.42	2.69	70	5.92	2.85
TS-3	29.6	1.18	2.69	67	5.94	2.86
1ST#4	20.7	0.60	2.67	92	5.91	2.88
2ST#1	33.5	1.41	2.79	66.0	5.87	2.86
2ST#2	33.1	1.43	2.85	65.9	5.88	2.86
2ST#3	38.9	1.64	2.79	66.2	5.79	2.88
2ST#5	14.8	0.79	2.60	48.4	5.71	2.85
2ST#7	12.6	0.84	2.60	39.1	5.67	2.83
2ST#8	15.0	0.87	2.60	45.0	5.82	2.83
2ST#9	26.2	1.01	2.69	69.8	5.72	2.86
2ST#10	29.6	1.12	2.75	72.9	5.82	2.86
2ST#11	29.6	1.14	2.71	70.6	5.89	2.86
3ST#2	23.9	1.32	2.75	49.7	5.89	2.85
3ST#2L	22.9	1.24	2.75	50.6	5.58	2.85
3ST#3	26.8	1.14	2.67	63.0	5.78	2.87
3ST#4	23.6	1.17	2.66	53.6	5.72	2.86
3ST#5L	18.4	1.16	2.69	42.7	5.72	2.87
3ST#6	19.5	0.93	2.75	57.5	5.84	2.92
3ST#8	22.8	1.24	2.72	50.2	5.57	2.87
3ST#9	15.3	0.86	2.74	48.8	5.84	2.85
3ST#10L	34.8	1.42	2.76	67.5	5.86	2.85
3ST#11A	50.3	1.78	2.74	77.6	5.78	2.86
3ST#11B	36.6	1.48	2.74	67.7	5.75	2.87
3ST#12	35.6	1.43	2.72	67.7	5.87	2.85
4ST#1	16.6	0.49	2.81	96.1	5.78	2.88
4ST#4	24.7	0.72	2.79	96.6	5.80	2.90
5ST#2	50.9	1.48	2.86	98.7	5.79	2.88

Table 3.3 USCS Classification of Each Specimen Tested

Specimen No.	Gravel Size > # 4 (> 4.75 mm)	Coarse Sand Size # 4 to # 10 (2 to 4.75 mm)	Medium Sand Size # 10 to # 40 (0.42 to 2 mm)	Fine Sand Size # 40 to # 200 (0.074 to 0.42 mm)	Silt Size (0.074 to 0.002 mm)	Clay Size (< 0.002 mm)	LL	PL	PI	USCS
RC-1	0	0	15.5	36.5	25	23	48	40	8	SM-ML
RC-2	0	0	15.5	36.5	25	23	48	40	8	SM-ML
RC-3	0	0	1.8	8.5	61.7	28	57	43	14	MH
RC-4	0	0	1.8	8.5	61.7	28	57	43	14	MH
RC-5	0	0	1.8	8.5	61.7	28	57	43	14	MH
TS-1	0	0	15.5	26.5	44	14	44	34	10	ML
TS-2	0	0	15.5	26.5	44	14	44	34	10	ML
TS-3	0	0	15.5	26.5	44	14	44	34	10	ML
1ST#4	0	0	3	46	31	20	30	19	11	SC-CL
2ST#1	0	0	0.6	22	47.4	30	75	46	29	MH
2ST#2	0	0	1	15.4	53.6	30	75	48	27	MH
2ST#3	0	0	0.5	27.2	44.3	28	92	61	31	MH
2ST#5	0	0	15	54.6	19.4	11	-	-	NP	SM
2ST#7	0	0	14	60.3	19.7	6	-	-	NP	SM
2ST#8	0	0	14	56.6	18.4	11	-	-	NP	SM
2ST#9	0	0	0	35.6	40.4	24	-	-	NP	SM-ML
2ST#10	0	0	2	41.6	41.4	15	-	-	NP	SM-ML
2ST#11	0	0	0.5	35.5	44	20	-	-	NP	SM-ML
3ST#2	0	0	4	42.8	48.2	5	29	-	NP	SM-ML
3ST#2L	0	0	4	42.8	48.2	5	29	-	NP	SM-ML
3ST#3	0	0	3	27.2	67.8	2	34	-	NP	ML
3ST#4	0	0	1	31.9	65.1	2	35	-	NP	ML
3ST#5L	0	0	1	35.2	62.8	1	37	-	NP	ML
3ST#6	0	0	1	28.1	69.9	1	33	-	NP	ML
3ST#8	0	0	0.8	34.2	61.9	3.1	36	-	NP	ML
3ST#9	0	0	6	16.3	69.7	8	35	30	5	ML
3ST#10L	0	0	2.2	13.5	75.3	9	52	46	6	MH
3ST#11A & B	0	0	0.6	5.2	84.2	10	78	56	22	MH
3ST#12	0	0	1.5	18	72.5	8	56	43	13	MH
4ST#1	0	0	10	70.4	18.1	1.5	-	-	NP	SM
4ST#4	5.3	6.9	6.9	74.6	9.8	0.2	-	-	NP	SP-SM
5ST#2	0	0	0.4	8.5	86.1	5	59	45	14	MH

• NP = Nonplastic

torsional shear tests in Phase I and that of 1 and 10 Hz was employed during Phase II. During the torsional shear testing in Phase I, 100 cycles were applied to each specimen. In Phase II, specimens were subjected to 1000 cycles at each shear strain amplitude. To study the effect of large number of cycles on densification, certain specimens were subjected to about 0.2 to 1 million cycles. These tests can be identified by "L" (long test) after the specimen number.

As the soils were collected from different sites, the soil type, initial water content, void ratio, density and degree of saturation also varied for each specimen (Table 3.2). As considerable data is available in the literature for sand and clay, silty sands to sandy-silts were tested in this project. To study the effect of degree of saturation (and thereby suction) on densification of the specimens, samples were collected from both above and below (sites II-4 and II-5, Table 3.1) the ground water table.

Table 3.4 shows the conditions under which each of the specimen was tested.

3.5 Test Equipment

3.5.1 Overall system

The test equipment for the resonant column/ torsional shear device comprises the following components :

1. Basic Stokoe cell with optional anisotropic loading apparatus,
2. Cell pressure system,
3. Height change measurement system,
4. High torque capacity drive system,
5. Resonant frequency measurement system, and
6. Low frequency (torsional shear) measurement system.

These components allow the resonant column/torsional shear device to :

Table 3.4 Test Conditions for Each Specimen Tested

Specimen No.	Confining Pressure* (kPa)	Estimated Shear Strain Amplitude** (%)	Number of Cycles***	Cyclic Frequency**** (Hz)
Phase I				
RC-1	25	0.001 - 0.25	–	Resonant
	50	0.0005 - 0.1	–	Resonant
	100	0.0005 - 0.075	–	Resonant
RC-2	25	0.001- 0.25	–	Resonant
	50	0.0005 - 0.1	–	Resonant
	100	0.001 - 0.1	–	Resonant
RC-3	25	0.0025 - 0.25	–	Resonant
	50	0.001 - 0.25	–	Resonant
	100	0.00075 - 0.25	–	Resonant
RC-4	25	0.0015 - 0.25	–	Resonant
	50	0.0015 - 0.15	–	Resonant
	100	0.0015 - 0.15	–	Resonant
RC-5	25	0.0015 - 0.25	–	Resonant
	50	0.001 - 0.15	–	Resonant
	100	0.00075 - 0.1	–	Resonant
TS-1	25	0.001 - 0.15	100	0.2
	50	0.0075 - 0.075	100	0.2
	100	0.0075 - 0.075	100	0.2
TS-2	25	0.0075 - 0.1	100	0.2
	50	0.0075 - 0.1	100	0.2
	100	0.0005 - 0.075	100	0.2
TS-3	100	0.0005 - 0.1	100	0.2
Phase II				
1ST#4	25	0.001, 0.0025, 0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	50	0.001, 0.0025, 0.005, 0.01, 0.025, 0.05	1000	1
	100	0.001, 0.0025, 0.005, 0.01, 0.025	1000	1
2ST#1	50	0.0025, 0.005, 0.01, 0.025, 0.05	1000	1
2ST#2	100	0.005, 0.01, 0.025, 0.05, 0.075	1000	1
2ST#3	25	0.0025, 0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	50	0.005, 0.01, 0.025, 0.05, 0.075	1000	1
	100	0.005, 0.01, 0.025, 0.05	1000	1
2ST#5	50	0.0025, 0.005, 0.01, 0.025, 0.05	1000	1
	100	0.005, 0.01, 0.025	1000	1
2ST#7	25	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	50	0.005, 0.01, 0.025, 0.05, 0.075	1000	1
	100	0.005, 0.01, 0.025, 0.05	1000	1
2ST#8	100	0.005, 0.01, 0.025, 0.05	1000	1
	50	0.005, 0.01, 0.025, 0.05	1000	1

* Confining pressures were applied in the order as presented here
** Attempt was made to apply these shear strains
*** Number of cycles for each shear strain amplitude at the given confining pressure
**** Cyclic frequency for each test

Table 3.4 (Continued)

Specimen No.	Confining Pressure* (kPa)	Estimated Shear Strain Amplitude** (%)	Number of Cycles***	Cyclic Frequency**** (Hz)
2ST#9	25	0.0025, 0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	50	0.0025, 0.005, 0.01, 0.025, 0.05	1000	1
	100	0.005, 0.01, 0.025, 0.05	1000	1
	25	0.005, 0.01, 0.025, 0.05	1000	1
2ST#10	100	0.0025, 0.005, 0.01, 0.025	1000	1
2ST#11	50	0.0025, 0.005, 0.01, 0.025	1000	1
	50	0.05	420000	1
3ST#2	25	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	50	0.005, 0.01, 0.025, 0.05	1000	1
	100	0.005, 0.01, 0.025, 0.05, 0.075	1000	1
3ST#2L	25	0.075	180000	1
3ST#3	50	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	100	0.005, 0.01, 0.025, 0.05, 0.075	1000	1
3ST#4	25	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	50	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	100	0.005, 0.01, 0.025, 0.05, 0.075	1000	1
3ST#5L	25	0.1	180000	1
3ST#6	50	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	100	0.005, 0.01, 0.025, 0.05, 0.075	1000	1
3ST#8	25	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	50	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	100	0.005, 0.01, 0.025	1000	1
3ST#9	50	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	100	0.005, 0.01, 0.025, 0.05	1000	1
3ST#10L	25	0.1	1050	1
3ST#11A	25	0.01, 0.025, 0.05	1000	10
	25	0.1	1000000	10
3ST#11B	25	0.01, 0.025, 0.05, 0.1	1000	10
	50	0.01, 0.025, 0.05, 0.1	1000	10
	100	0.01, 0.025, 0.05	1000	10
	100	0.1	1000000	10
3ST#12	25	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	50	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	100	0.005, 0.01, 0.025, 0.05, 0.075	1000	1
	50	0.05, 0.1	1000	1
4ST#1	50	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	100	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
4ST#4	50	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
	100	0.005, 0.01, 0.025, 0.05, 0.1	1000	1
5ST#2	50	0.01, 0.025, 0.05	1000	10
	50	0.1	1000000	10

* Confining pressures were applied in the order as presented here

** Attempt was made to apply these shear strains

*** Number of cycles for each shear strain amplitude at the given confining pressure

**** Cyclic frequency for each test

- operate in a low frequency (< 2 Hz) cyclic torsional shear mode,
- operate in a high frequency (> 10 Hz) resonant column mode,
- test solid or hollow cylindrical specimens up to 2.8 inches in diameter,
- provide for specimen consolidation and volume change,
- develop shear strain amplitudes below 0.001 percent to more than 0.1 percent,
- apply a large range of confining pressures, and
- apply anisotropic stress states.

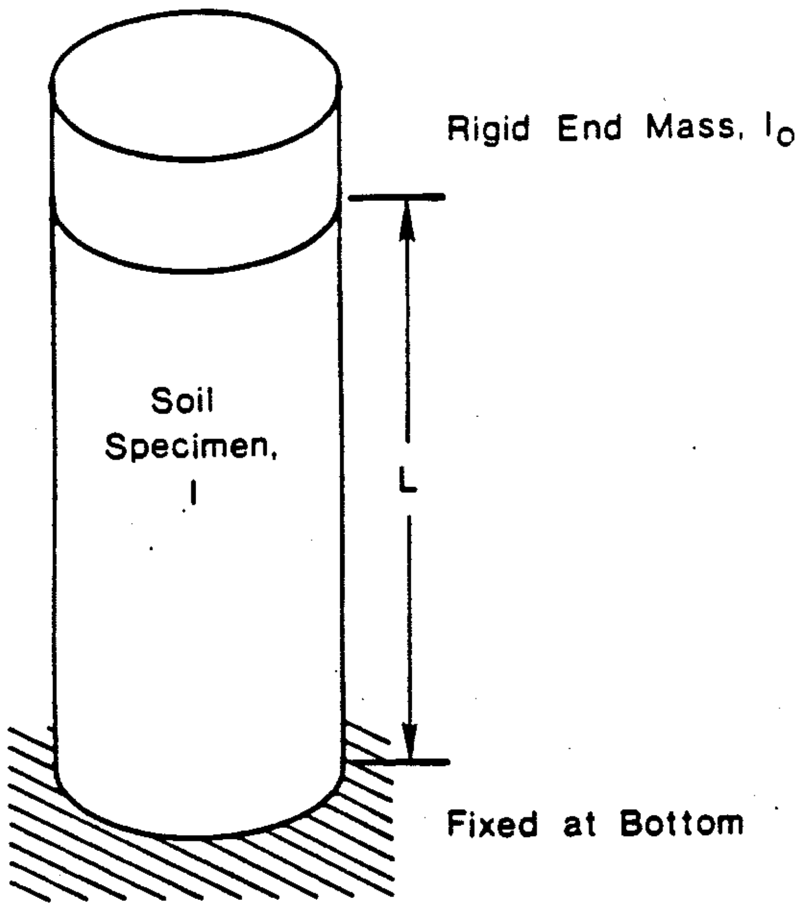
This resonant column/ torsional shear device is built in a fixed-free configuration -- the lower end of the specimen is rigidly fixed to the base of the device while the top end is allowed to vibrate in torsion (see Fig. 3.1). A detailed list of the parts which make up each of the major components is found in Tables 3.5 and 3.6.

3.5.2 Resonant frequency measurement system

To determine the shear modulus and material damping values for a specimen in the resonant column test, it is necessary to determine the resonant frequency. The resonant frequency measurement system is comprised of the following components as described in Table 3.6 :

- an accelerometer,
- a charge amplifier,
- a digital voltmeter,
- a period counter,
- a digital oscilloscope, and
- a triggering device.

These components allow the operator to determine the resonant frequency of the specimen for the entire range of shear strain amplitudes and to measure the viscous



$$\frac{I}{I_o} = \frac{\omega L}{V_s} \tan \frac{\omega L}{V_s}$$

$$G = \rho V_s^2$$

Figure 3.1 Fixed-Free Configuration of Specimens (after Isenhower, 1979)

Table 3.5 Basic Components Used in the Resonant Column/Torsional Shear Systems

1. Stokoe Cell		
•Basic Cell with Drive Plate, Coils, and 1.4" and 2.8" Platens	to confine, hold, and test solid cylindrical specimens	Structural Behavior Measurements, Inc. (SBEL)
•High Power Coils	to increase the torque capacity of the Stokoe Cell	SBEL
•Anisotropic Loading Apparatus	to allow the application of non-hydrostatic states of stress	SBEL
2. Cell Pressure System		
•Pressure Board with Regulator, Pressure Gage, Air Filter, and Pressure Transducer	to control confining chamber pressure	-NCSU Equipment
3. Height Change Measurement System		
•LVDT	to measure vertical height change	Schaevitz 500HR
•Signal Conditioner/ Amplifier	to read LVDT output	Schaevitz -NCSU Equipment
4. Diameter Change Measurement System		
•Proximty Probes (3)	to measure change in diameter	Kaman KD-2310 -2UB
•Oscillator Demodulator (3)	to condition proximity probe signals	Kaman KD-2310 -2UB
•DC Power Suppply	to power proximitors	Kaman P-3500
•Digital Voltmeter	to read output of the 3 proximity probes	Kaman P-3500
5. Drive System		
•Sine Wave Generator	to generate sinusoidal input current to drive coils	Rapid Systems PX2565
•Variable Gain Amplifier	to amplify input current to drive coils	Hewlett Packard HP6824A

Table 3.6 Resonant Frequency and Low Frequency Measurement Systems

6. Resonant Frequency Measurement System

•Accelerometer	to measure torsional accelerations	Columbia Research Labs 3030
•Charge Amplifier	to condition accelerometer output signal	Columbia Research Labs 4102M
•Digital Voltmeter	to measure accelerometer output voltage	Fluke Multimeter 27 -NCSU Equipment
•Period Counter	to measure resonant frequency	Computer Meas. Co. model 609 -NCSU Equipment
•Digital Oscilloscope	to monitor vibrations in the specimen	Rapid Systems and National Instruments Labview
•Trigger	to interrupt drive signal to obtain viscous damping curves	NCSU Equipment

7. Low Frequency (Torsional Shear) Measurement System

•X-Y Recorder	to record torque-twist curves	Moseley 7000A -NCSU Equipment
•Proximity Probes (2)	to measure torsional displacements	Bentley-Nevada model 30000
•Proximitor Conditioners (2)	to condition proximity probe signals	Bentley-Nevada model 7200
•Operational Amplifier	to subtract proximitor signals	Tektronix TM504 with AM501
•DC Power Supply	to power proximitors	Lambda LL-902-OV

damping properties of the specimen. These components are interconnected as shown in Fig. 3.2.

Basically, the accelerometer responds to the torsional vibration of the specimen and sends the signal to the signal conditioner. The signal conditioner linearizes the accelerometer signal by converting it to a voltage which can be read on the digital voltmeter. The peak voltage output represents the specimen resonant frequency for the shearing strain amplitude selected. The period counter is used to quickly check the value of the resonant frequency. The digital oscilloscope is used to monitor the specimen vibrations and to capture the record of the transient decay of the vibration curves during material damping evaluations. The triggering device is external to the computer and provides an interruption of the signal to the drive plate. The operator should also activate the trigger for the digital oscilloscope (by pressing the space bar on the computer) immediately after activating the external trigger. By activating the computer's trigger the transient decay (damping) curves can be captured on screen and saved in a file for later analysis.

3.5.3 Low frequency (torsional shear) measurement system

To determine the shear modulus and material damping values at low frequencies, the measurement system used must display the torque-twist behavior of the soil specimen being analyzed. The low frequency or torsional shear measurement system includes the following components as described in Table 3.6 :

- a DC power supply,
- a set of proximitor conditioners,
- a set of proximity probes,
- an operational amplifier, and
- an X-Y recorder.

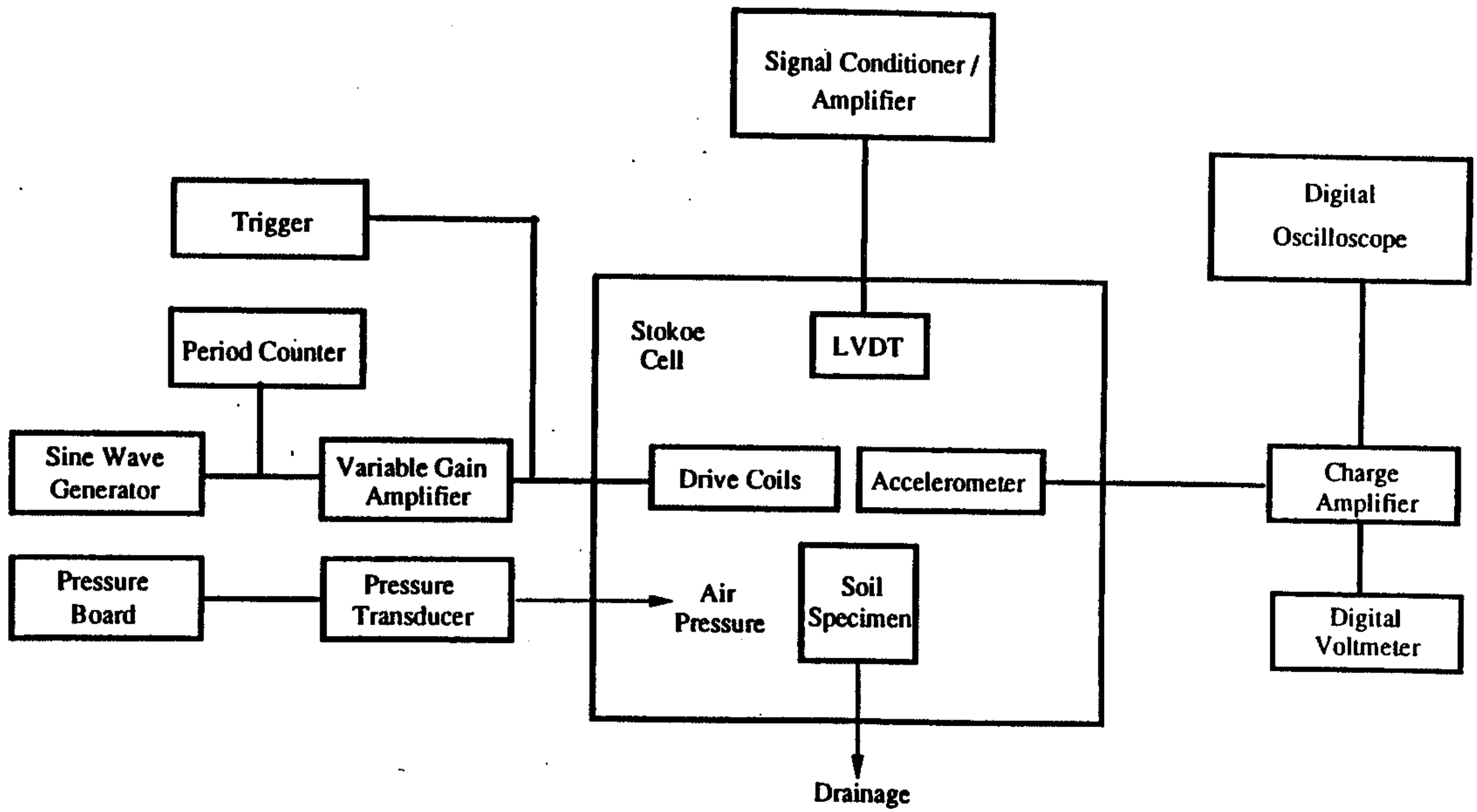


Figure 3.2 Resonant Column Instrumentation

These components allow the operator to test specimens at low frequencies (below 2 Hz). By having this capability, the effect of the number of loading cycles on a specimen can be observed. The hysteretic damping characteristics of the specimens can also be determined with torsional shear testing. The schematic for the complete resonant column/torsional shear device is shown in Fig. 3.3.

At low vibration frequencies, the accelerometer used in resonant column testing is no longer accurate. Thus, in the torsional shear tests, sensors called proximity probes are used to monitor displacements at the top of the specimen. These probes work by measuring the width of the air gap between the probe tips and a metal target fastened at the center of the drive plate.

In general, the DC power supply is used to power the proximitor conditioners. The conditioners in turn condition the signal to the proximity probes. The conditioners and probes together form an eddy current inductance measurement system. This system will give a linear output for a distance range of 0.01 to 0.065 inches between the probe tip and the metallic target. The output voltage for this range varies approximately from -1 to -18 volts (negative values are due to the DC power supply). As designed, the system can measure shearing strain amplitudes greater than 0.1 percent. However, the system is not designed for very low (below 0.0001 percent) or very high (1.0 percent) shearing strain amplitudes. Due to the design of the system and the accuracy of the measurements made, the shear strain cannot be accurately determined below 0.0001 percent. Above 1.0 percent, the probes would come into contact with the magnets.

The operational amplifier, along with the use of two probes, allows the low frequency measurement system to be insensitive to specimen bending which may be caused by sample anisotropy, twisted membranes, or other causes. The output from the proximity probes is passed through the operational amplifier subtraction circuit. As this

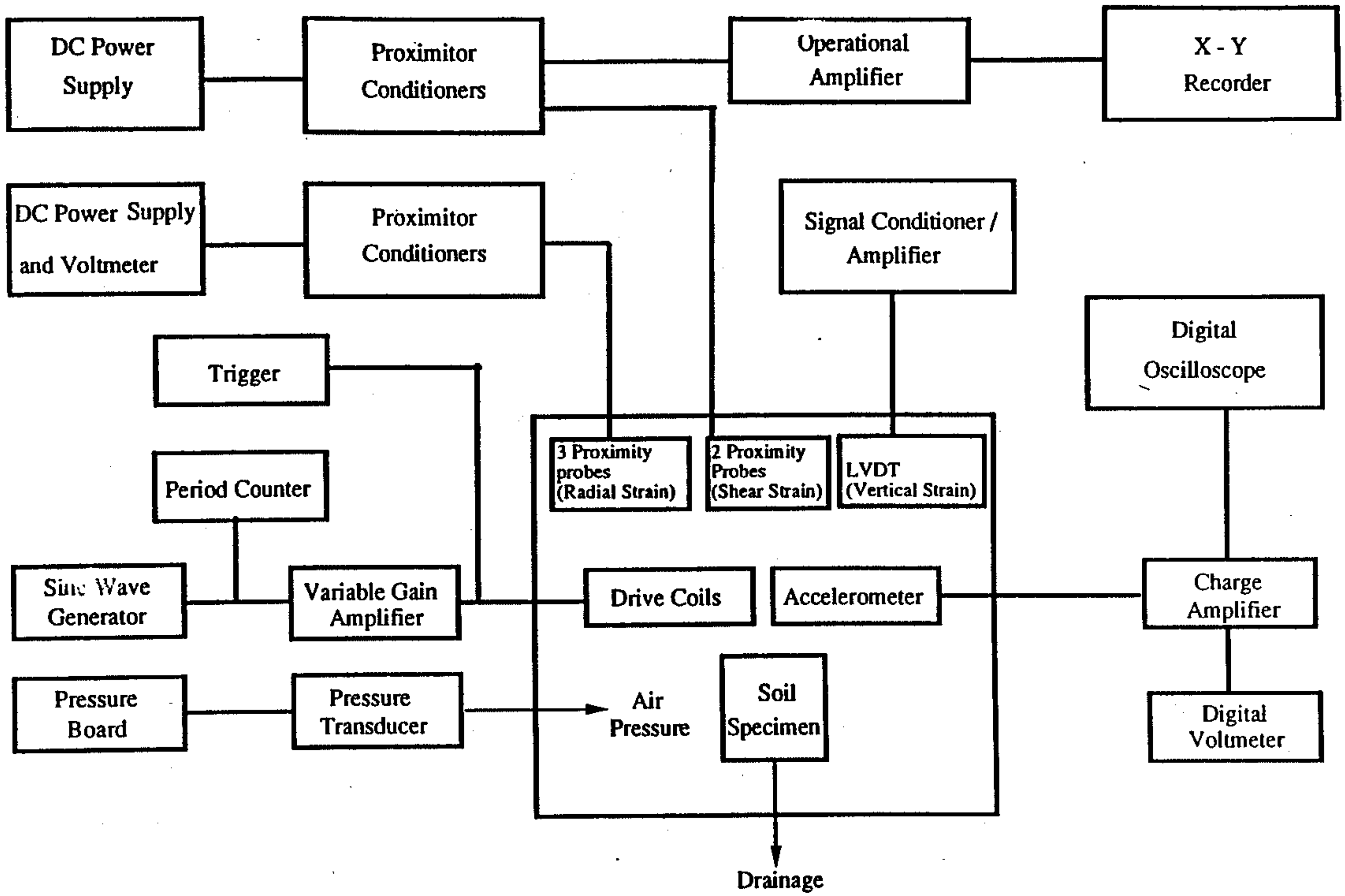


Figure 3.3 Schematic of Resonant Column/Torsional Shear Instrumentation

circuit subtracts the signal of one probe from the other, the output from the operational amplifier does not change. This is true for any bending motion -- perpendicular or parallel to the probe tips. Bending perpendicular to the probes does not change the gap between the probes and the target and thus causes no change in the reading of either probe. Bending towards or away from (parallel to) the probes causes an equal change in reading for each probe.

Lastly, the X-Y recorder is used to plot the input voltage and the torsional displacement of the specimen, which correspond to shearing stress and shearing strain respectively. This plot is referred to as a hysteresis loop. From this loop, both the shear modulus and hysteretic damping ratio can be determined.

3.6 Experimental Procedure

3.6.1 Specimen preparation

Before the sample was extruded from the Shelby tube, all necessary equipment such as rubber membranes, membrane expander, O-rings, and hand tools were gathered. The sample was then extruded vertically from the tube and a specimen roughly 6 inches in height was cut carefully. This specimen was then trimmed to the required height (usually 5.6" to 5.9") ensuring that there is no rocking or tilting of the specimen in the upright position. This makes the specimen preparation one of the most difficult and time consuming part of the test. Next, the length and diameter of the specimen were measured using dial calipers and a tape respectively.

After cutting the specimen, some of the trimmings were weighed and placed in the oven to measure the natural moisture content. The specimen itself was then carefully placed on the base pedestal. At this point the top cap was positioned on top of the specimen, the rubber membrane was placed over the specimen by means of the membrane stretcher, and the o-rings were placed over the membrane both on the top and the bottom end platens. The top and bottom platens were greased with a vacuum grease before the membrane was placed.

The outer cylinder was assembled next and the LVDT, accelerometer, proximity probes, and power connections were made. The cell was then closed and all the outer connections were made such that testing could begin.

3.6.2 Resonant column testing

The method of testing during Phase 1 involved applying a range of shearing strain amplitudes from 0.001 to greater than 0.1 percent to each specimen confined at the three confining pressures. The confining pressures selected were approximately 25, 50, and 100 kPa (0.5, 1, and 2 ksf).

Basically, after the specimen was trimmed, prepared, and placed in the resonant column/torsional shear device, the initial confining pressure of 25 kPa was applied. LVDT readings were made until the specimen was fully consolidated under the given pressure. At this point the resonant column tests were initiated. First, the resonant frequency was found by making a sweep of frequencies. This corresponded to the peak voltage output of the accelerometer for the torque applied. It was necessary during this sweep of frequencies to apply shearing strain amplitudes of less than 0.001 percent -- within the linear response range of the specimen. The shearing strain amplitude was calculated based on Eqn. 2.11 described in Section 2.5.4.

After determining the resonant frequency of the specimen, the accelerometer output for the initial shearing strain amplitude of 0.001 percent was estimated from Fig. 3.4 for specimens with a length to diameter ratio of close to 2. Next, the drainage lines to the specimen were closed, which is the standard procedure for all high amplitude resonant

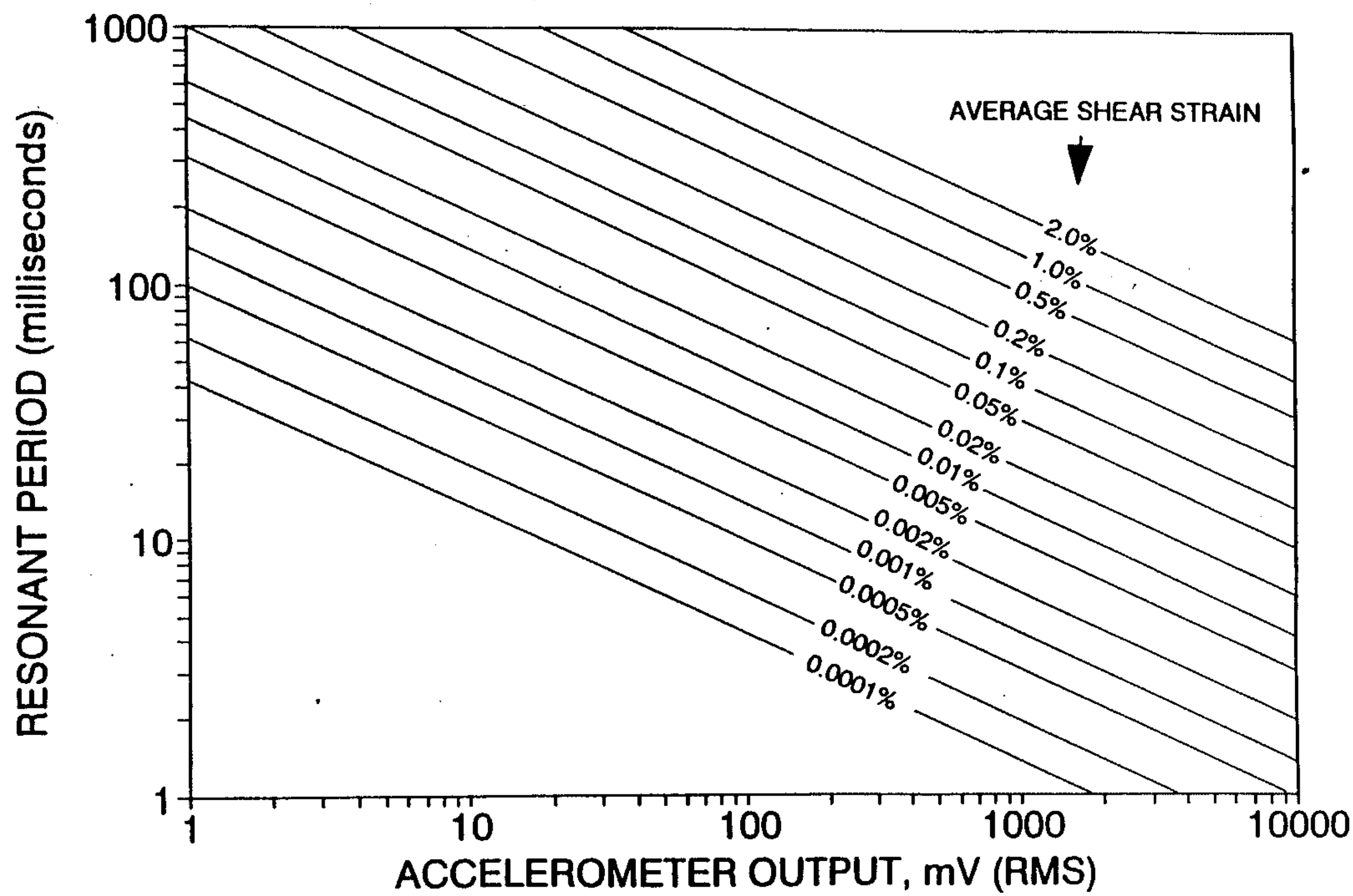


Figure 3.4 **Relationship Between Accelerometer Output, Resonant Period, and Shearing Strain Amplitude for a 2:1 Solid Specimen**

column tests. The gain was then increased on the variable gain amplifier such that the estimated output voltage was achieved. After checking to see if the resonant frequency had changed slightly due to the increase in shearing strain, readings for the resonant frequency and accelerometer output were recorded along with 3 records of the free vibration decay in the specimen. At this time the input voltage was reduced to zero and the drainage lines were opened for about 5 minutes of rest time before this process was repeated for the next shearing strain amplitude. During the test at each strain level, the specimen was vibrated from about 30 seconds to one minute.

After reaching the highest shearing strain amplitude desired, the confining pressure was increased to the next level. At the completion of testing at 100 kPa, the specimen was removed from the resonant column device and the necessary specimen parameters were recorded.

The calculations that were used in the data reduction for the resonant column test can be found in Appendix 3.2.

3.6.3 Torsional shear/resonant column testing

The combined torsional shear/resonant column tests of Phase II were conducted in a similar manner to the resonant column tests of Phase I. The same shear strain amplitudes and confining pressures were chosen for the specimens tested. The only difference was the addition of the torsional shear equipment to the overall set up and the torsional shear measurements made during testing.

In general, once the specimen was properly set up in the apparatus, the proximity probes were adjusted such that the output for each probe was approximately at the center of its measuring range. Also, it was desired to set the output for each probe as closely as possible to that of the other probe. If the values varied too much, it was impossible to use the lower gain settings on the X-Y plotter such that hysteresis loops may appear as diagonal lines. This, however, was only a difficulty at smaller shear strains.

Once the probes were set, the initial confining pressure of 25 kPa was applied. Again, LVDT readings were taken until the specimen was fully consolidated. After consolidation, a low amplitude (< 0.001 %) resonant column test was performed on the specimen to find the specimen's maximum shear modulus. This modulus value was then used to estimate the torque (i.e. voltage) required to twist the specimen at the various levels of selected shear strain amplitudes. Utilizing these shear strain and torque values along with the torque and proximitor calibration factors, prediction was made for the input voltage for the torque to be applied and the proximitor output voltage. This enabled the operator in setting the X-Y plotter for each strain level.

After the correct settings were chosen for the expected voltages, the input voltage and DC offset values were selected for the shear strain value selected. This was done with the leads to the sample disconnected to avoid applying torque to the specimen. It was necessary to change the DC offset so that the specimen would be twisted the same amount both positively and negatively. This was adjusted on the Rapid Systems function generator until a voltmeter showed the torque voltage to be equal in both directions.

The next steps were to disconnect the function generator, set the pen of the X-Y plotter at the desired starting position, prepare the period counter to count the number of loading cycles, and to mark the plotter paper as to the test number and scale settings. After performing these steps, the leads were reconnected to the specimen, and the function generator was reconnected to start the test.

In Phase I, during the torsional shear test, the specimen was twisted at 0.2 Hz for 100 cycles, with ten to twelve cycles recorded on the X-Y plotter. After the last cycle was recorded, the input voltage was set to zero and the equipment was adjusted for a resonant column test which was performed at approximately the same shear strain. In this manner, torsional shear and resonant column tests were performed for shear strains from 0.001 percent to greater than 0.1 percent.

A major problem encountered during the torsional shear test was with the proximity probes. Sometimes, due to specimen bending, the probes would either go out of their measuring range or the individual values would differ by an amount such that the lower gain settings on the plotter could not be used. When this occurred, the confining pressure had to be released, the cylinder disassembled, and the probes readjusted.

The calculations that were used in the data reduction for the torsional shear test can be found in Appendix 3.2 along with calculations for the resonant column test.

During the course of this project, the original Stokoe cell was modified to enable the measurement of change in radial dimensions as well during the tests. In the modified cell, three proximity probes (mounted on micrometers) were placed along the outer cylinder at 120° to one another. The height of these three probes corresponded approximately to the mid-height of the soil specimen. Thin circular metallic foils were stuck on the specimen and these served as the target for the three proximity probes. The output voltage of these probes was recorded along with the LVDT readings. Thus, the modified cell enabled the measurement of change in the vertical as well as the radial dimensions.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The experimental program was carried out in two phases. The testing program in *Phase I* was further divided in two parts. During *Phase I(a)*, resonant column tests were conducted on five specimens, each confined at 0.5, 1, and 2 ksf. In *Phase I(b)*, resonant column and torsional shear tests were conducted on three specimens, also confined at 0.5, 1, and 2 ksf. The main objective of the testing program in *Phase I* was to evaluate the shear modulus and damping characteristics of the residual soils at different shear strain amplitudes. This phase also included comparison of these parameters for like specimens, comparison between the values obtained by resonant column & torsional shear test for the same specimens, and correlation of these values to those reported by other authors/researchers.

In *Phase II*, torsional shear tests were performed to study the influence of shear strain amplitude, confining pressure, cyclic frequency, and the number of cycles on the dynamic densification of the residual soil specimens. This phase was also divided into three parts based on the manner in which the sample densification was evaluated.

In *Phase II(a)*, the change in vertical dimensions of the specimens was recorded. To calculate the change in volume of the specimen, it was assumed that the vertical strain is equal to the radial strain i.e. volumetric strain is three times the vertical strain recorded.

During this project, the Stokoe's cell was modified to enable the measurement of change in vertical as well as the radial dimensions of the specimen. Thus for specimens tested in *Phases II(b)* and *II(c)*, the change in both the vertical as well as radial dimensions was observed. As a result, the volumetric strain reported was evaluated based on the vertical and radial strains recorded.

4.2 Phase I(a) : Resonant Column Test Results

Before resonant column tests were conducted, each specimen was allowed to fully consolidate under the applied confining pressure. Due to the rapid initial compression characteristics of residual soils and the fact that the specimens were not fully saturated, complete consolidation occurred within ten minutes for each specimen and confining pressure. For each specimen, the shear modulus (G) and viscous damping ratio (D) were determined over a range of shear strains from less than 0.001 percent to greater than 0.1 percent. These values were then plotted as absolute and normalized values.

As shown in Figs. 4.1 and 4.2 for specimen RC-1, the results for shear modulus and damping ratio and the normalized plots for the same parameters definitely display the expected trends. That is, the shear modulus decreases, from a maximum value at shear strains of less than 0.001 percent, with increase in the shear strain amplitudes. Also, as the shear modulus decreases at higher shear strains, the damping ratio increases. Tests on specimens RC-2 through RC-5 generated similar results (Figs. A4.2.3 to A4.2.10, Appendix 4.2), though the specimens RC-3, RC-4, and RC-5 were from a different site than specimens RC-1 and RC-2. Specimens RC-3, RC-4, and RC-5 were cut from a somewhat softer material and thus, produced lower values for shear modulus.

In addition to showing the expected trends for shear modulus and material damping, a good correlation was found between results for like specimens. Figures 4.3 to 4.5 show the results for the shear modulus and viscous damping for specimens RC-3, RC-4, and RC-5 over each of the three confining pressures. Figures A4.2.11 to A4.2.13 (Appendix 4.2) show the same comparisons for specimens RC-1 and RC-2.

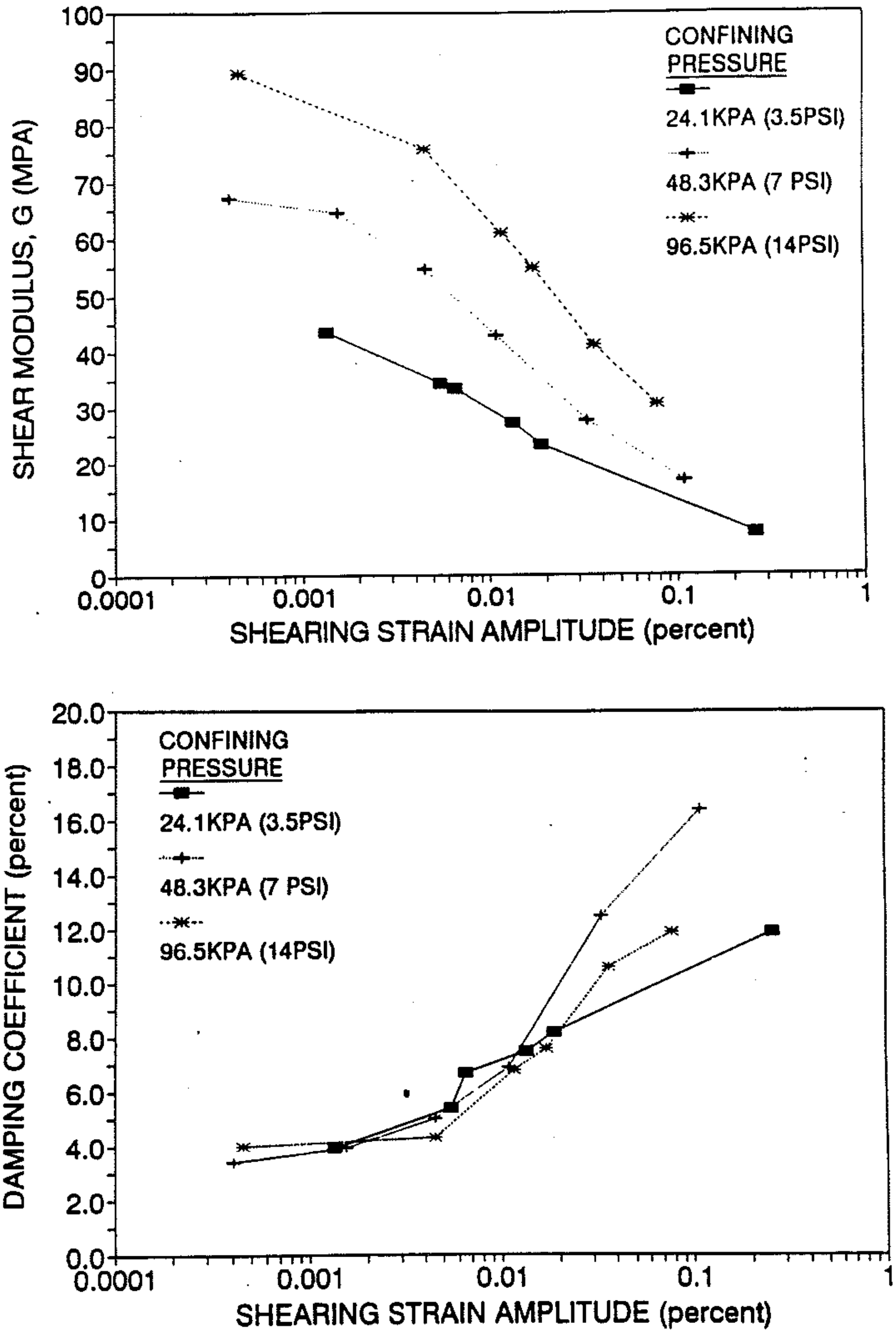


Figure 4.1 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-1

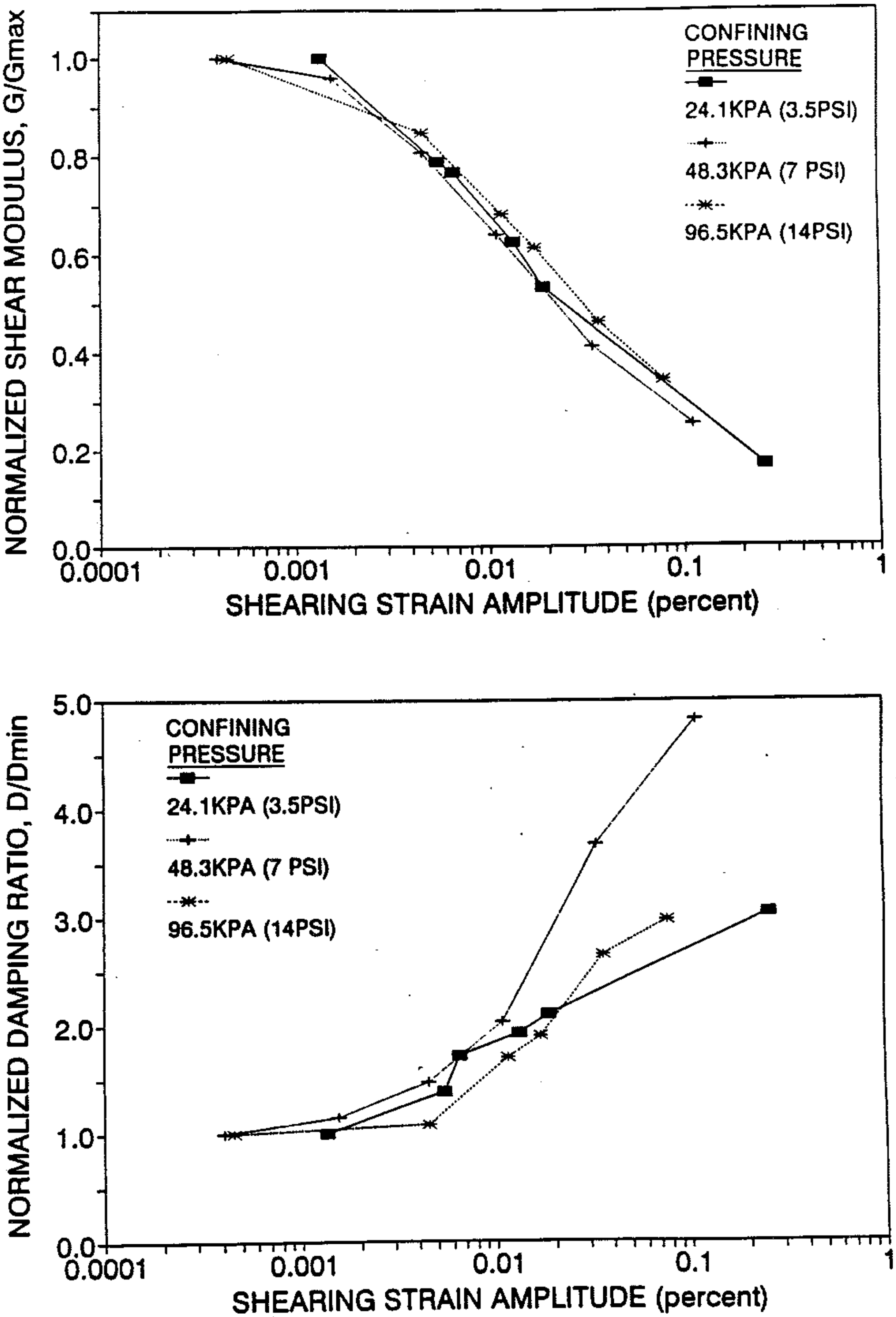


Figure 4.2 **(A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-1**

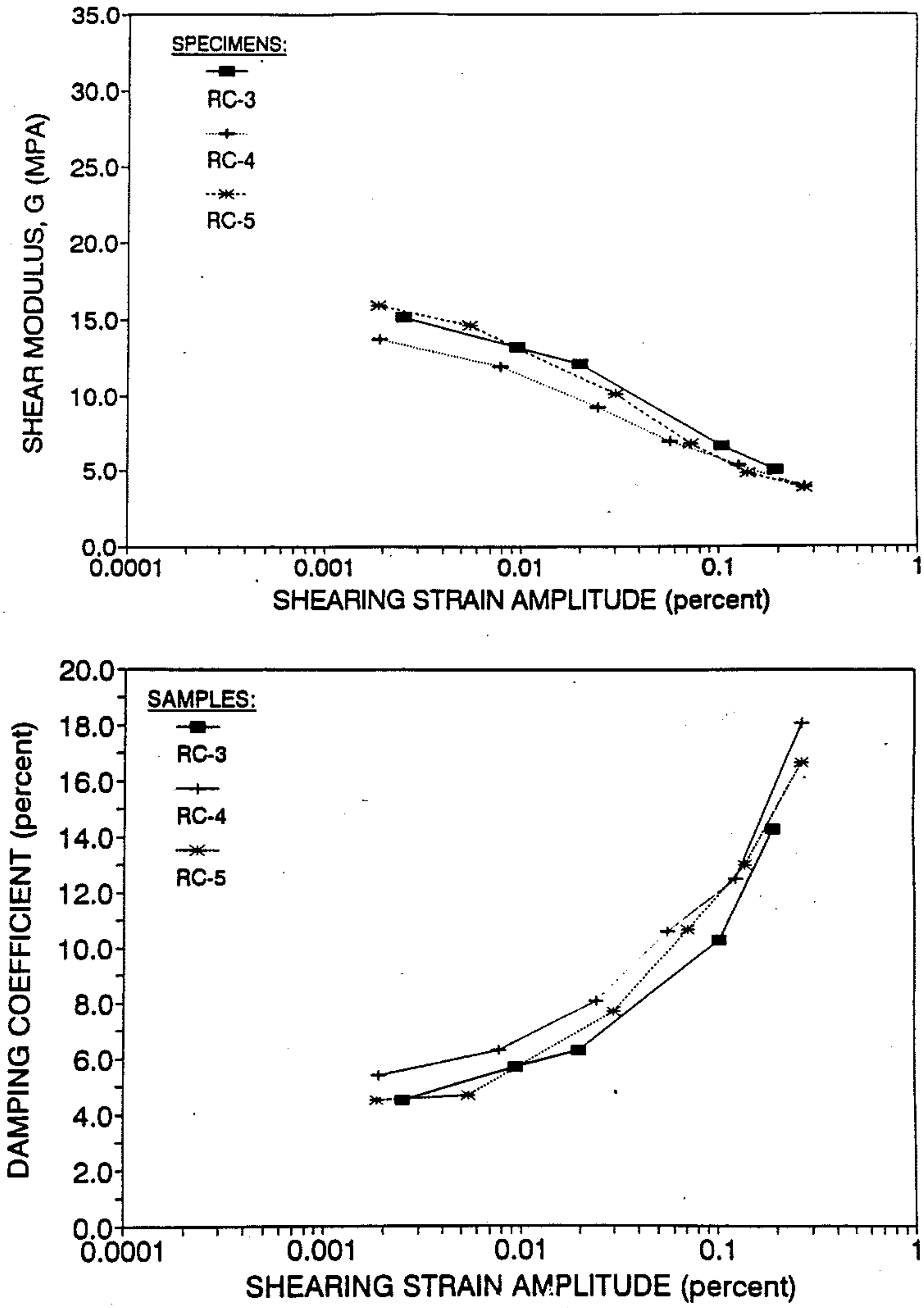


Figure 4.3 **(A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens RC-3, RC-4, and RC-5 at 25 kPa Confining Pressure**

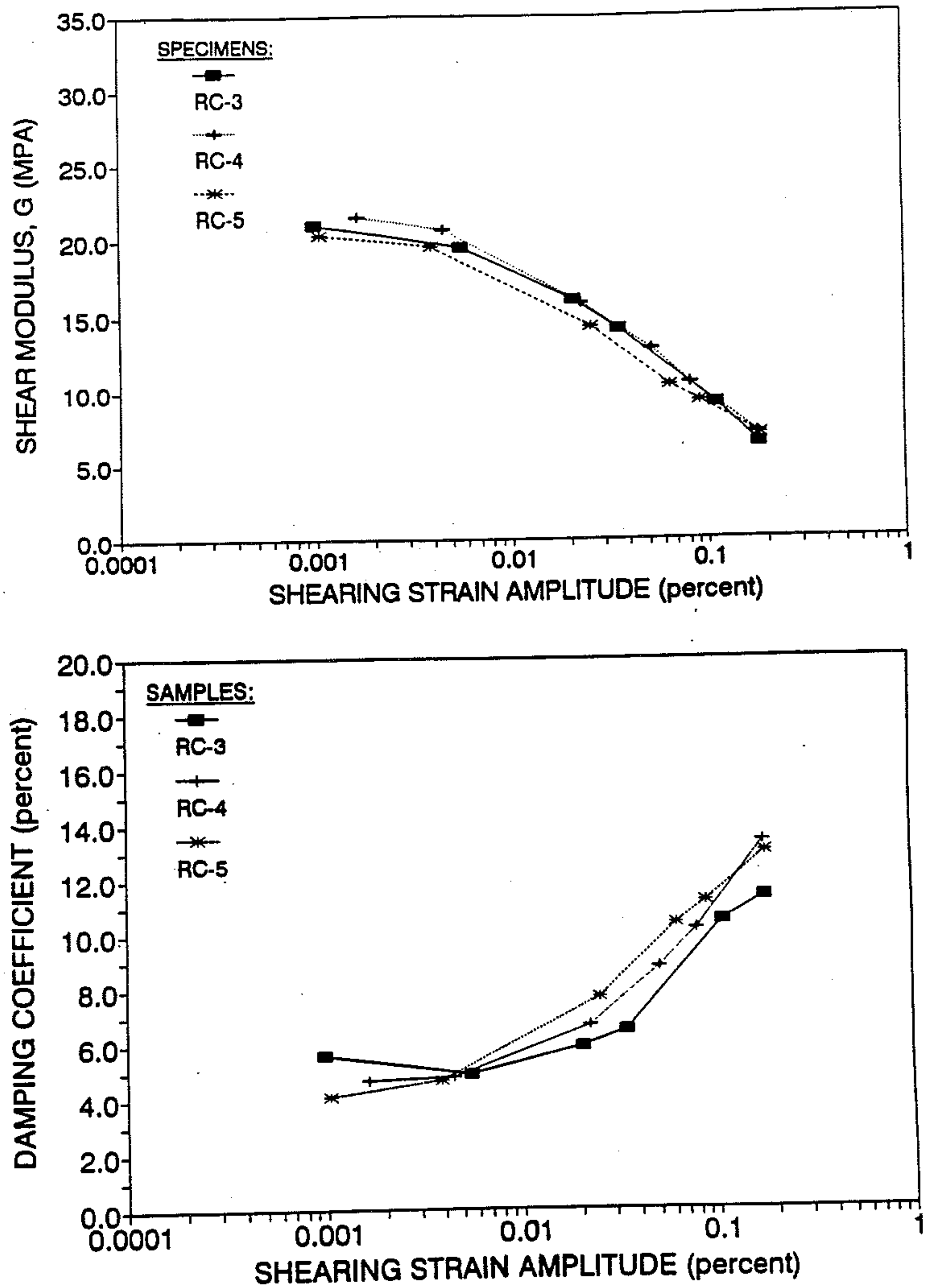
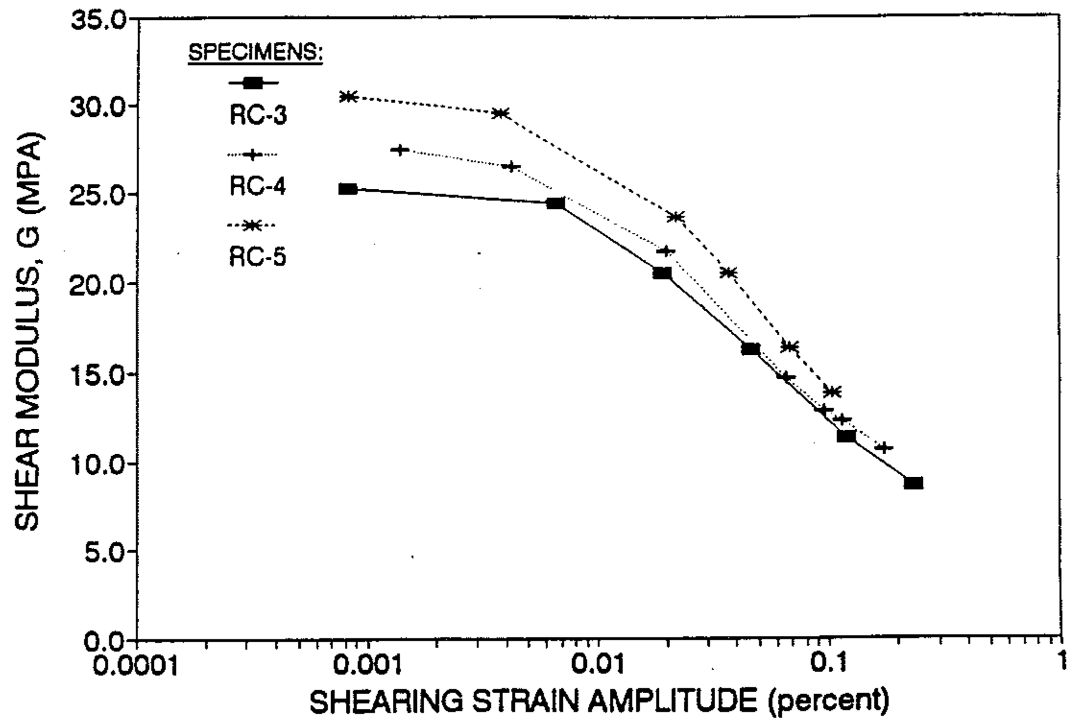


Figure 4.4 **(A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens RC-3, RC-4, and RC-5 at 50 kPa Confining Pressure**



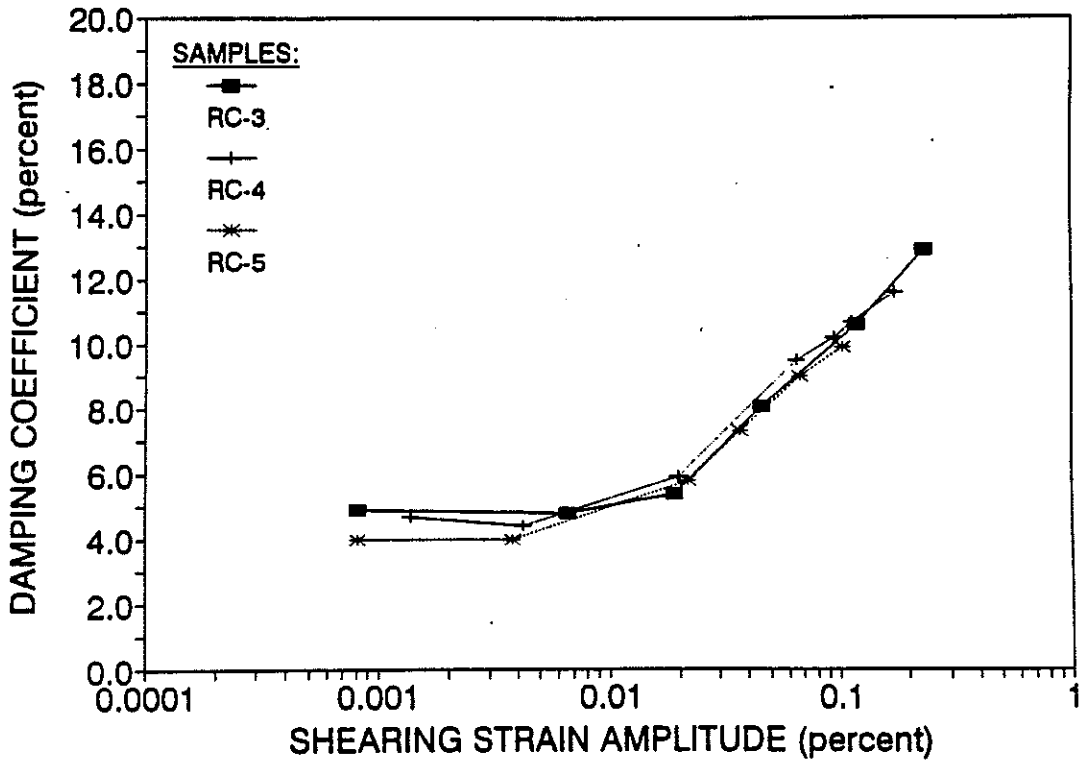


Figure 4.5 **(A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens RC-3, RC-4, and RC-5 at 100 kPa Confining Pressure**

The plot of the normalized shear modulus and damping ratio values versus shearing strain amplitude for all of the Phase I(a) specimens (see Fig. 4.6) shows very consistent results for these two residual soils. These plots show that if a good estimate for the maximum shear modulus (Gmax) and minimum damping ratio (Dmin) can be obtained, the behavior at higher shear strain can be predicted reasonable confidence. Section 5.4 also details how shear modulus and damping ratio can be predicted at any required shear strain amplitude if Gmax and Dmin are known.

A detailed data summary and graphical presentation for the results of Phase I(a) can be seen in Appendices 4.1 and 4.2 respectively.

4.3 Phase I(b) : Resonant Column/Torsional Shear Test Results

As for the resonant column test specimens in Phase I(a), each of the three Phase I(b) specimens were prepared and consolidated in the same manner. Also, as described in Section 3.6.3, these tests were performed by alternating a torsional shear test and a resonant column test at each selected shear strain amplitude following an initial low amplitude (< 0.001 percent) resonant column test to define an estimated maximum shear modulus. For each specimen, the shear modulus (G) and material damping (D) were plotted for both the resonant column and torsional shear tests (first load cycle) over a range of shear strains from less than 0.001 percent to greater than 0.1 percent. These values were plotted as absolute and normalized values, as in Phase I(a).

The results for shear modulus and material damping over the range of selected shear strains once again showed a distinct decrease in shear modulus and increase in material damping with increasing shear strain as shown in Figs. 4.7 and 4.8 for specimen TS-2. However, when compared to the resonant column values, the damping values for the torsional shear test tend to be a bit more erratic. The rea[illegible] for this could be related

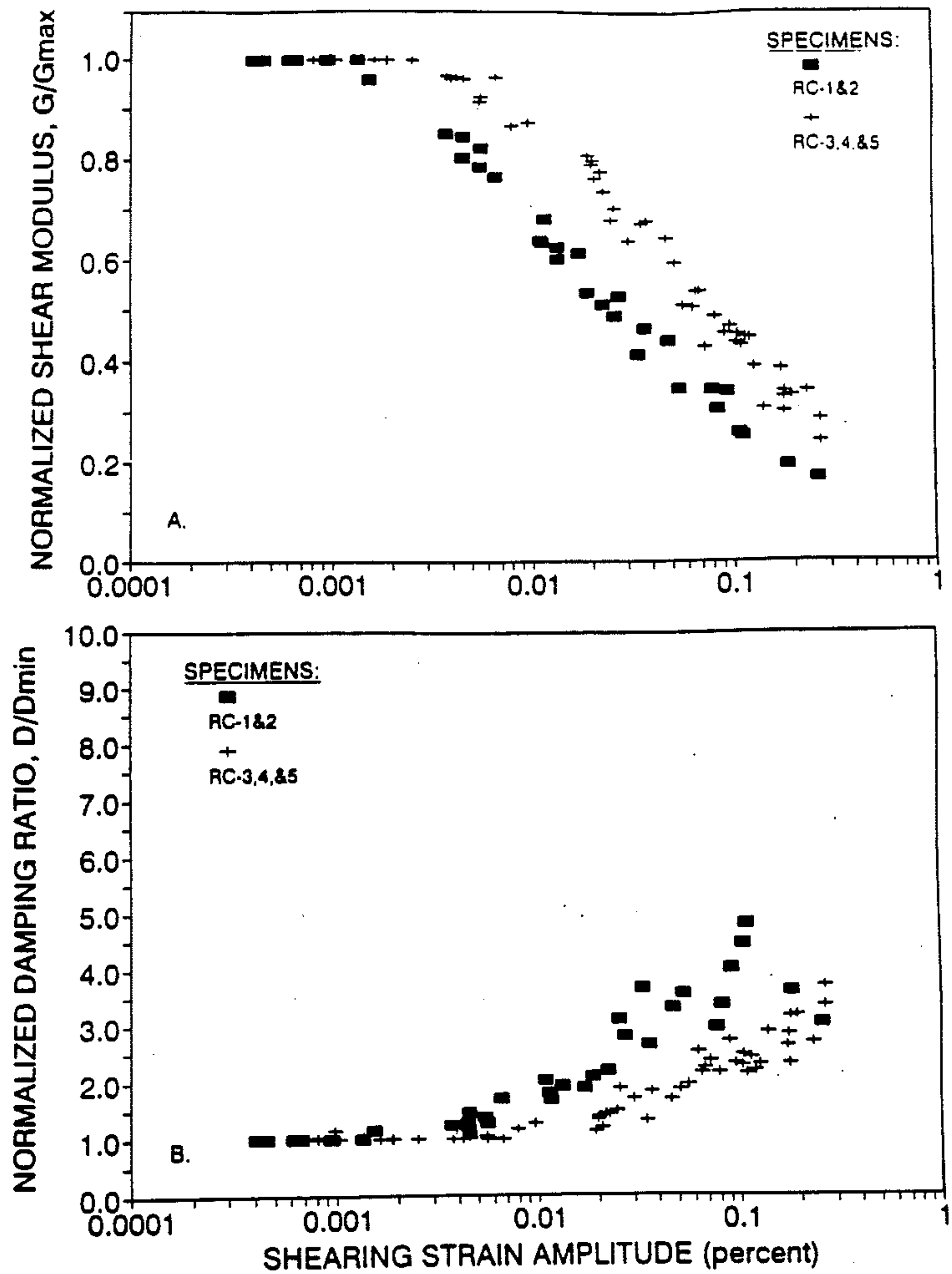
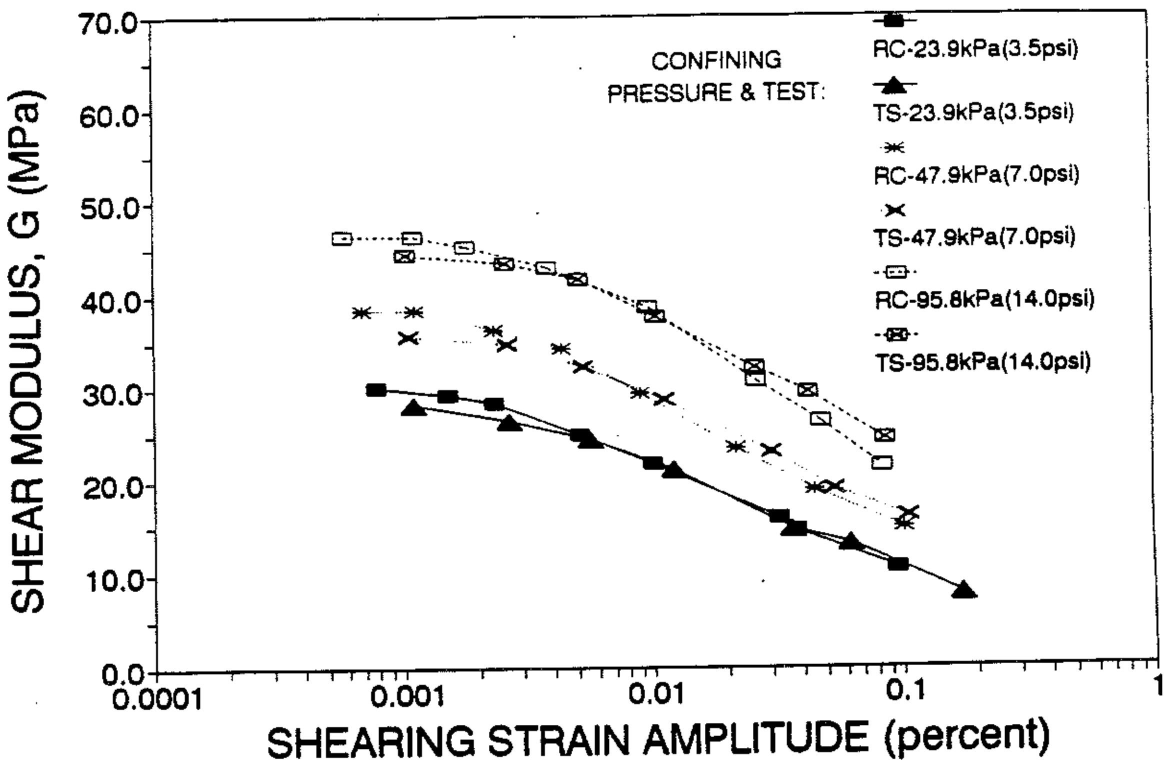


Figure 4.6 **(A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimens RC-1,RC-2, RC-3, RC-4, and RC-5 at 25, 50, and 100 kPa Confining Pressures**



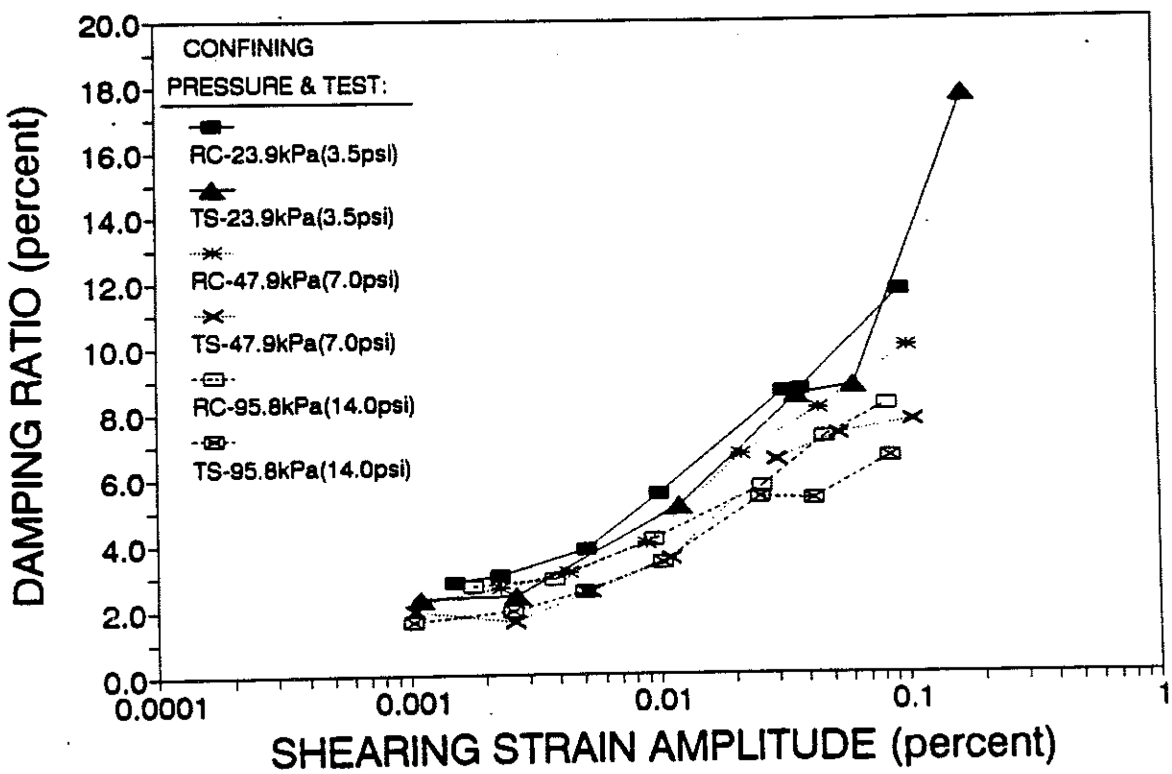
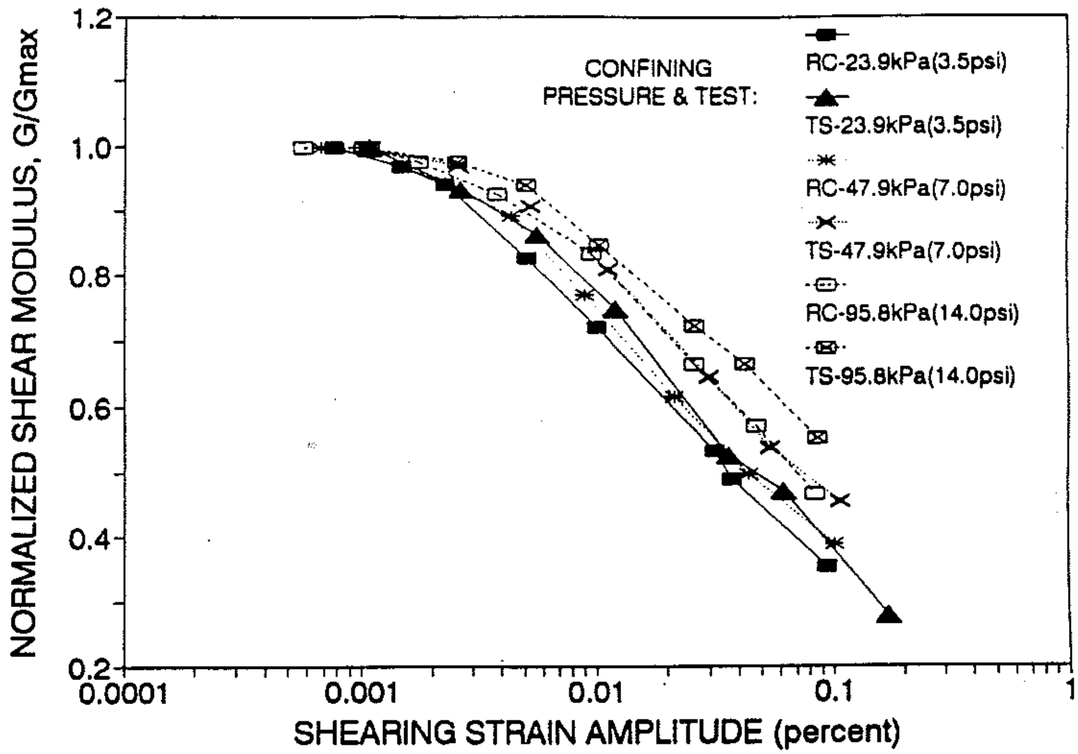


Figure 4.7 **(A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimen TS-2**



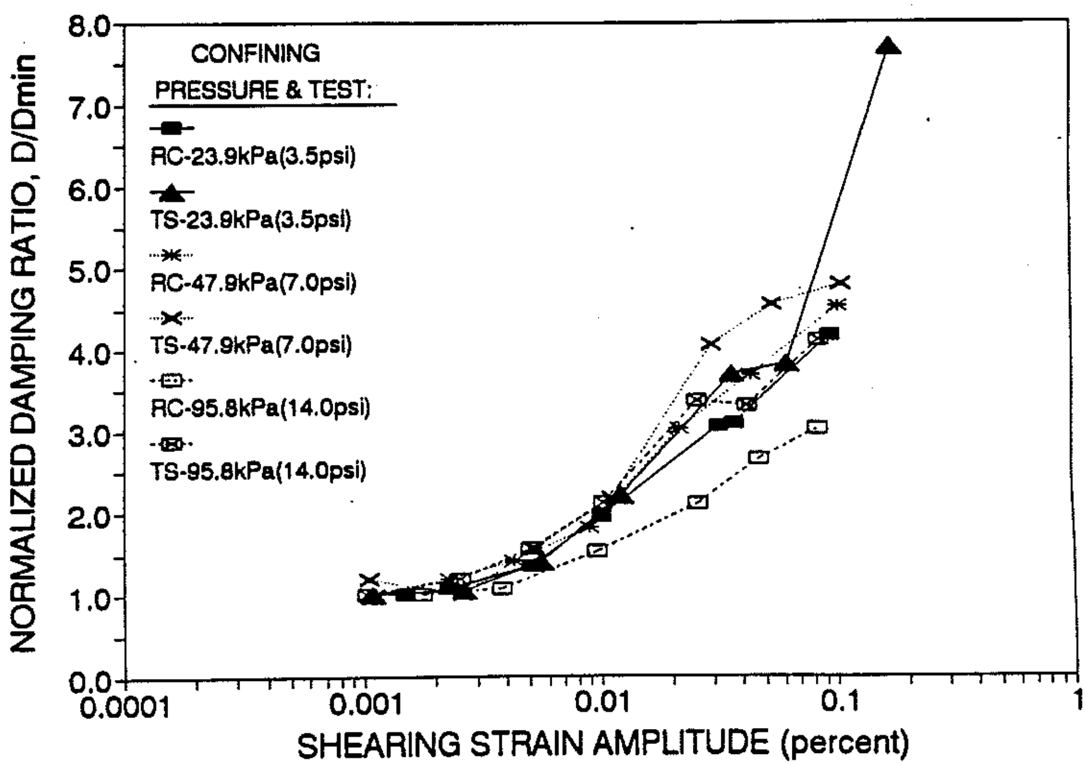


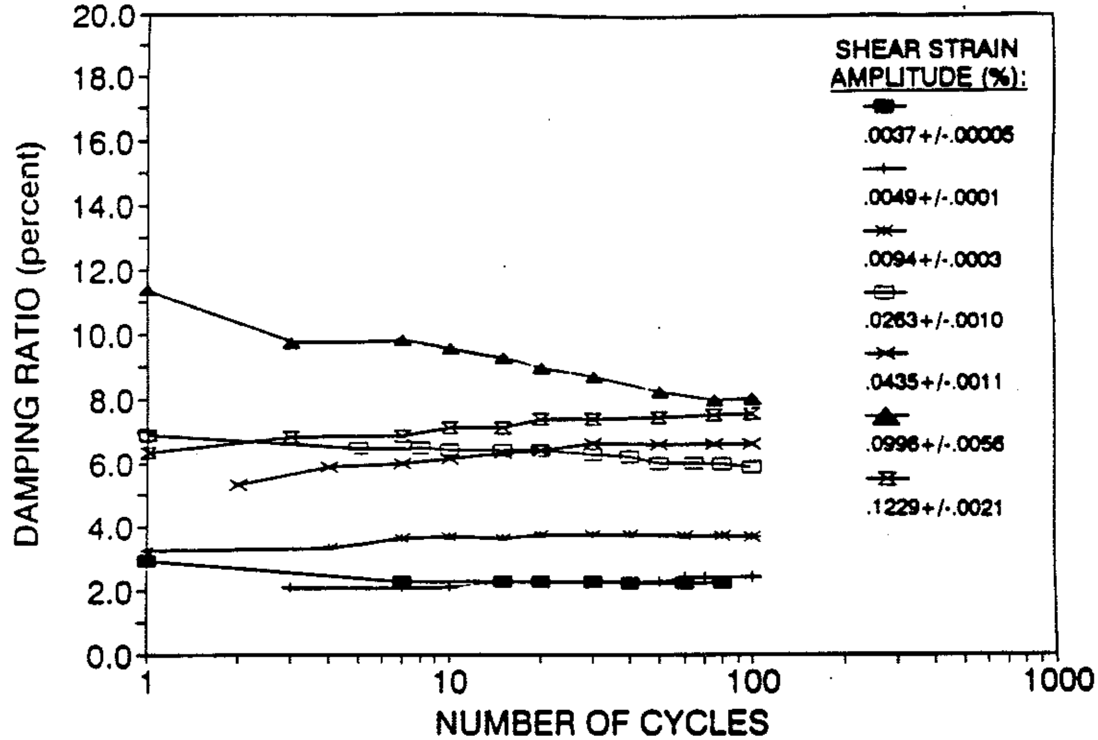
Figure 4.8 **(A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimen TS-2**

to obtaining the precise width of the hysteresis loops (B dimension), especially at lower shear strains. It was also observed that the values for shear modulus from the resonant column test were higher than the shear modulus values from the torsional shear test at lower shear strain amplitudes but decrease to lower values than the torsional shear test at higher shear strains. Other authors have explained this behavior as being related to shearing strain rate (see Section 4.4). The results for shear modulus and material damping for specimens TS-1 are shown in Figs. A4.2.17 & A4.2.18 and for specimens TS-3 in Figs. A4.2.21 & A4.2.22 respectively.

From the plots of shear modulus and material damping versus number of loading cycles, little effect was observed with increase in the number of loading cycles (Figs. A4.2.23 to A4.2.29). Only specimens TS-1 and TS-2, each confined at nearly 25 kPa (0.5 ksf) (as shown in Fig. 4.9), exhibited some influence of number of cycles on material damping. Little effect was observed at higher confining pressures.

The shear modulus and material damping values for each of the Phase I(b) specimens taken from the same sample (Figs. A4.2.30 to A4.2.32) are in quite good agreement. Specimens TS-1 did, however, show slightly higher values of shear modulus than did TS-2 and TS-3.

As part of the experimental program in Phase I, it was desired to gain an insight into the effect of strain history on shear modulus and damping. To this end, tests were run on specimen TS-3 at nearly 100 kPa (2 ksf) confining pressure without prior testing at lower confining pressures. The results were plotted against results for specimens TS-1 and TS-2 at 100 kPa as shown in Fig. 4.10. The results were nearly identical to specimen TS-2, with values for TS-1 being slightly higher, as mentioned previously. This seems to indicate that stress history at lower confining pressures has little effect on a specimen's behavior, thus supporting the use of stage testing.



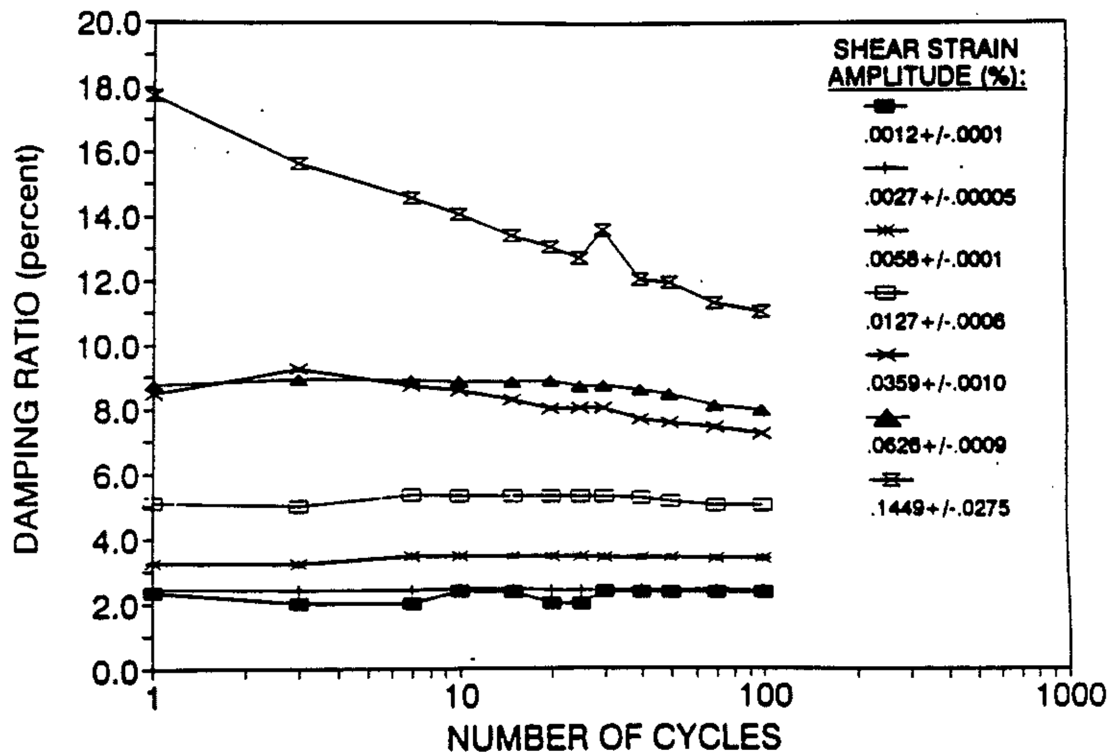
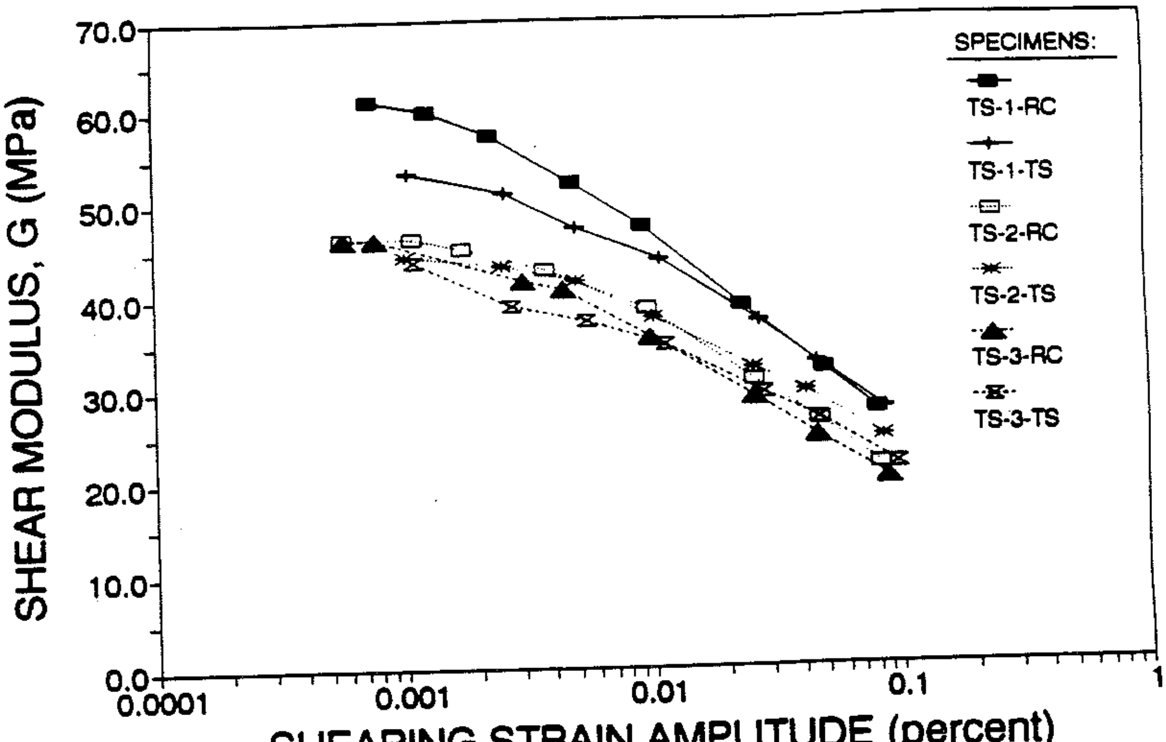


Figure 4.9 **Damping Ratio as a function of Number of Loading Cycles at 25 kPa Confining Pressure for Specimens TS-1 and TS-2**



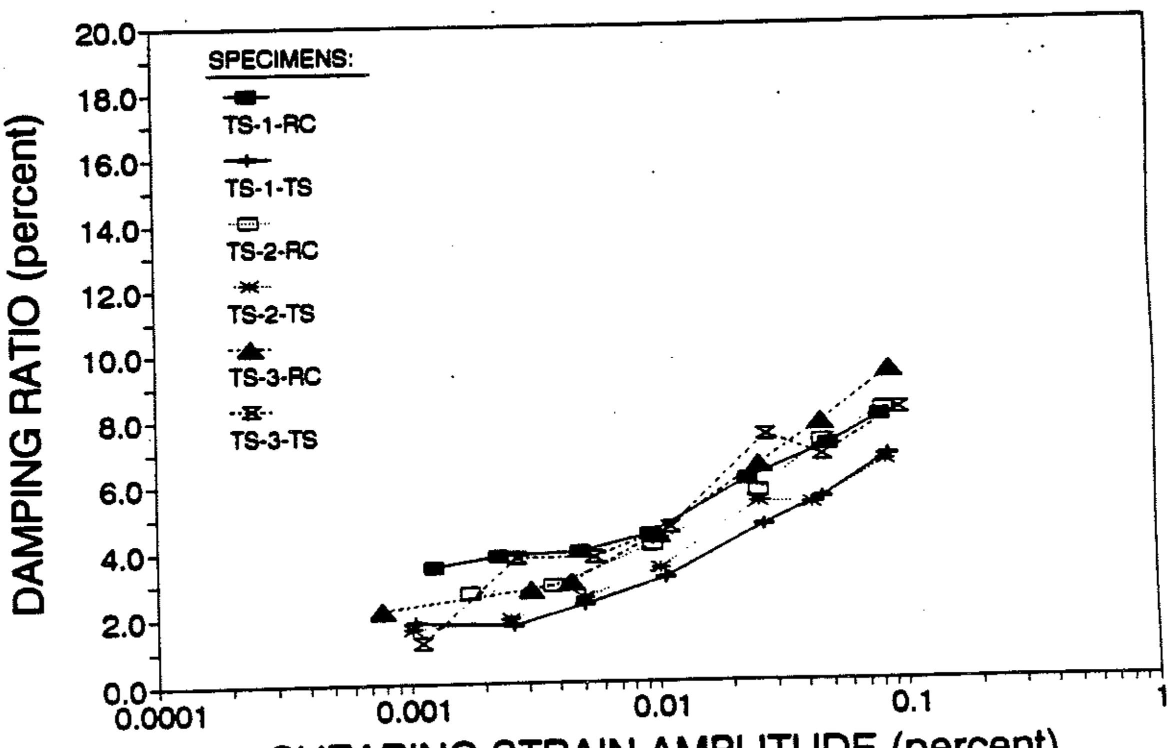


Figure 4.10 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens TS-1, TS-2and TS-3 at 2 ksf Confining Pressure

In plotting the normalized values of shear modulus and material damping for the three Phase I(b) specimens along with the values determined form the resonant column tests of Phase I(a) (Fig. 4.11), one first notices the extra scatter induced by the Phase I(b) results. With only three specimens tested in Phase I(b), it is difficult to evaluate the reasons for this scatter; however, several issues are suggested in Section 4.4. Nevertheless, the majority of values match up fairly well with the values obtained from the two residual soils tested in Phase I(a).

A detailed data summary and graphical presentation for the results of Phase I(b) can be seen in Appendix 4.1 and 4.2 respectively.

4.4 Comparisons with Studies on Different Soils

Figure 4.12 compares the normalized shear modulus and material damping values as a function of shear strain obtained during this study (shaded areas) to those values from Seed and Idriss (1970), Stokoe and Lodde (1978), and Isenhower (1979). While the Seed and Idriss values were from sands and saturated clays, as indicated on the graphs, the Stokoe and Lodde and Isenhower values were from studies performed on San Francisco Bay Mud. Also shown in Fig. 4.13 are the results of studies performed on offshore silty samples (Stokoe et al. 1980) which are plotted against the Seed-Idriss, Stokoe-Lodde, and Isenhower curves as well.

There are two main reasons for the scatter observed in these figures for the results of this study and those of the Stokoe et al. study. First, the level of confining pressure has the effect of changing the absolute and normalized values, as shown in Fig. 4.14 for normalized shear modulus and absolute values of damping. That is, for higher confining pressures, the normalized shear modulus increases and the normalized damping values decrease. Secondly, normalized data for specimens taken from different samples is likely

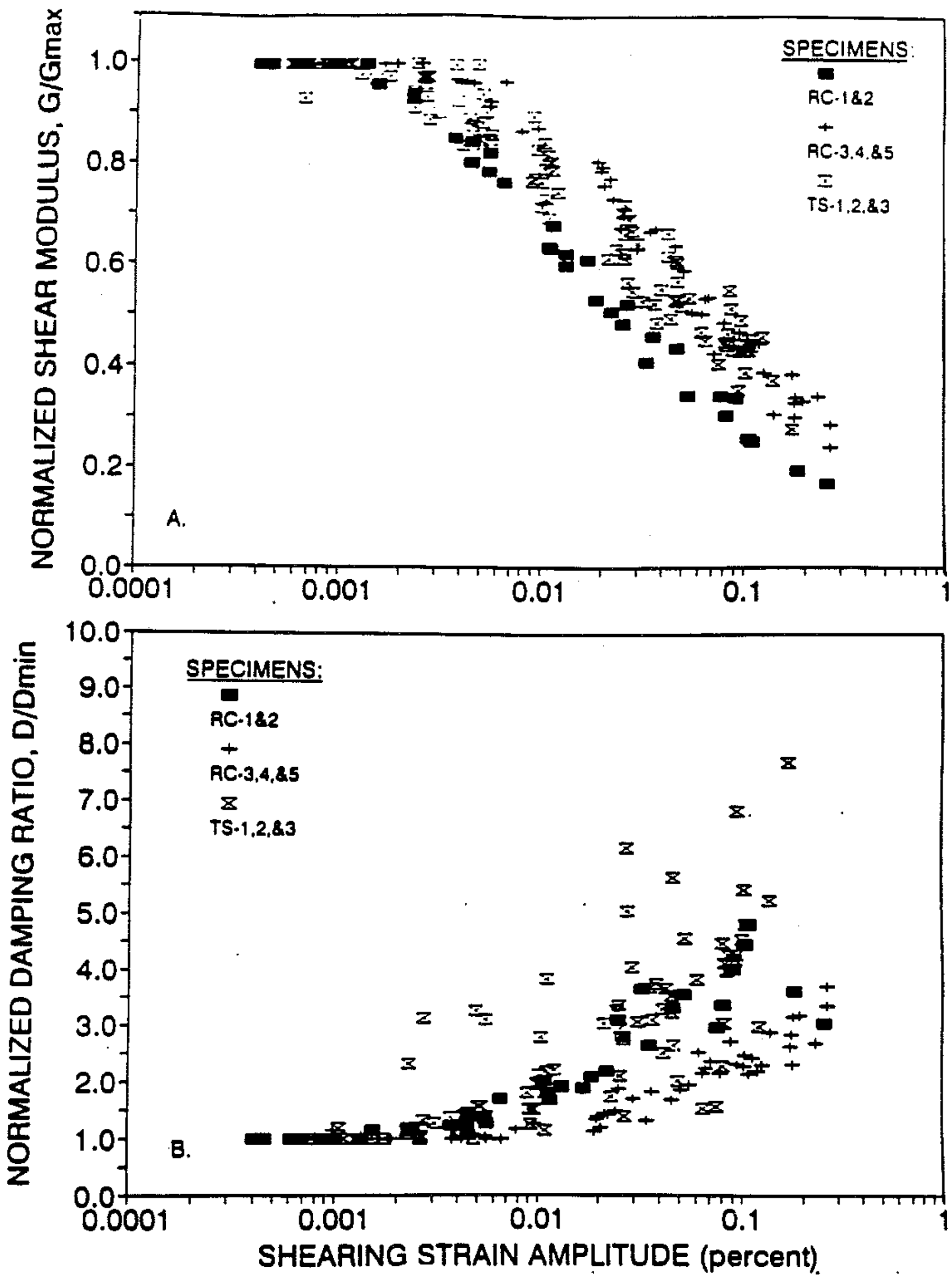


Figure 4.11 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Phase 1 and Phase 2 Specimens at 25, 50, and 100 kPa Confining Pressures

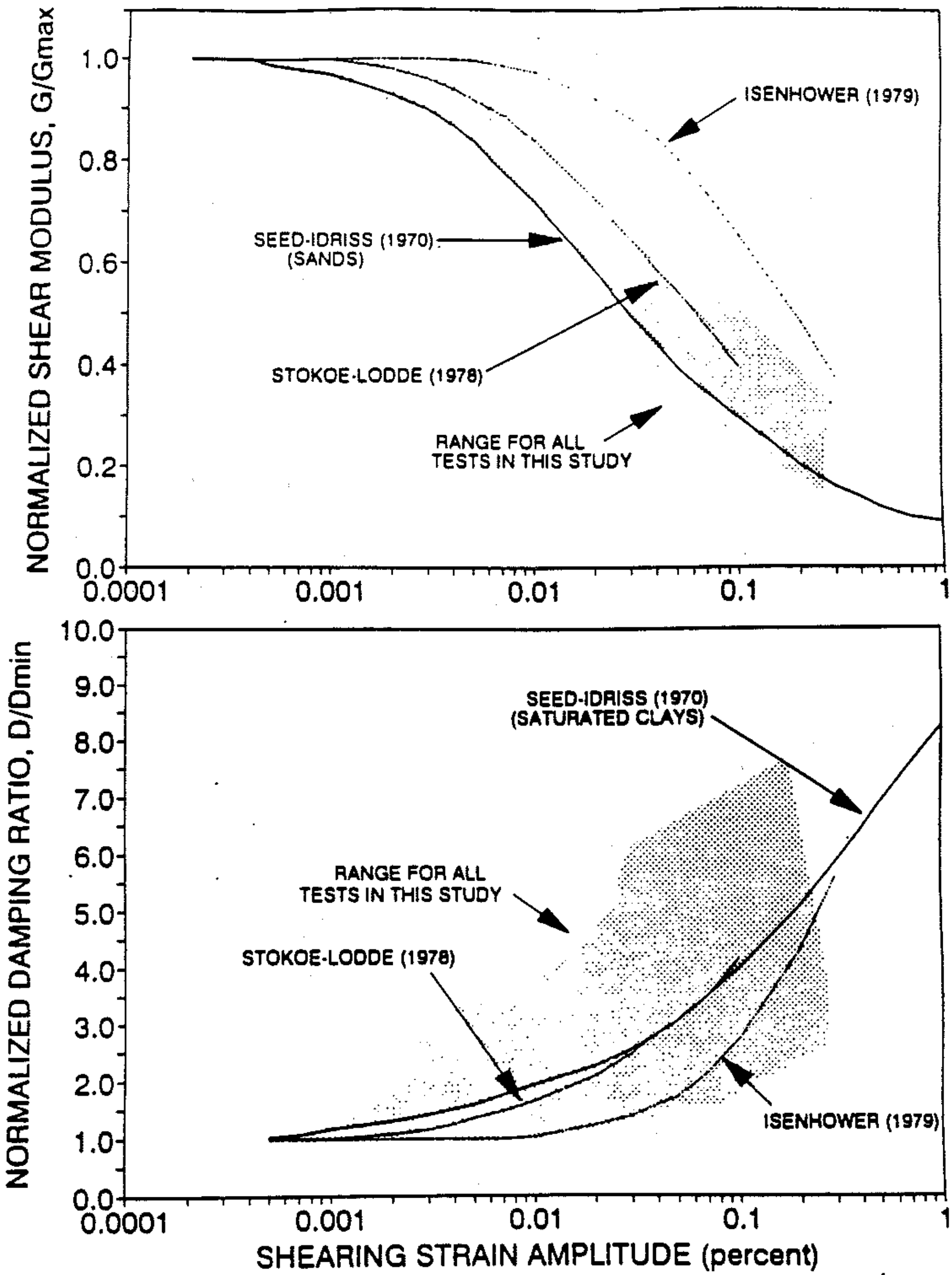


Figure 4.12 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for the Results of This Study Versus Results from Seed and Idriss (1970), Stokoe and Lodde (1978), and Isenhower (1979)

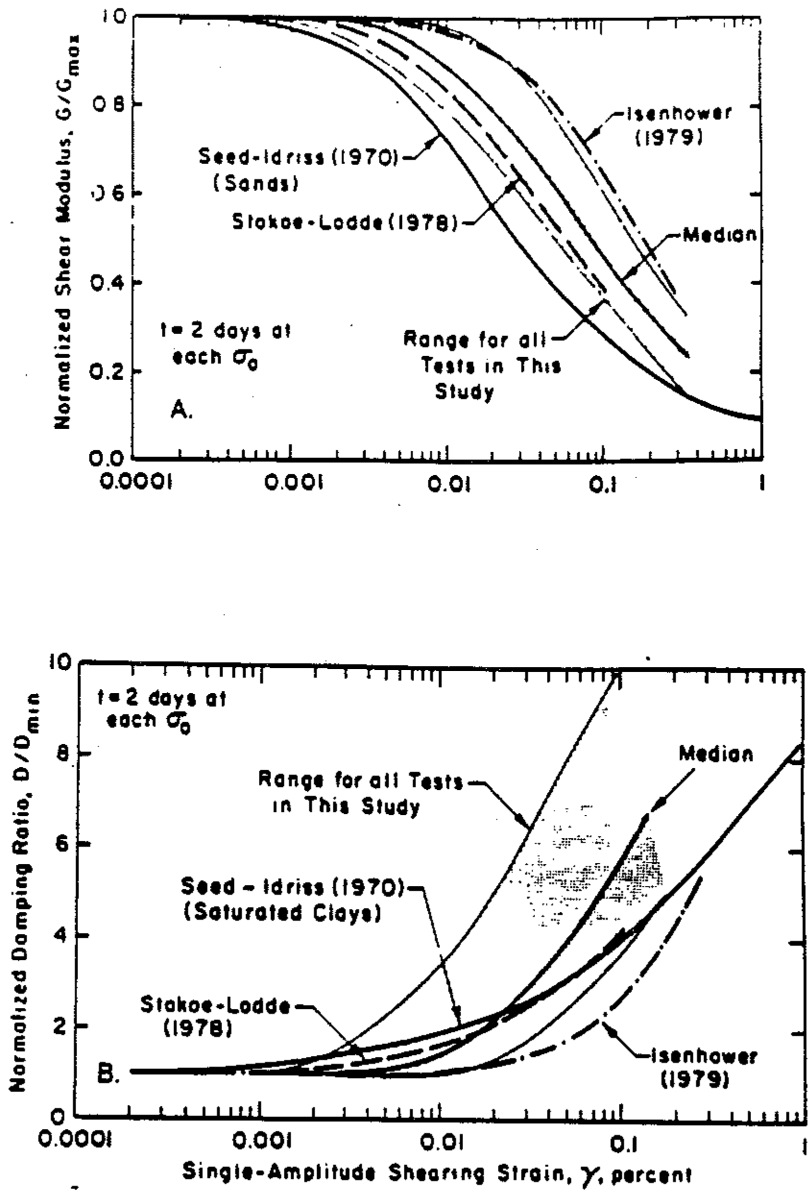
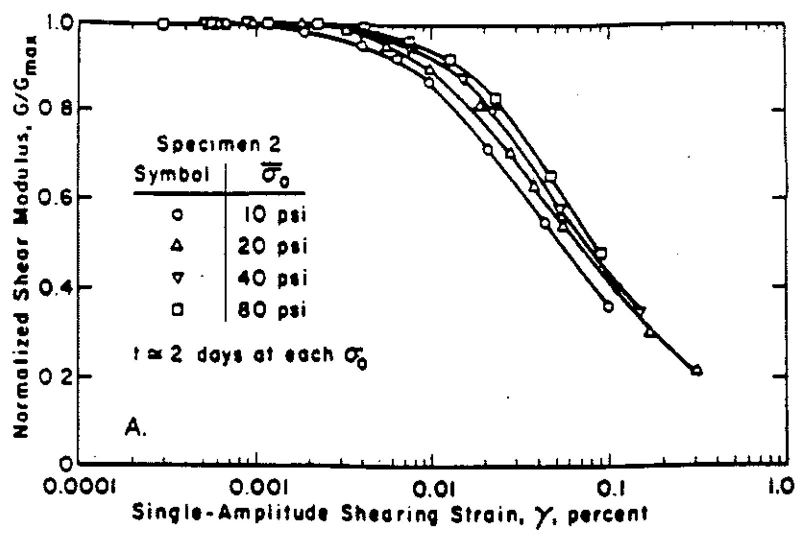


Figure 4.13 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for the Results of Stokoe et al. (1980) Versus Results from Seed and Idriss (1970), Stokoe and Lodde (1978), and Isenhower (1979)



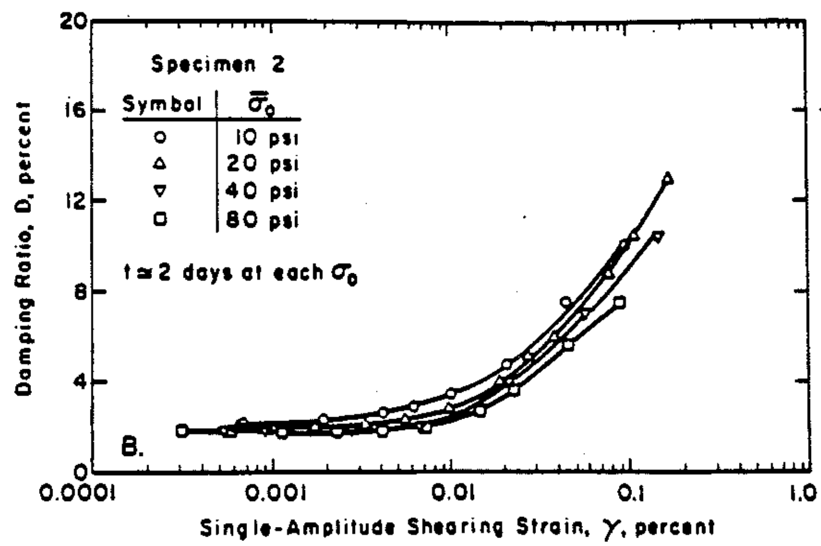


Figure 4.14 (A.) Normalized Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Offshore Silty Samples (after Stokoe et al. 1980)

to cause some scatter.

In comparing the results of resonant column and torsional shear tests for the same specimens, similarities were seen between the results of this study and the results of the Stokoe et al. (1980) study. As shown in Fig. 4.7(A) for specimen TS-2, the shear modulus values from the resonant column test are higher at lower shear strain amplitudes than those from the torsional shear test, as mentioned in Section 4.3. Stokoe et al. also found this to be the case as shown in Fig. 4.15. Stokoe et al. (1980) and Isenhower (1979) have indicated this to be an effect of shearing strain rate. As shown in Fig. 4.16 for San Francisco Bay Mud (Isenhower 1979), the shear modulus is lower for lower shearing strain rates, i.e., at shear strains of 0.0355% and below; but for a shear strain of 0.11%, the modulus values are about the same for the first cycle of torsional shear loading and the resonant column test.

A comparison of damping values obtained from the resonant column and torsional shear tests for the Stokoe et al. study is shown in Fig. 4.17. The higher damping values for the torsional shear test (first load cycle), as seen in this figure, were not seen clearly in this study, perhaps due to the aforementioned scatter.

Another thing not observed in this study was any significant effect of the number of loading cycles on the shear modulus and damping values of the specimens analyzed, as discussed in Section 4.3. Stokoe et al. (1980) display a more clear effect of the number of loading cycles on these parameters for a clayey material as shown in Fig. 4.18.

4.5 Phase II : Torsional Shear Test Results For Dynamic Densification

During the second phase of the project, 25 residual soil specimens from five different sites were tested to study the densification due to construction vibrations and to

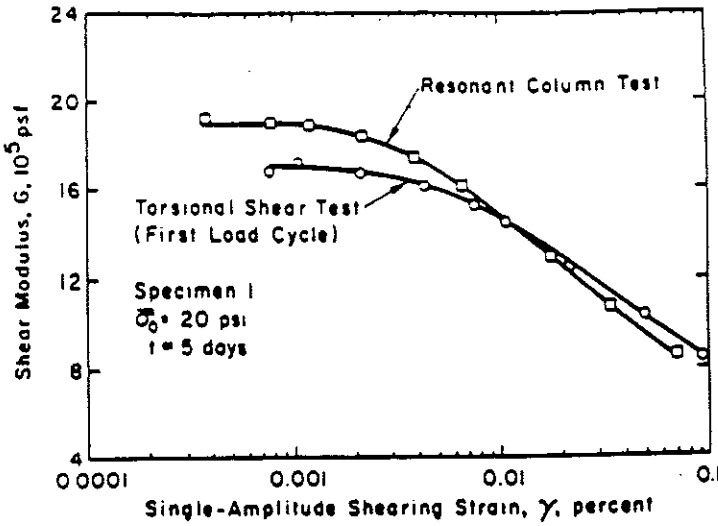


Figure 4.15 Comparison of Shear Moduli by Resonant Column and Torsional Shear Tests for Offshore Silty Samples (after Stokoe et al. 1980)

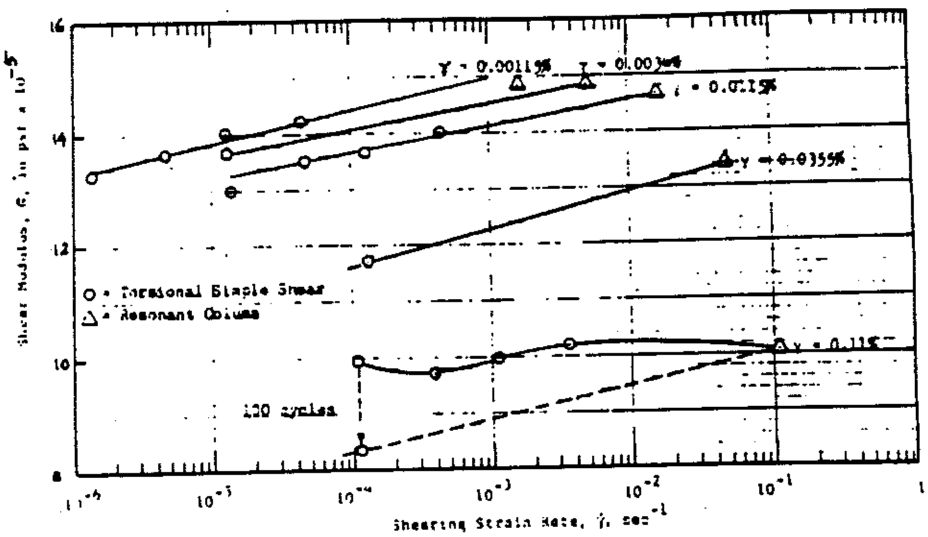


Figure 4.16 Variation in Shear Modulus with Shearing Strain Rate for San Francisco Bay Mud (after Isenhower 1979)

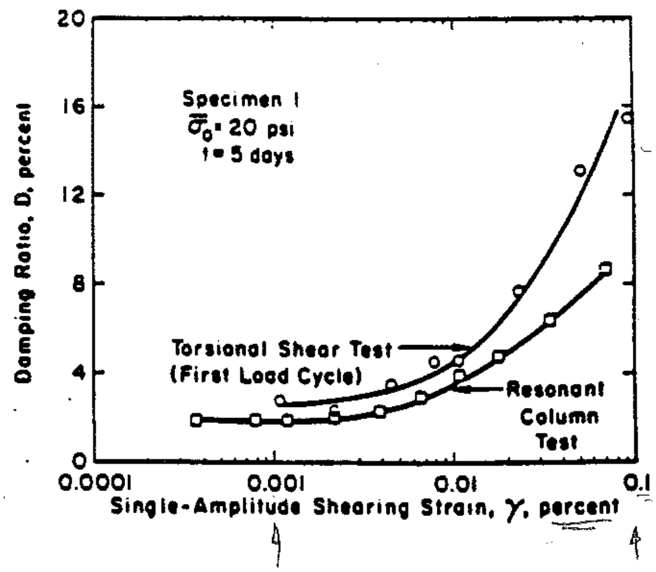


Figure 4.17 Comparison of Damping Ratios by Resonant Column and Torsional Shear Tests for Offshore Silty Samples (after Stokoe et al. 1980)

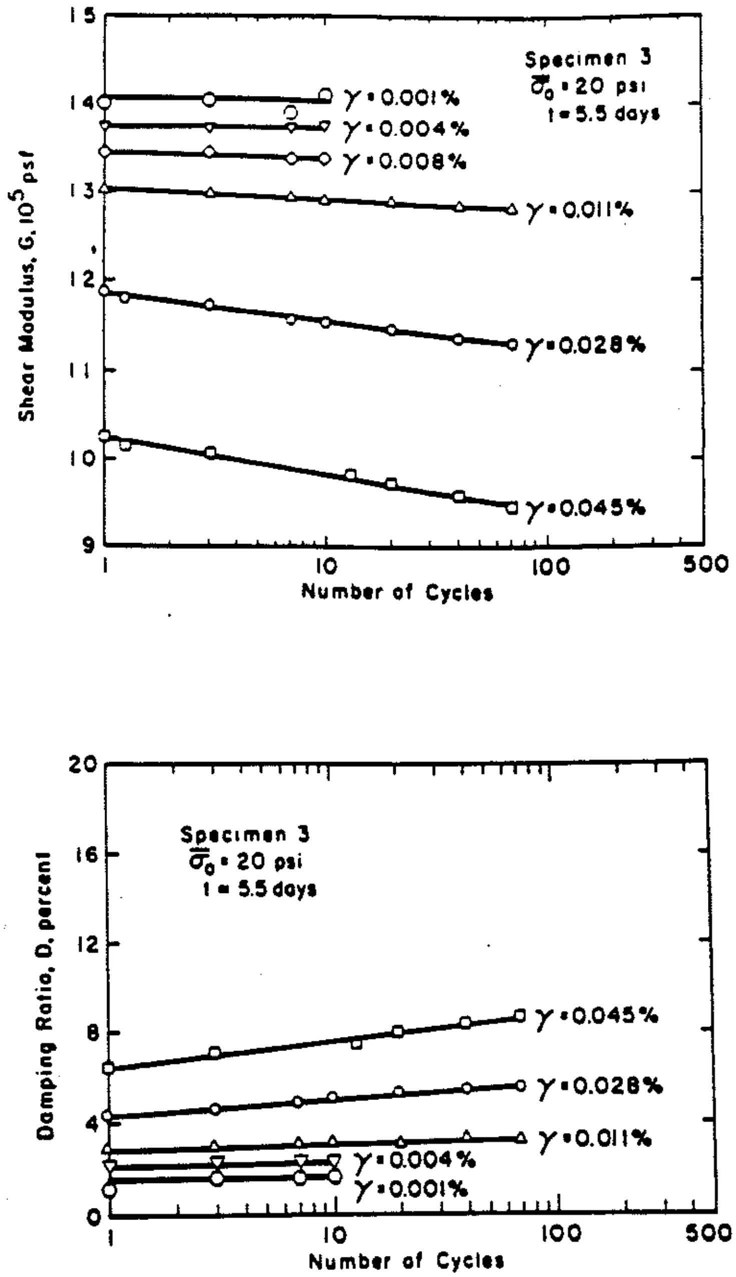


Figure 4.18 (A.) Shear Modulus and (B.) Damping Ratio as a function of Number of Loading Cycles for Offshore Silty Samples (after Stokoe et.al. 1980)

evaluate the influence of confining pressure, shear strain amplitude, cyclic frequency, and the number of cycles on it.

In Phase II(a), the specimen densification was evaluated by recording the change in vertical dimensions of the specimens only. To calculate the change in volume of the specimen, it was assumed that the vertical strain is equal to the radial strain, i.e., the volumetric strain is three times the vertical strain recorded. Specimens 1ST#4 to 3ST#9 (18 specimens) were tested in this phase of the project.

In this phase, the shear strain amplitudes applied were in the range of 0.001 % to 0.1 %, confining pressures were 25, 50, and/or 100 kPa, cyclic frequency was 1 Hz for all tests, and 1000 cycles of each shear strain were applied (except for specimens 2ST#11, 3ST#2L & 5L, where nearly 0.2 to 0.4 million cycles were applied).

The Stokoe cell was modified to enable the measurement of change in the radial dimension of the specimen along with the change in vertical dimensions during the tests. However, during Phase II(b), due to certain limitations of the available instrumentation control software, the specimen diameter could be recorded only for the first and the last cycle of any applied shear strain. Thus, for the specimens tested in this phase of the project, the volumetric strain reported for the first and last cycle is based on the measured change in sample length and diameter but for all other cycles, the volumetric strain is three times the observed vertical strain. (This was done for two reasons. First, no discernible relation could be observed between vertical and radial strain values even at high shear strain amplitudes. Secondly, this assumption gave conservative results). Four specimens 3ST#10L & 12 and 4ST#1 & 4 were tested in this phase. The test conditions in this phase were the same as that for Phase II(a).

In Phase II(c), the instrumentation software was updated as well which enabled the measurement of specimen height and diameter for any/every cycle of the applied shear strain. This data acquisition software program was developed in the Labview window environment. Thus for the three specimens - 3ST#11A & B and 5ST#2 tested in this phase, the volumetric strain reported at each cycle is based on the measured vertical and radial strain. The test conditions during this phase also otherwise same as those in Phases II(a) & II(b) except that the cyclic frequency for all the tests was 10 Hz.

In each of the tests in Phase II, after the specimen was fully consolidated under the applied confining pressure, a low amplitude (< 0.001 %) resonant column test was performed to obtain the maximum shear modulus. Then torsional shear tests were performed on the specimen and LVDT and proximitor readings (corresponding to specimen length and diameter respectively) were taken at certain specific cycles (1, 15, 30, 60, 100, 200, 400, 600, 800, and 1000 typically). Both the resonant column test and the torsional shear test were performed under drained conditions.

Figure 4.19 shows how each test was carried out in principle. The lowest confining pressure was applied and the specimen was allowed to consolidate fully (usually overnight). Then, 1000 cycles of incrementally increasing shear strains were applied to the specimen. After, the test at the highest shear strain amplitude was completed, the pressure was increased and the procedure was repeated.

It is important to clearly define two terms that have been frequently used. ***Total*** vertical/horizontal/volumetric strain refers to the cumulative strain resulting from the static (applied confining pressures) as well as the dynamic (applied shear strain cycles) loadings. ***Dynamic*** refers to the vertical/horizontal/volumetric strain caused only by specific number of cycles of a specific shear strain at any given confining pressure.

The data collected during Phase II of the project and the processed results are presented in Appendix 4.3. For each of the 25 specimens, four data sheets have been presented. The first one (Data Sheet # 1) shows the results of the low amplitude resonant

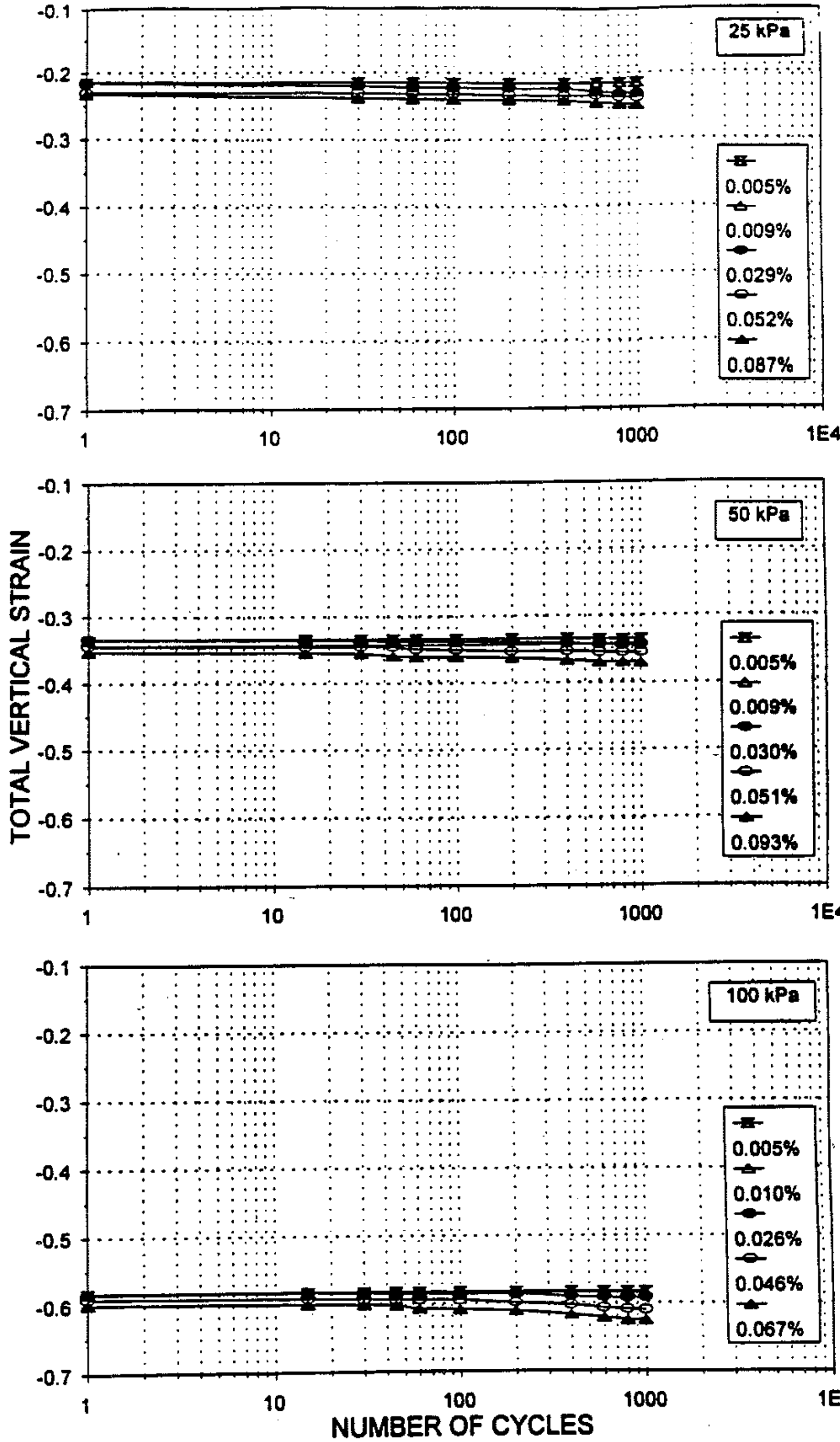


Figure 4.19 Total Vertical Strain for Specimen 3ST#12 at Different Shear Strain Amplitude as a Function of Number of Cycles at 25, 50, and 100 kPa

column test conducted to determine the maximum shear modulus at each confining pressure. This sheet also presents the basic properties of each specimen. The second data sheet (Data Sheet # 2) gives the results of the torsional shear tests conducted for each specimen. It shows the shear stress applied, shear strain experienced by the specimen and the corresponding shear modulus. This data sheet highlights the decrease in shear modulus with the increase in shear strain amplitude. The third data sheet (Data Sheet # 3) gives LVDT readings recorded, the settlement, total vertical strain, total horizontal (or radial) strain (for Phases II-b & II-c) and the corresponding total volumetric strain due to specific number of cycles of applied shear strain amplitude at different confining pressures. (Note that the volumetric strains have been reported differently for each phase as explained in detail earlier). The fourth data sheet (Data Sheet # 4) shows the total and dynamic vertical, horizontal (or radial), and volumetric strain due to 1000 cycles of applied shear strains at different confining pressures. The results obtained for only some of these specimens are discussed in detail below.

4.5.1 Influence of shear strain amplitude and confining pressure

Figures 4.20 and 4.21 show the results obtained for three specimens 1ST#4, 2ST#7, and 3ST#8 tested during Phase II(a). Each of these specimens is one of those that experienced maximum dynamic settlement under a confining pressure of 25 kPa among all the specimens tested from that particular site. The results obtained for three specimens tested during Phases II(b) and II(c) are presented in Figs. 4.22 and 4.23. Figures 4.20 and 4.22 show the total volumetric strain ,i.e., volumetric strain caused due to the applied confining pressures and 1000 cycles of each shear strain amplitude shown. The results presented in Figs. 4.21 and 4.23 show the dynamic volumetric strain caused due to the 1000 cycles of each specific shear strain amplitude shown. Two trends need to be

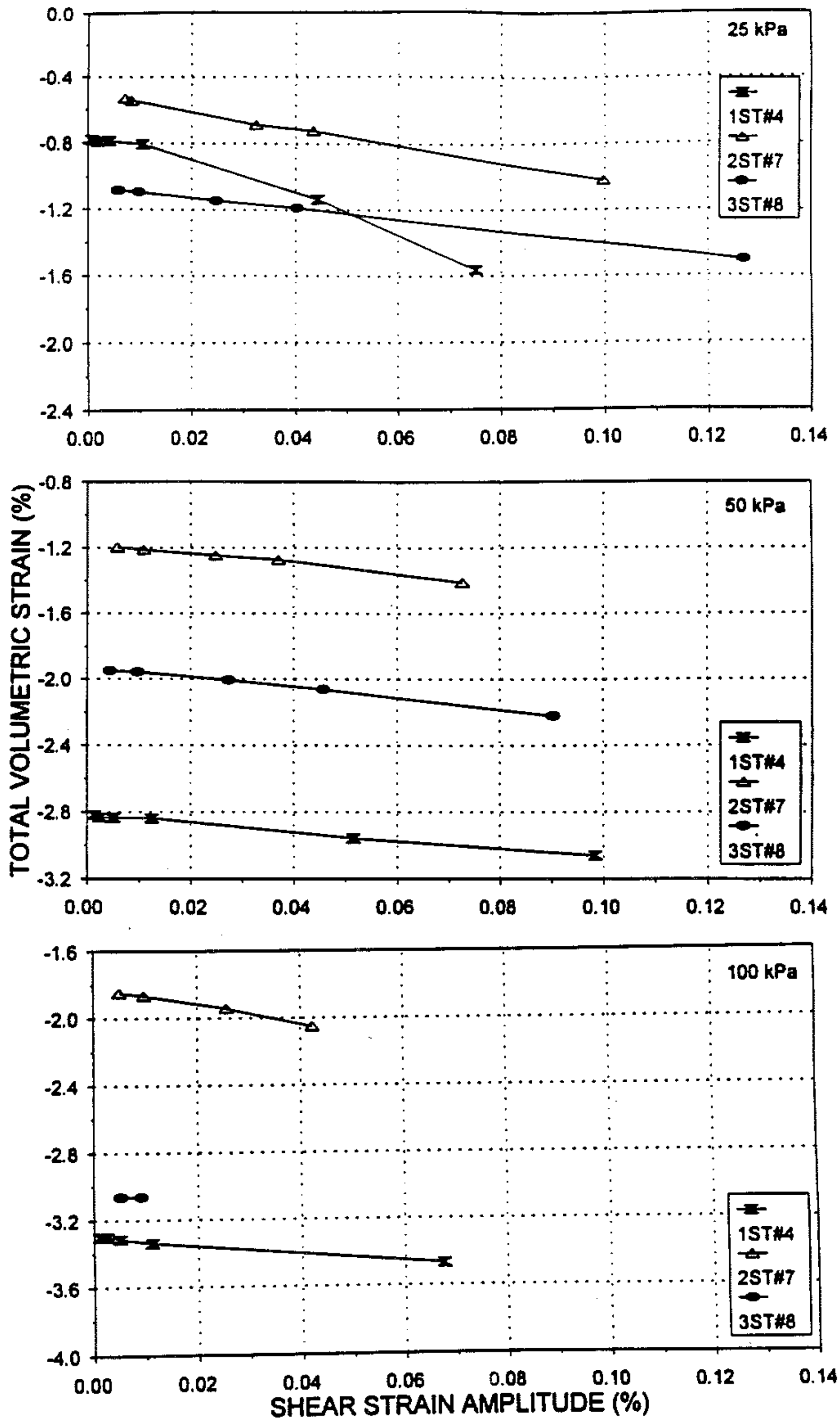


Figure 4.20 Total Volumetric Strain for 1000 Cycles as a Function of Shear Strain Amplitude for Three Specimens Tested during Phase II(a)

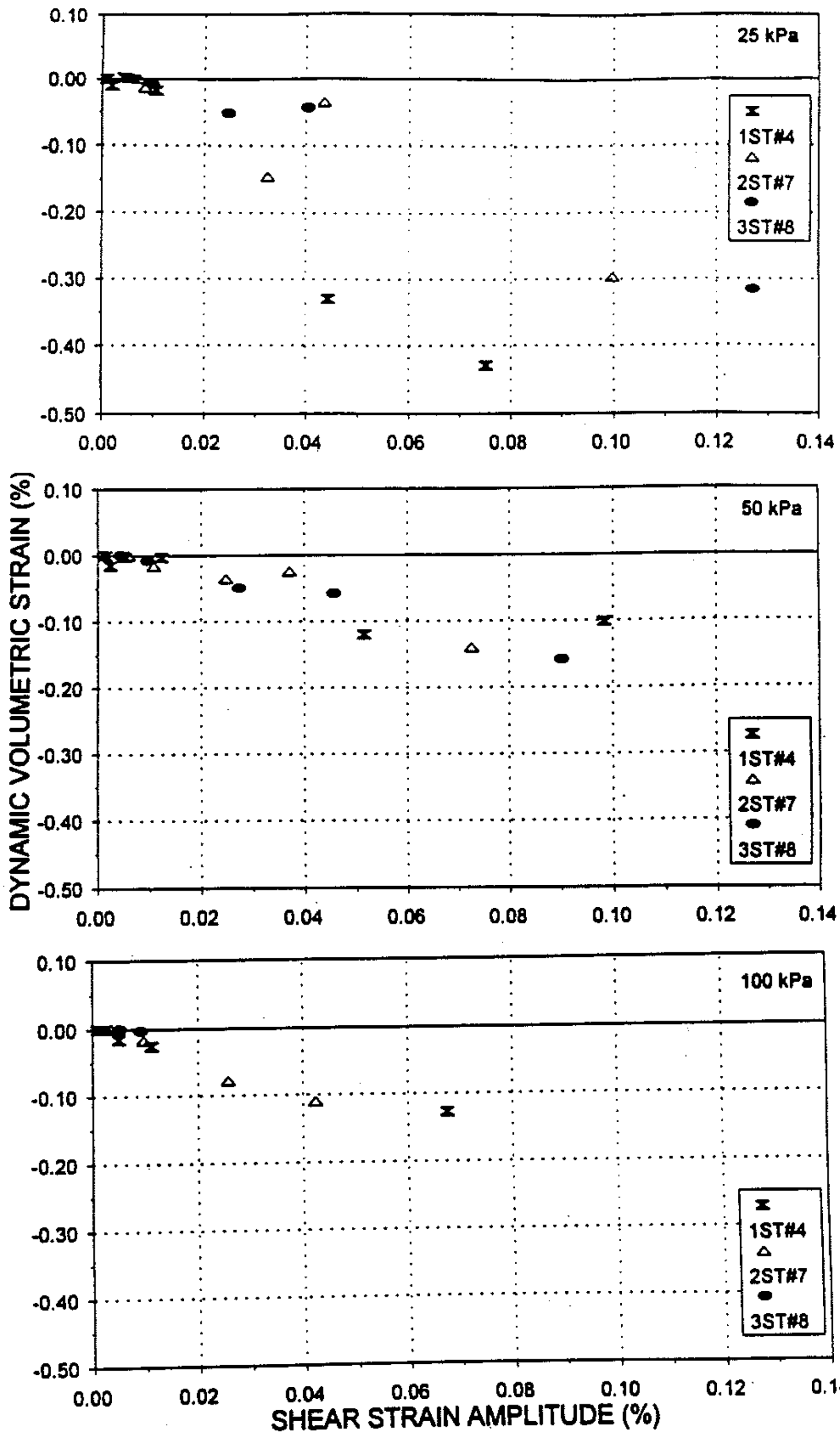


Figure 4.21 **Dynamic Volumetric Strain for 1000 Cycles as a Function of Shear Strain Amplitude for Three Specimens Tested during Phase II(a)**

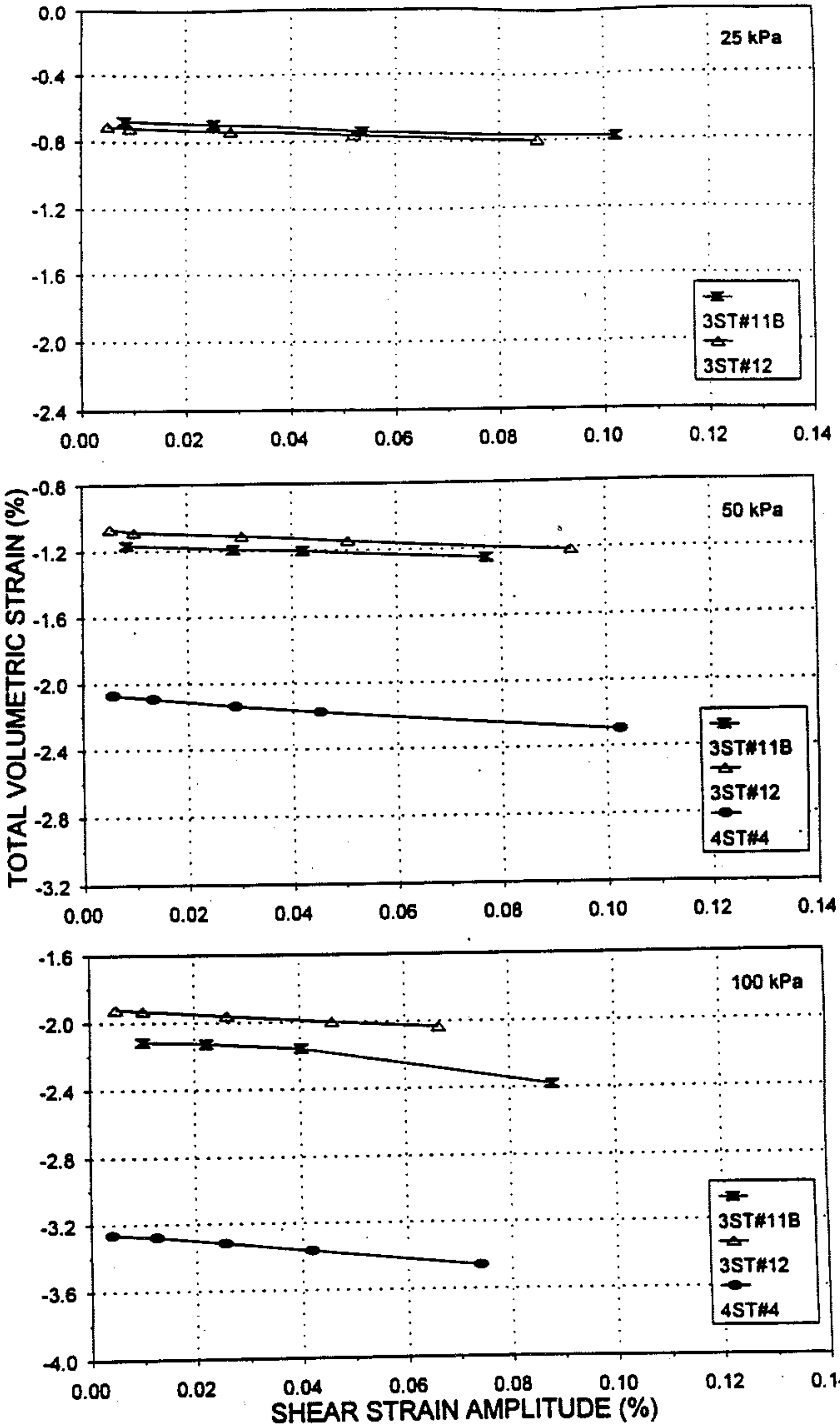


Figure 4.22 Total Volumetric Strain for 1000 Cycles as a Function of Shear Strain Amplitude for Three Specimens Tested during Phase II (b) and (c)

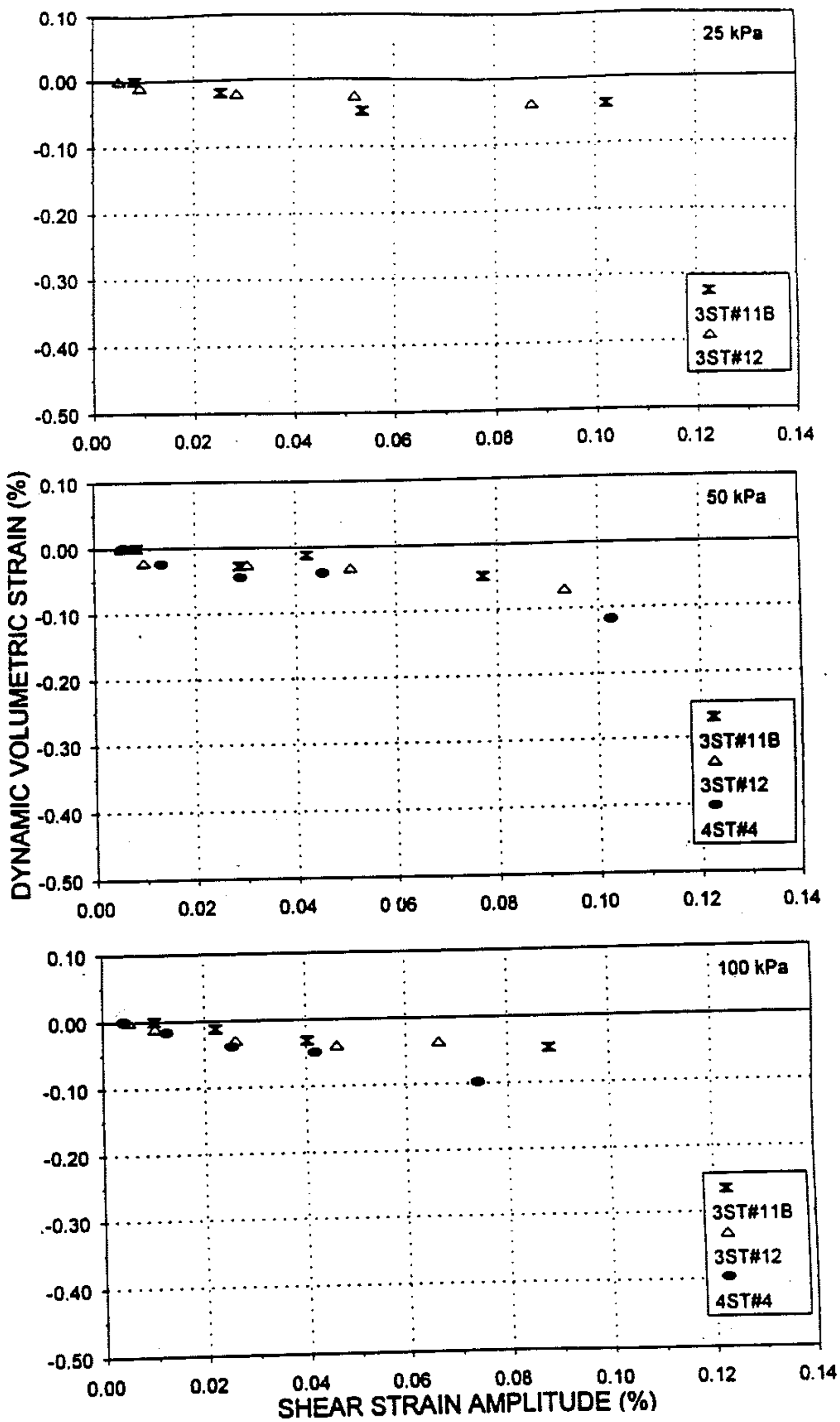


Figure 4.23 Dynamic Volumetric Strain for 1000 Cycles as a Function of Shear Strain Amplitude for Specimens Tested during Phase II (b) and (c)

highlighted in Figs. 4.21 and 4.23. First, the dynamic densification increases with the increase in shear strain amplitude. Further, there seems to be a minimum (threshold) shear strain amplitude for these residual soils for which virtually no dynamic densification takes place. This minimum shear strain amplitude was observed to be in the range of 0.005% to 0.01%. Secondly, as the confining pressure increases, the dynamic densification caused by 1000 cycles of the same shear strain amplitude decreases. Figures 4.19, 4.20 and 4.22 clearly show that the densification due to static loading (confining pressures) is much larger than that due to dynamic loading (cycles of different shear strain amplitudes). Similar trends were observed for most specimens tested in this project.

4.5.2 Influence of cyclic frequency

Figures 4.22 and 4.23 also show the influence of cyclic frequency on dynamic densification. Specimens 3ST#11B and 3ST#12 were tested at a frequency of 10 Hz and 1 Hz respectively. These two specimens were from the same site and had almost the same basic soil properties. It can be clearly seen from these figures that the two specimens underwent virtually the same total and dynamic volumetric strain. Further, the specimens tested in Phase II(c), at a (higher) frequency of 10 Hz, did not exhibit any unusual behavior as compared to all other specimens tested at 1 Hz in Phases II(a) and II(b). Thus it seems that for the range investigated, frequency has no influence on dynamic densification of these residual soils.

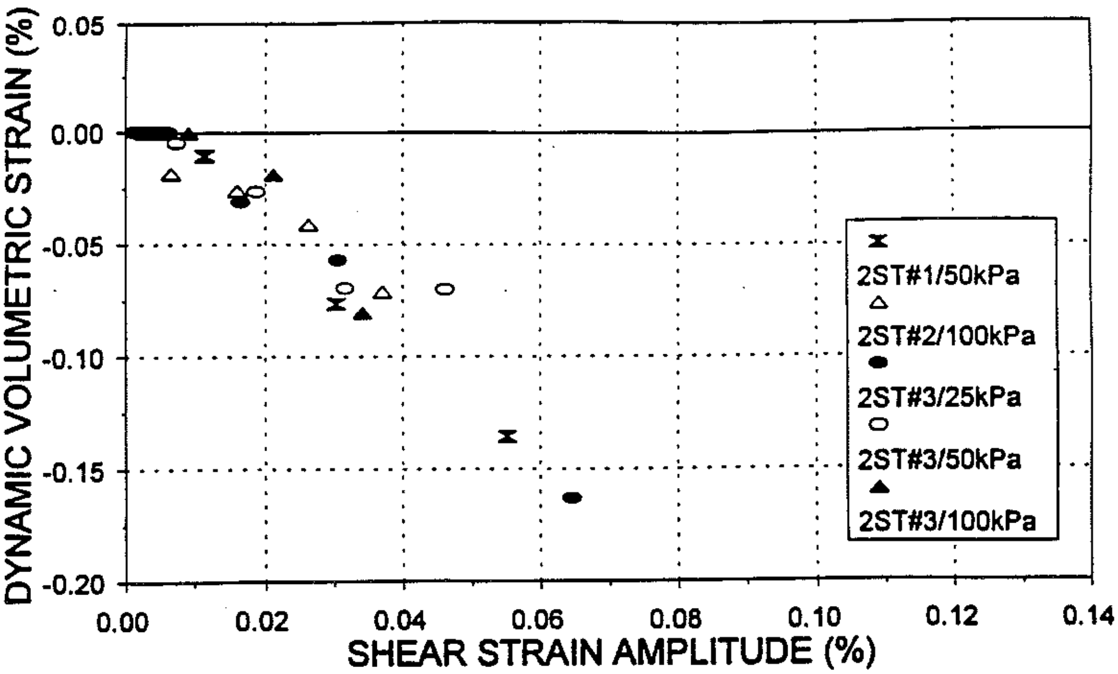
4.5.3 Influence of stress history

As a part of the experimental program, tests were conducted to gain an insight into the effect of stress history on subsequent dynamic response. To this end, specimens 2ST#3 and 2ST#9 were tested at confining pressures of 25, 50 and 100 kPa, whereas specimens 2ST# 1 & 11 were tested directly at 50 kPa and specimens 2ST# 2 & 10 were tested directly at 100 kPa, without prior testing at lower confining pressure. The results obtained for these specimens are presented in Fig. 4.24. The dynamic volumetric strain due to 1000 cycles applied shear strain were almost in the same range at the corresponding confining pressures. This suggests that prior loading/disturbances of residual soils at a lower confining pressure has little or no influence on its dynamic behavior at a higher confining pressure.

Figure 4.25 shows the influence of overconsolidation on dynamic densification. "After" here refers to dynamic testing at the mentioned confining pressure after dynamic testing at 100 kPa. Specimens 2ST#9 was tested at 25 kPa and 3ST#12 was tested at 50 kPa initially and then again after testing at 100 kPa. The dynamic volumetric strains (for 1000 cycles) for overconsolidated specimens were observed to be much smaller at the same confining pressure. Similar results were also obtained for specimens 2ST# 7 & 8. These two specimens were from the same site and have similar basic soil properties. 2ST#7 was tested at 25, 50, and 100 kPa respectively whereas 2ST#8 was tested at 100 kPa and then at 50 kPa. Even though 2ST#8 showed higher dynamic volumetric strain (for 1000 cycles) at 100 kPa, the dynamic volumetric strain at 50 kPa for the overconsolidated 2ST#8 was lesser as compared to 2ST#7. From the above observations, it seems that overconsolidation causes significant reduction in the dynamic densification of residual soils.

4.5.4 Influence of degree of saturation

Due to the unusually low dynamic densification observed for most of the partially saturated specimens, it was postulated that this behavior may be due to suction. As a result, samples (4ST# 1 & 4 and 5ST#2) were specifically obtained from depths below the



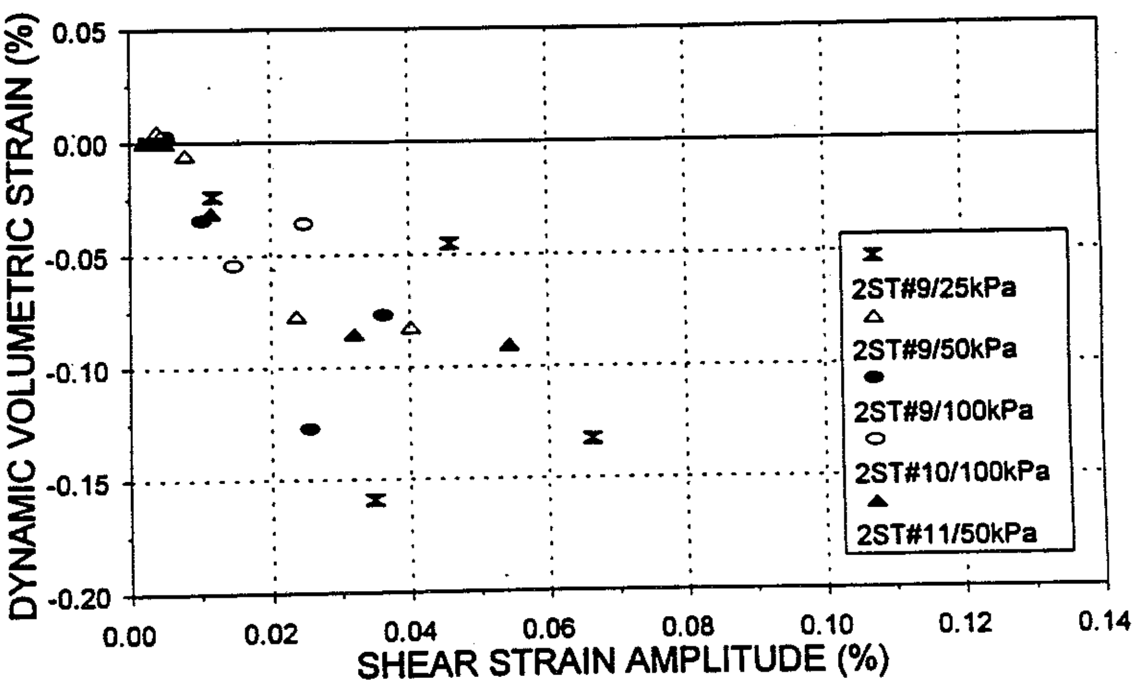
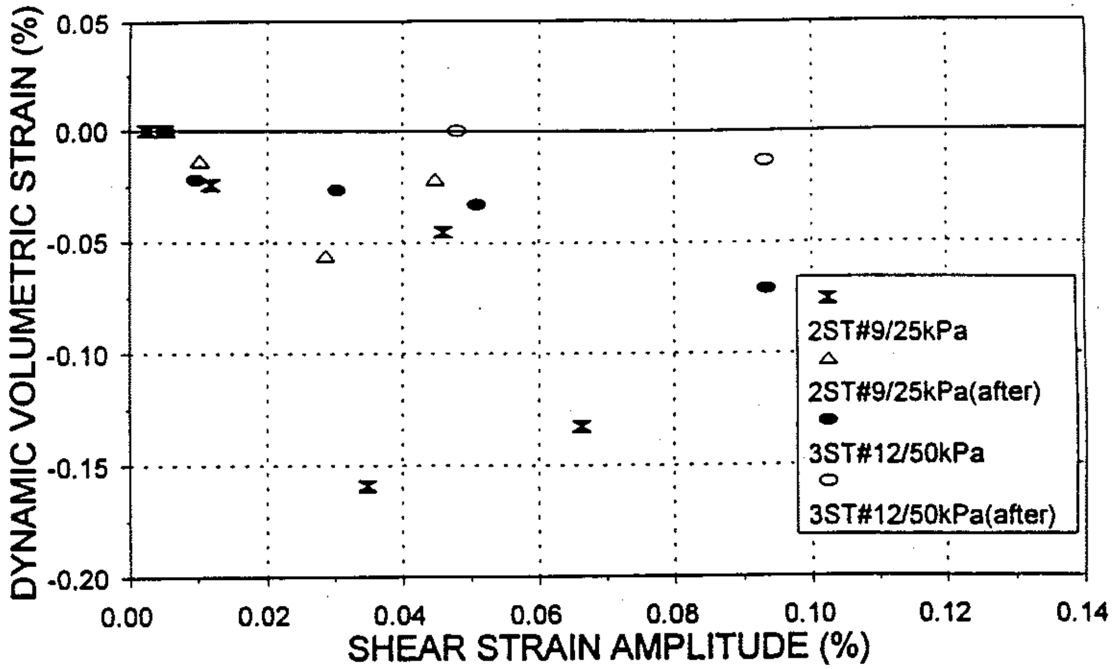


Figure 4.24 **Dynamic Volumetric Strain for 1000 Cycles as a Function of Shear Strain Amplitude Showing the Influence of Stress History**



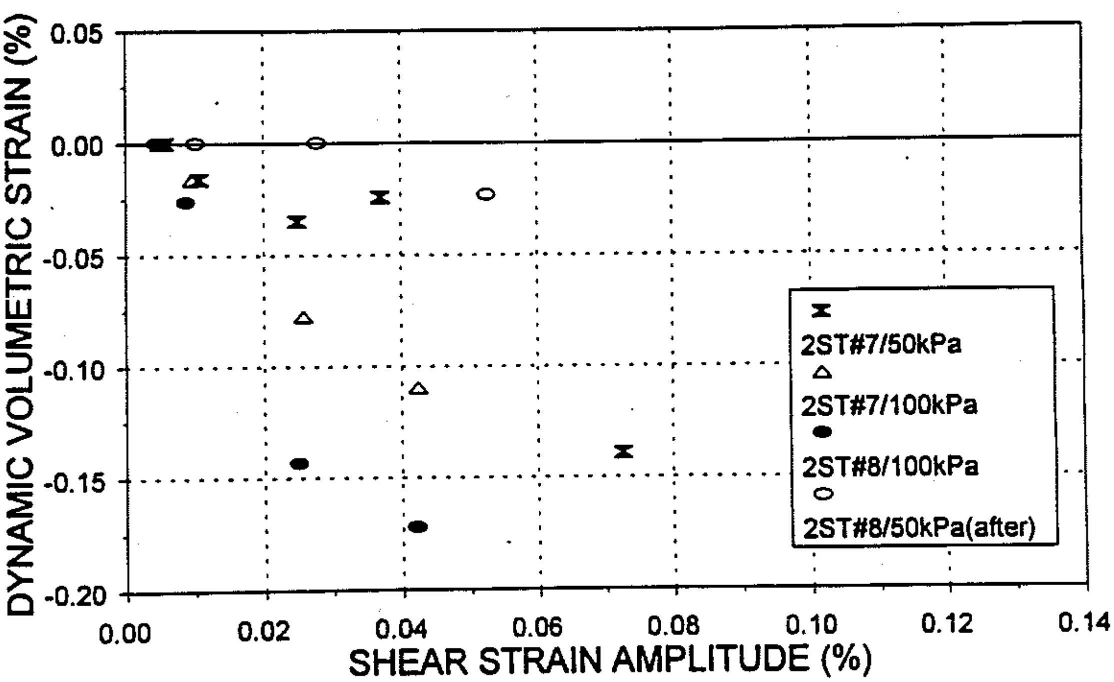


Figure 4.25 Dynamic Volumetric Strain for 1000 Cycles as a Function of Shear Strain Amplitude for Showing the Influence of Overconsolidation

groundwater table and tested in Phases II (b) and II(c) of the project. Figure 4.26 shows the dynamic volumetric strain (for 1000 cycles) for these specimens at different shear strains applied. It also shows the results obtained for other partially saturated specimens tested during these two phases. Saturated specimens showed almost the same dynamic densification as all other specimens. 4ST# 1& 4 had high percentage of sand and showed somewhat higher dynamic volumetric strain whereas 5ST#2 was plastic in nature with a small sand content and showed much smaller dynamic densification. Thus, it seems that soil type has greater influence on the dynamic behavior as compared to the degree of saturation. Among all the specimens tested in Phase II(a), specimen 1ST#4 had the highest degree of saturation. Figure 4.27 shows the results obtained for this specimen along with the results of other specimens from site # 2 & 3 which showed maximum and minimum dynamic densification. It was observed that all the results fall within a small range. This suggests that the degree of saturation doesn't have a significant influence on the dynamic densification of these residual soils.

4.5.5 Influence of number of cycles

To study the influence of number of cycles on dynamic densification, specimens were tested for 0.2 to 1 million cycles. Most of these long tests were run at a high shear strain amplitude and a low confining pressure to simulate worst conditions that would lead to maximum dynamic densification. Figure 4.28 shows the results obtained for all the long tests conducted during this project. It can be observed that the specimens continued to densify with increasing number of cycles. 2ST#11 underwent somewhat smaller dynamic densification as compared to the other specimens shown because of the lower shear strain amplitude applied. 3ST#11A was obtained from a depth of 5.8 - 7.8 ft and seems to have behaved like an overconsolidated specimen when tested at 25 kPa and thus showed

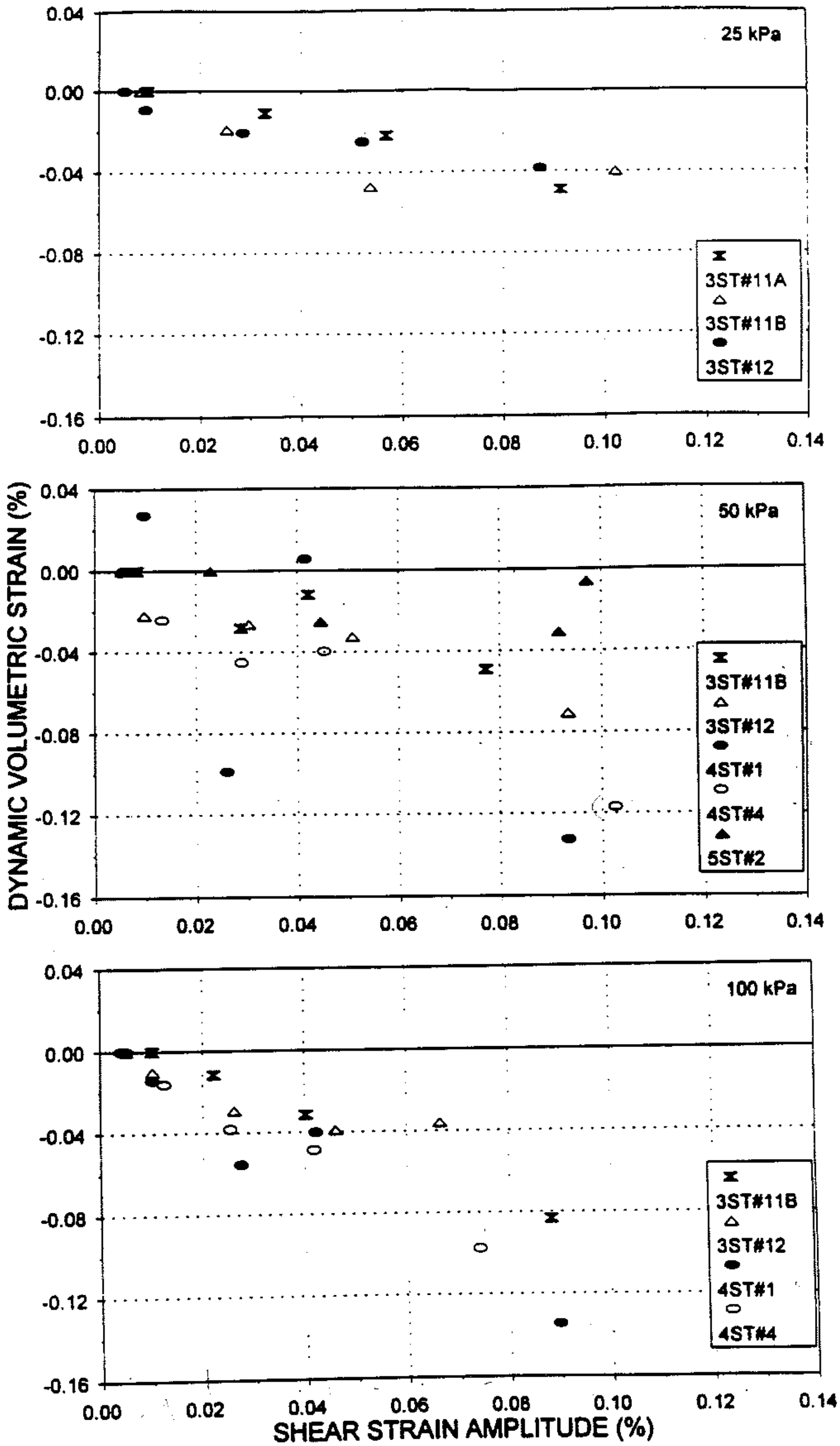


Figure 4.26 **Dynamic Volumetric Strain for 1000 Cycles as a Function of Shear Strain Amplitude for Specimens Tested during Phase II (b) and (c) Showing the Influence of Degree of Saturation**

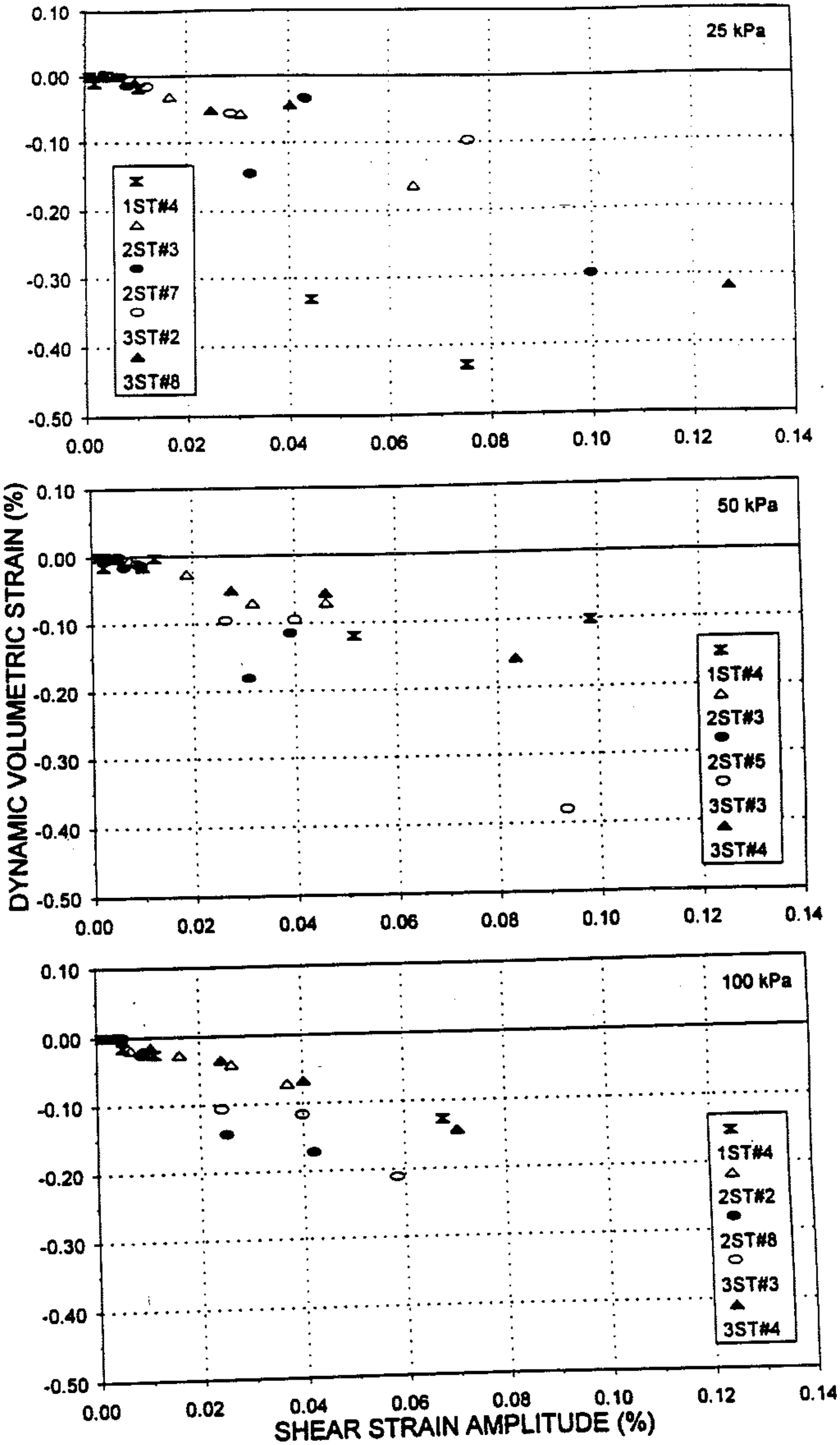


Figure 4.27 **Dynamic Volumetric Strain for 1000 Cycles as a Function of Shear Strain Amplitude for Specimens Tested during Phase II (a) Showing the Influence of Degree of Saturation**

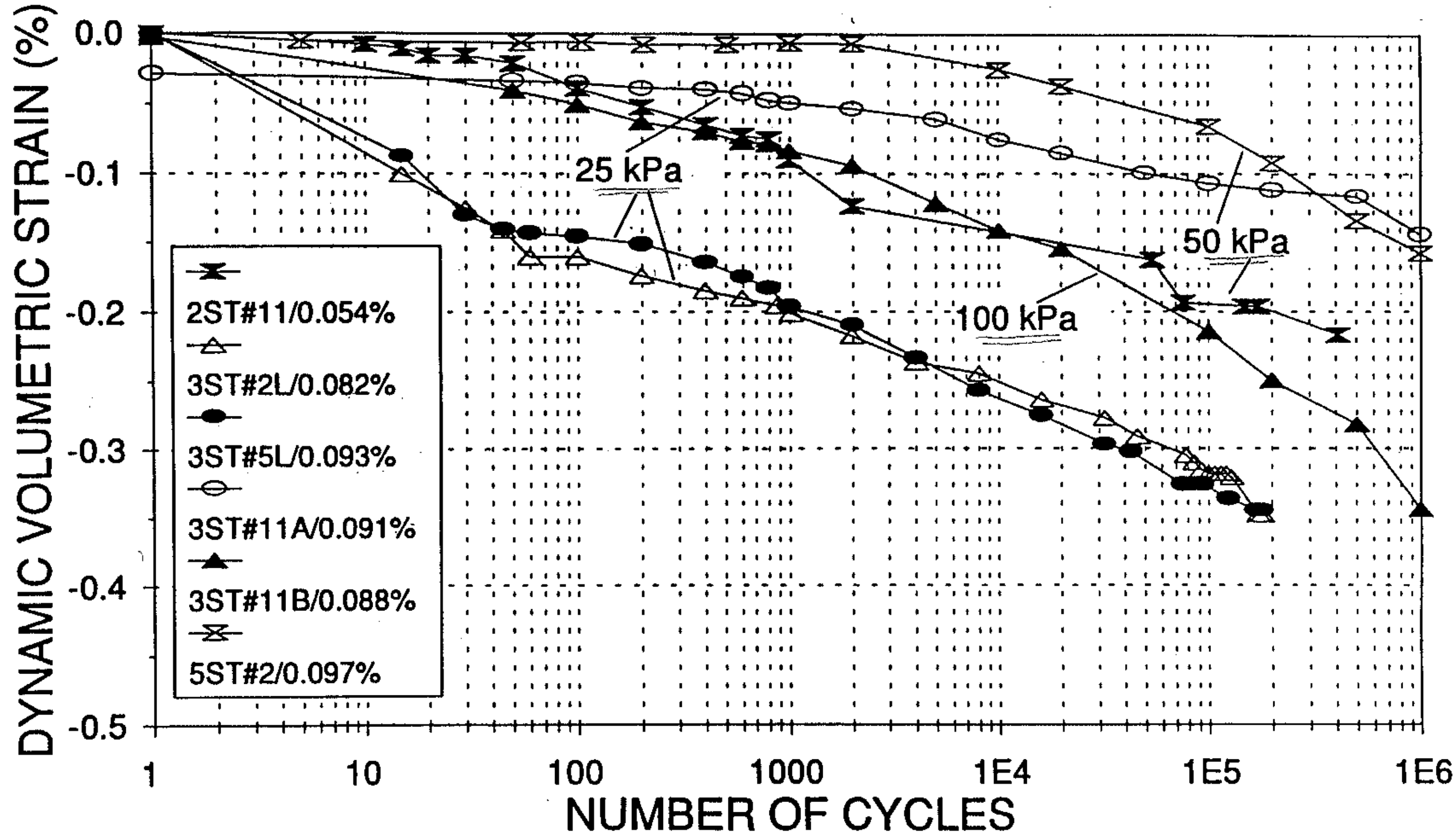


Figure 4.28 Dynamic Volumetric Strain as a Function of Number of Loading Cycles

smaller dynamic densification. 5ST#2 was plastic in nature with a small sand content and showed smaller dynamic volumetric strain. 3ST#2L and 3ST#5L showed somewhat higher densification perhaps because they were tested directly at a high shear strain amplitude without any prior testing at lower shear strain amplitudes. Some other specimens also exhibited such a behavior.

4.5.6 Influence of soil type

The results obtained for all the residual soil specimens tested in Phase II of the project are presented in Fig. 4.29. It shows the dynamic volumetric strain for 1000 cycles at varying shear strain amplitudes at different confining pressures on the basis of soil type (USCS classification) and sand content for each of the soil tested (Table 3.3). The figure in the parenthesis shows the approximate percentage of sand content in respective soils. From Fig. 4.29, one can observe that, in general, soils with high sand content tend to settle more, especially at low confining pressure. Further, the dynamic volumetric strain (for 1000 cycles) caused at varying shear strains falls within a narrow band of 0 to 0.2% at 50 and 100 kPa for all the soils tested, though some scatter is observed at 25 kPa. As mentioned earlier as well, there seems to be a threshold shear strain amplitude in the range of 0.005% to 0.01% for which essentially no dynamic densification takes place for these residual soils.

Summarizing the results of dynamic densification for all the specimens tested at a frequency of 1 and 10 Hz in Phase II of the project, the following observations can be made. At 25 kPa, the maximum dynamic volumetric strains for 1000 cycles for the highest shear strains applied (which were in the range of 0.065% to 0.127%) were in the range of 0.1% to 0.43%. At 50 kPa, for highest shear strains in the range of 0.04% to 0.103%, the maximum dynamic volumetric strains were in the range of 0.07% to 0.38%. The

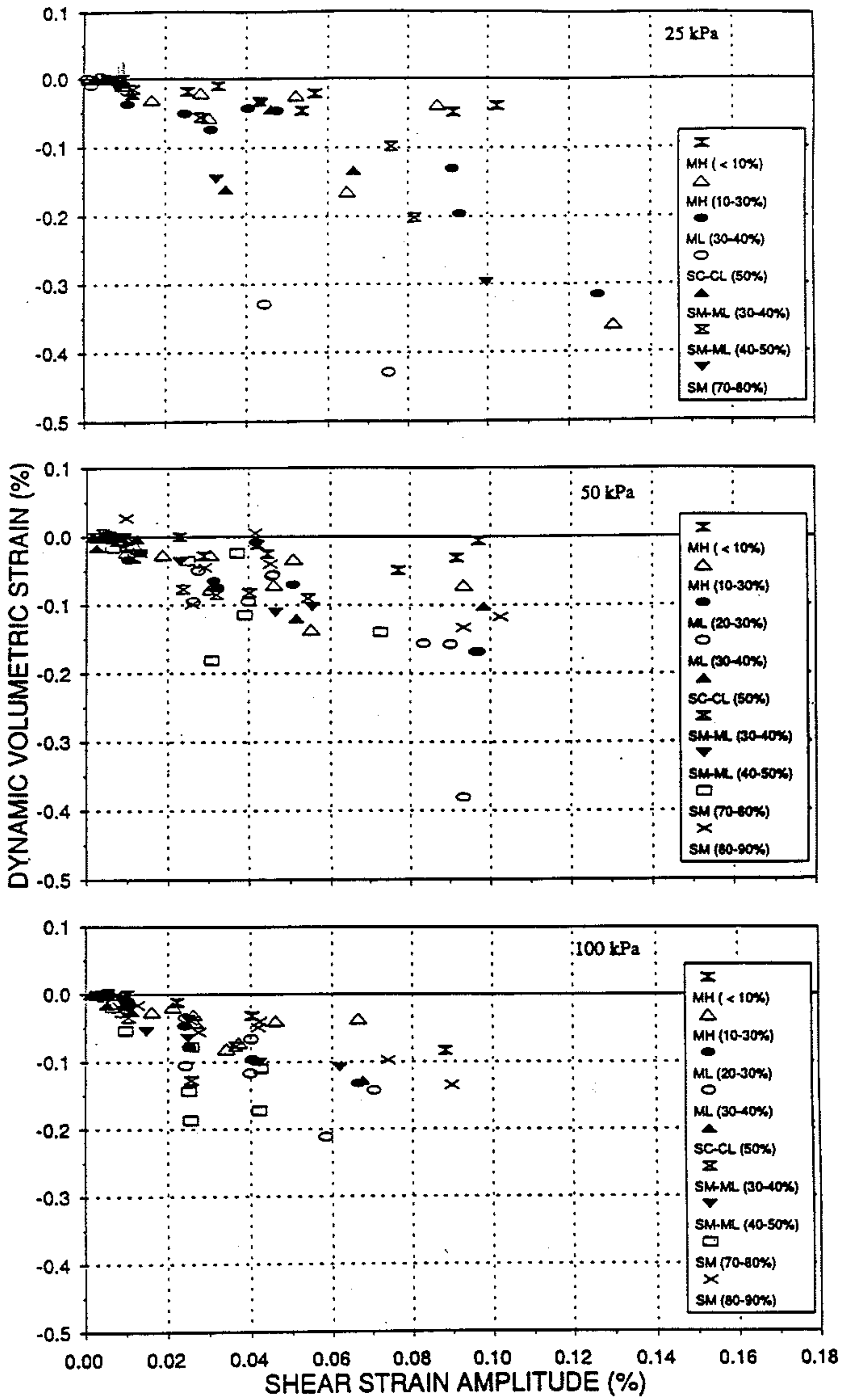


Figure 4.29 Dynamic Volumetric Strain for 1000 Cycles as a Function of Shear Strain Amplitude for All Specimens Tested during Phase II on the Basis of Soil Type and Percent Sand Content

corresponding values were in the range of 0.04% to 0.21% at 100 kPa for shear strains in the range of 0.025% to 0.089%.

4.6 Maximum Shear Modulus

Table 4.1 shows the basic soil properties of all the specimens tested in this project, their USCS classification and the value of the maximum shear modulus observed for each at the lowest shear strain amplitude applied. This data may be used to estimate the maximum shear modulus of other residual soils which will be required in the model presented in the next chapter. The decrease in shear modulus with increase in shear strain amplitude has been discussed earlier. It may also be estimated from the torsional shear test data (data sheets # 2) presented in Appendix 4.3. It must be pointed out here that in the first few resonant column tests (1ST#4, 2ST# 2 & 3), a lower value of shear modulus was observed in the low amplitude resonant column tests as compared to that in the high amplitude torsional shear tests. This finding may have been caused due to two factors. First, a large enough range of frequencies was not checked for the exact determination of the resonant frequency. Secondly, the vibrations of the variable gain amplifier were found to be significantly [illegible] the results of the resonant column tests. In all the future tests, adequate mea[illegible] to eliminate both these problems.

4.7 Observed Relation [illegible] Vertical Strain

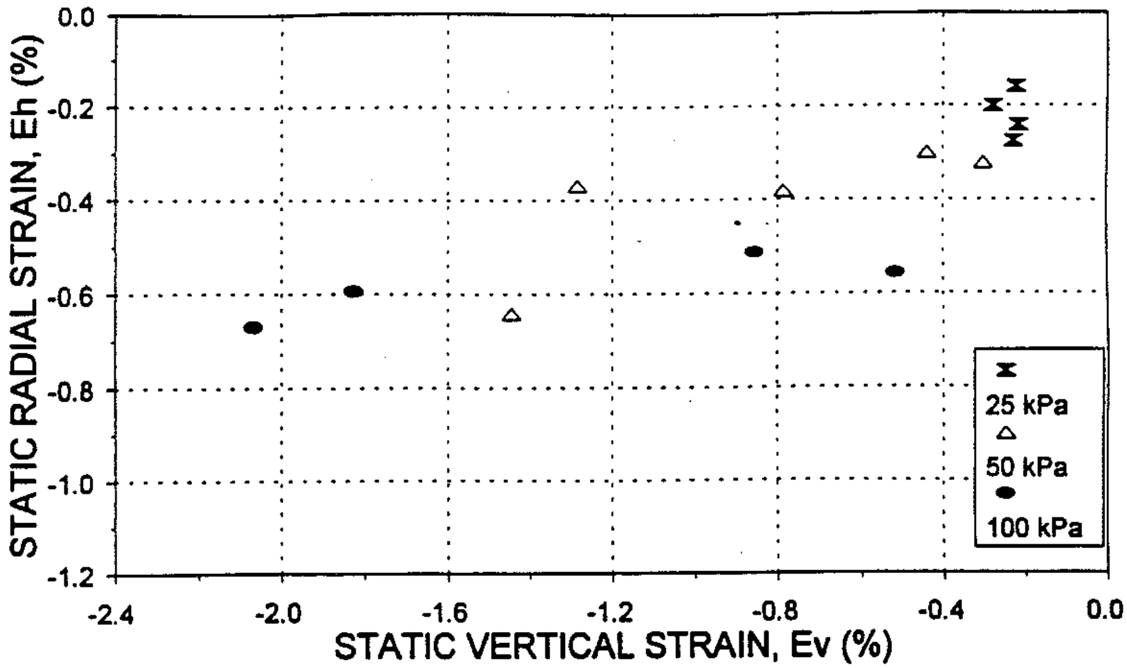
Figure 4.30 shows the o[illegible] static (i.e. due to applied confining pressures) radial and vertical strains in Phases II(b) & II(c). A large scatter was observed in these values. It needs to be highlighted that the assumed ratio of radial to vertical strain equal to one (Eh/Ev = 1) is somewhat conservative. Thus, the results presented in this report are on the conservative side. No discernible trend was observed with respect to dynamic radial and vertical strains.

Table 4.1 Maximum Shear Modulus and Basic Soil Properties of All the Specimens Tested

Specimen No.	Water Content (%)	Initial Void Ratio	Specific Gravity	Saturation (%)	USCS	Confining Pressure (kPa)	Gmax (MPa)
RC-1	24.6	0.89	2.74	75	SM-ML	25	43.4176
						50	67.1469
						100	89.4111
RC-2	30.5	1.00	2.74	84	SM-ML	25	43.0058
						50	66.6921
						100	85.8536
RC-3	39.2	1.25	2.81	88	MH	25	15.1301
						50	21.0433
						100	25.3572
RC-4	40.7	1.31	2.81	87	MH	25	13.6937
						50	21.4981
						100	27.5118
RC-5	41.9	1.35	2.81	87	MH	25	15.9393
						50	20.3346
						100	30.4900
TS-1	37.8	1.50	2.69	68	ML	25	38.2130
						50	47.3533
						100	61.2720
TS-2	36.8	1.42	2.69	70	ML	25	30.1883
						50	38.3662
						100	46.3670
TS-3	29.6	1.18	2.69	67	ML	100	43.7863
1ST#4	20.7	0.60	2.67	92	SC-CL	25	43.4863
						50	56.1686
						100	87.2824
2ST#1	33.5	1.41	2.79	66.0	MH	50	70.5333
2ST#2	33.1	1.43	2.85	65.9	MH	100	53.2307
2ST#3	38.9	1.64	2.79	66.2	MH	25	32.4692
						50	46.7608
						100	62.5148
2ST#5	14.8	0.79	2.60	48.4	SM	50	99.3501
						100	127.8996
2ST#7	12.6	0.84	2.60	39.1	SM	25	63.9541
						50	82.7848
						100	105.8662
2ST#8	15.0	0.87	2.60	45.0	SM	100	98.0549
						50	83.5684

Table 4.1 (Continued)

Specimen No.	Water Content (%)	Initial Void Ratio	Specific Gravity	Saturation (%)	USCS	Confining Pressure (kPa)	Gmax (MPa)
2ST#9	26.2	1.01	2.69	69.8	SM-ML	25	63.7109
						50	76.3614
						100	88.8509
						25	65.5546
2ST#10	29.6	1.12	2.75	72.9	SM-ML	100	97.6214
2ST#11	29.6	1.14	2.71	70.6	SM-ML	50	68.3081
3ST#2	23.9	1.32	2.75	49.7	SM-ML	25	33.3771
						50	42.7552
						100	57.1716
3ST#2L	22.9	1.24	2.75	50.6	SM-ML	25	34.5151
3ST#3	26.8	1.14	2.67	63.0	ML	50	45.6096
						100	61.5068
3ST#4	23.6	1.17	2.66	53.6	ML	25	29.4634
						50	39.2536
						100	50.7238
3ST#5L	18.4	1.16	2.69	42.7	ML	25	35.2884
3ST#6	19.5	0.93	2.75	57.5	ML	50	46.4663
						100	60:2851
3ST#8	22.8	1.24	2.72	50.2	ML	25	30.1029
						50	39.7851
						100	54.5431
3ST#9	15.3	0.86	2.74	48.8	ML	50	59.1779
						100	73.0716
3ST#10L	34.8	1.42	2.76	67.5	MH	25	36.1723
3ST#11A	50.3	1.78	2.74	77.6	MH	25	29.5539
3ST#11B	36.6	1.48	2.74	67.7	MH	25	29.2699
						50	34.0273
						100	40.4805
3ST#12	35.6	1.43	2.72	67.7	MH	25	35.3535
						50	42.7166
						100	52.1725
						50	44.0316
4ST#1	16.6	0.49	2.81	96.1	SM	50	33.7300
						100	51.9146
4ST#4	24.7	0.72	2.79	96.6	SP-SM	50	36.2344
						100	55.8578
5ST#2	50.9	1.48	2.86	98.7	MH	50	20.1093



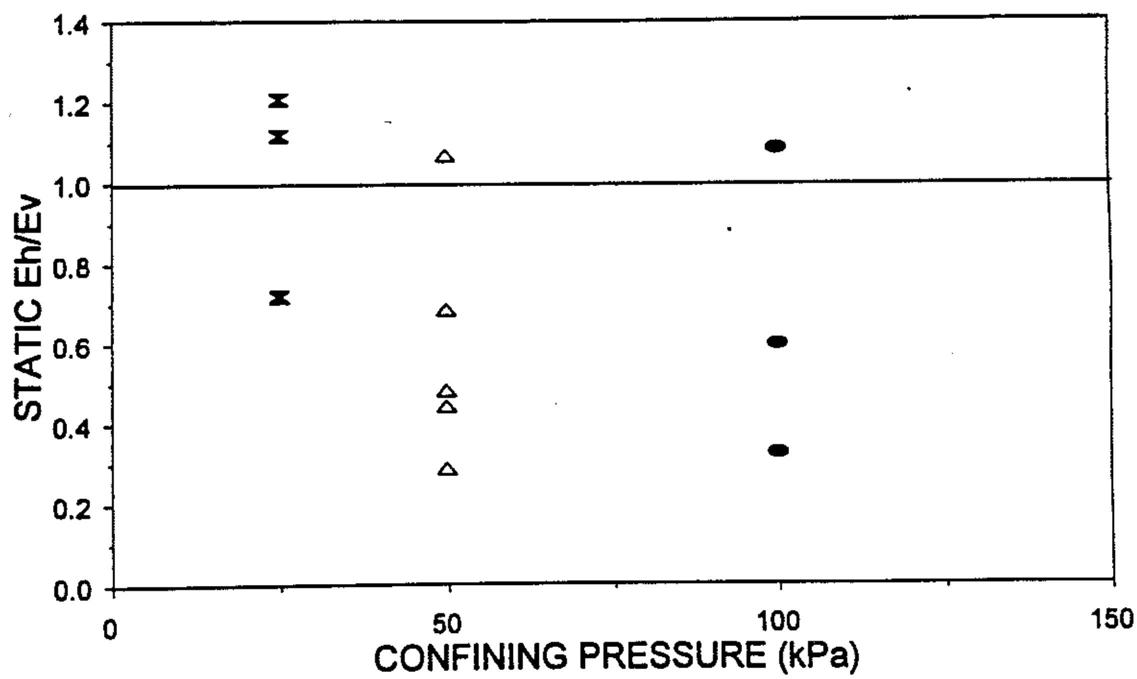


Figure 4.30 Observed Relation Between Static Radial and Vertical Strain for Isotropic Consolidation

CHAPTER 5

MODELING

The modeling of vibration induced settlement includes three major steps. First, determining the vibration energy and number of cycles based on characteristics of the sources. Secondly, assessing the peak particle velocity, and therefore, shear strain amplitude in the soil profile which is influenced by the attenuation of vibration waves. And, finally, evaluating the resulting soil densification as a function of the soil properties, confining pressure, shear strain amplitude, and number of cycles.

5.1 Attenuation of Construction Induced Vibrations in Soil Profile

The attenuation of construction induced vibrations as a function of distance from the source and depth below ground surface depends on type of soil and vibration amplitude. The peak particle velocity on the ground surface is better obtained from field measurement. If the field data is not available, one can estimated the peak particle velocity by Eqns. 2.1 and 2.3 for point source and line source respectively, or from Figs. 2.1 or 2.7, or other literature.

Beneath the ground surface, the peak particle velocity distribution can be calculated by Rayleigh wave propagation theory. Taniguchi and Sawada (1979) concluded that the Rayleigh wave is dominant in the traffic-induced vibration. They measured the soil particle velocity as a function of surface distance and depth. From the theoretical analysis of wave propagation in an elastic half-space, the Rayleigh wave carries 67% of total vibration energy, as shown in Fig. 5.1. The attenuation of Rayleigh waves is much slower than S-waves and P-waves. Therefore, for practical purposes, the Rayleigh

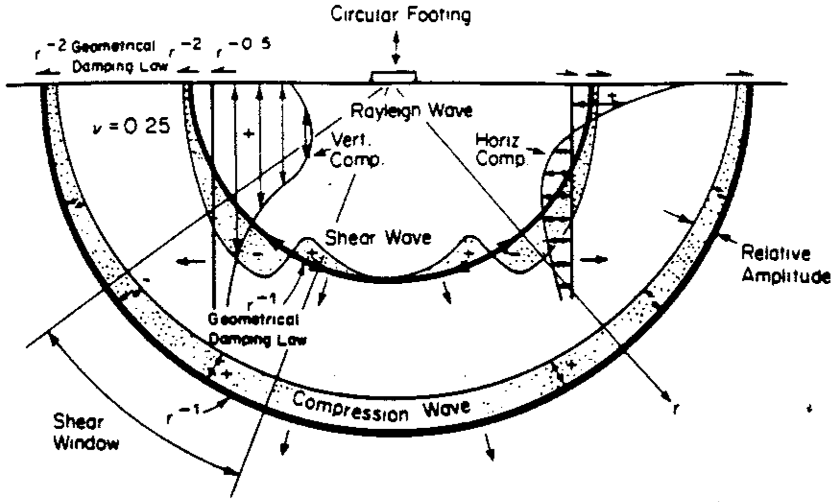


Figure 5.1 Distribution of Displacement Waves from a Circular Footing on a Homogeneous, Isotropic, Elastic Half-Space (after Woods, 1968)

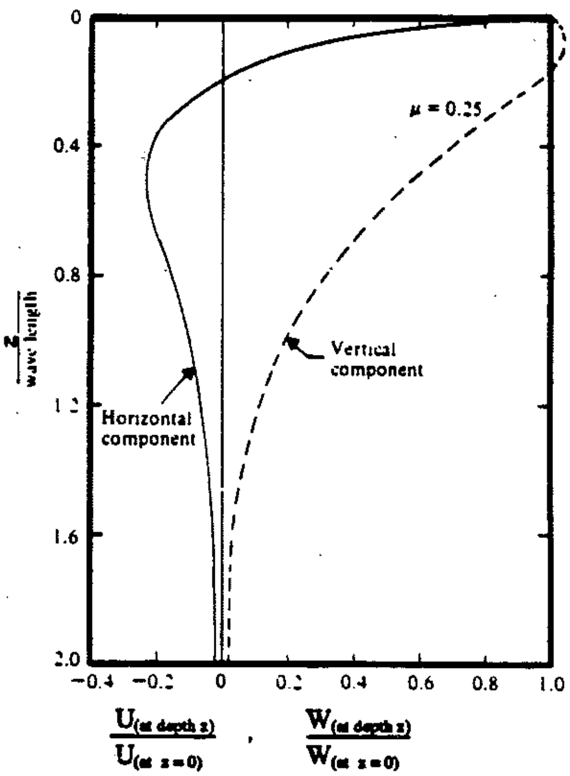


Figure 5.2 Variation of the Horizontal and Vertical Vibration Amplitudes of Raleigh Waves with Depth (Poisson's Ratio = 0.25) (Das, 1983)

wave controls the shear strain amplitude distribution in the ground. The attenuation of Rayleigh waves as a function of depth can be calculated by wave propagation theory. For a homogeneous soil profile and Poisson's ratio equals 0.25, the attenuation of the vertical component of a Rayleigh wave can be expressed as :

$$\frac{A_z}{A_{z=0}} = 1.366\left(e^{-1.695\pi\frac{z}{\lambda}} + 1.732\,e^{-0.786\pi\frac{z}{\lambda}}\right) \tag{5.1}$$

where A_z is the vertical amplitude at depth z, and λ is the wave length of the Rayleigh wave. As shown in Fig. 5.2, the horizontal component of the Rayleigh wave attenuates faster with depth than the vertical component. In this report, we conservatively estimate the attenuation of peak particle velocity with depth by the equation for the vertical component. As shown in Fig. 5.2, the resulting peak particle velocity decreases rapidly with depth. When the depth equals one Rayleigh wave length, the particle velocity amplitude is only 10% ~20% of the ground surface amplitude. Below this depth, the magnitude of vibration induced settlement is unlikely to be significant. For example, the ground vibration frequency caused by a loaded truck is in the range of 15 Hz to 30 Hz. The Rayleigh wave length of a residual soil profile is around 5m ~ 8m in this frequency range. For this reason, the cyclic torsional shear tests were performed using confining pressures of no more than 100 kPa.

After the peak particle velocity profile is obtained, the shear strain amplitude profile can be calculated as :

$$\gamma = \frac{A}{V_R} \tag{5.2}$$

The Rayleigh wave velocity, V_R, can be calculated as a function of shear wave velocity and Poisson's ratio, as shown in Fig. 5.3. The shear wave velocity, V_s, can be obtained from field measurement or calculated from shear modulus by $V_s = (G/\rho)^{1/2}$ and the shear

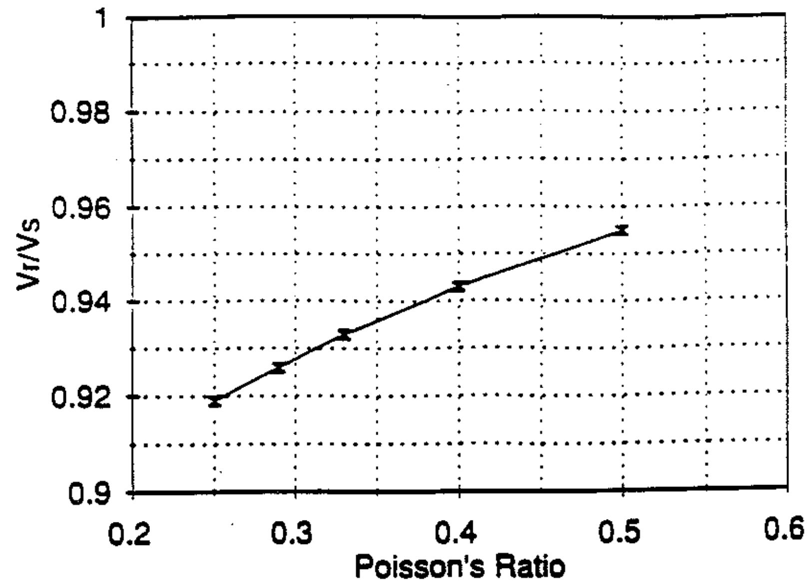


Figure 5.3 Relationship Between Rayleigh Wave Velocity, Shear Wave Velocity, and Poisson's Ratio

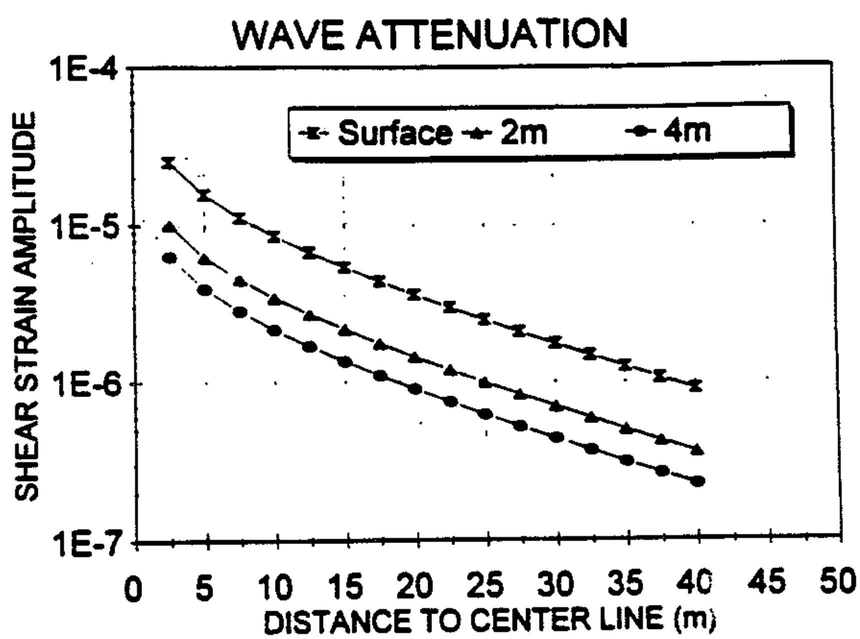


Figure 5.4 Wave Attenuation Profile for a Loaded Truck (20 Mg) over a 18 mm Thick Plank at 60 km/hour (Calculated from the Field Test Data Reported by Taniguchi and Sawada, 1979)

modulus, G, can be found from laboratory test results as a function of shear strain amplitude and confining pressure, as discussed in Chapter 4 and later in Section 5.4. By using an iteration procedure to obtain convergence of the relationship between $\gamma \sim V_R \sim V_s \sim G \sim \gamma$, the correct shear strain amplitude is obtained. Figure 5.4 shows shear strain amplitude as a function of distance from a loaded truck (20 Mg) driving over a 18 mm thick plank at 60 km/hour at three different depths. These results are based on the measured peak particle velocities as a function of depth reported in the literature at a particular site in Japan (Taniguchi and Sawada, 1979). As this is the only data of its kind known to be in the literature, the substantiation of this function should be a significant component of field verification.

5.2 Equivalent Number of Cycles for Construction Related Vibrations

Different kinds of sources produce different ground motion vibrations. Figures 5.5, to 5.7 provide the velocity time history for a loaded truck hitting a bumper, a D-9G bulldozer working pass and a 136 kg weight dropping from 1.7 m. These records came from NCDOT investigations for Corning Glass Works, in Wilmington, NC in 1981.

From these time histories, it can be seen that each event generates a different number of cycles at different particle velocities. For a loaded truck (11,500 Kg) hitting a 7.5 cm x 20 cm bump at a speed of 38.3 km/hour (23.8 mph) on a paved road, the velocity time history is shown in Fig. 5.5. In this record, there are 10 cycles with amplitude between 80 to 100% of the peak particle velocity, 10 cycles between 50 to 80%, and 18 cycles between 30 to 50%. Based on these results, we have chosen 10 cycles with amplitude at 90% of the peak particle velocity, 10 cycles at 65% and 18 cycles at 40% to be the equivalent number of cycles for the loaded truck hitting the bump. Similarly, the record of a 136 kg weight dropping from 1.7 m (Fig. 5.7) has 1 cycle at 90% of peak

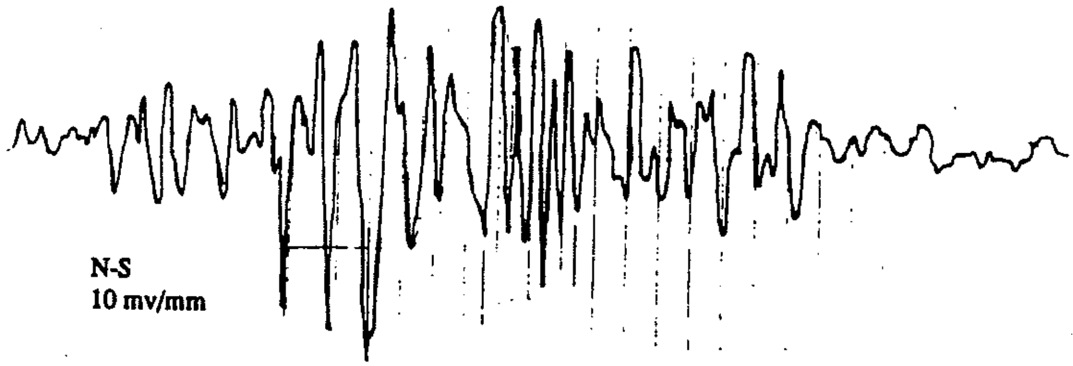


Figure 5.5 The Velocity Time History of a Loaded Truck (11,500 kg) Hitting a 7.5 cm x 20 cm Bump at a Speed of 38.3 km/hour on a Paved Road (NCDOT, 1982)

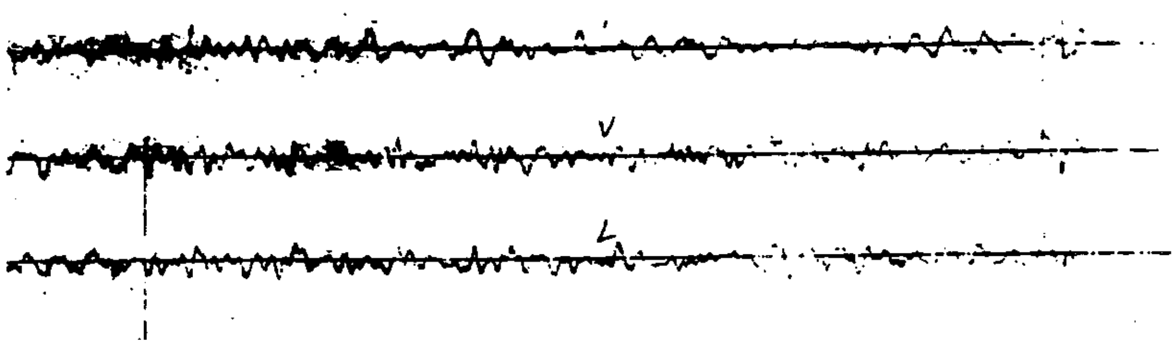


Figure 5.6 The Velocity Time History of a D-9G Bulldozer Working Pass at a Speed of 4.34 km/hour (NCDOT, 1982)

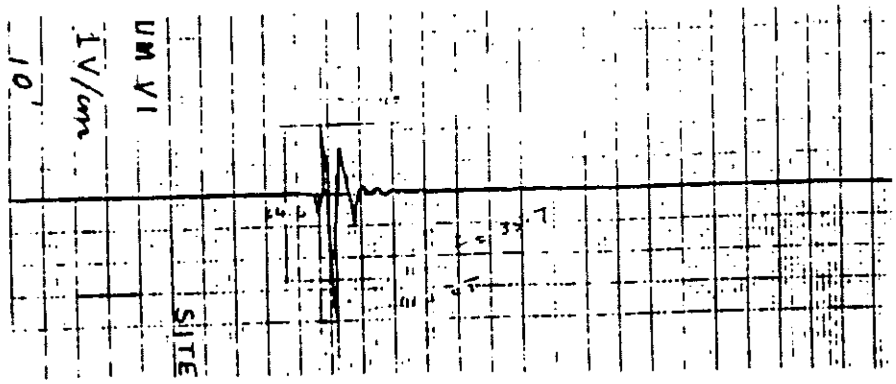


Figure 5.7 The Velocity Time History of a 136 kg Weight Dropping from a Height of 1.7 m (NCDOT, 1982)

particle velocity, 1 cycle at 65%, and 1 cycle at 40%. The bulldozer working pass generates quite uniform waves at 19 Hz. Therefore, we say that the soil particle vibrates at 100% peak particle velocity at 19 Hz continuously.

To evaluate the potential settlement of a foundation under construction induced vibration, it is very difficult to describe the properties of sources. For example, the dump truck induced vibration depends on the trucks weight, wheel base, type of suspension, road condition, speed, soil properties, etc. Therefore, we propose a simplified method to estimate the equivalent number of cycles for a line source (i.e., truck or bulldozer).

As shown in Fig. 5.8, we assume the road has potholes or bumps at equal space, s. The nearest distance from the foundation to the road is d and the distance from each pothole to the foundation, r_n is :

$$r_n = d\sqrt{n^2\left(\frac{s}{d}\right)^2 + 1} \qquad (n=-\infty,...-2,-1,0,1,2,...+\infty) \qquad (5.3)$$

Using Eqn. 2.3, the reduction of vibration amplitude, A_n/A_0 at distance r_n can be calculated as :

$$\frac{A_n}{A_o} = \frac{\sqrt{\frac{L}{\pi}+d}}{\sqrt{\frac{L}{\pi}+r_n}}\, e^{-\alpha(r_n-d)} \qquad (5.4)$$

where A_n and A_0 are the vibration amplitudes caused by the single bump at point n = n and n=0 respectively. This ratio depends on d and s/d, as shown in Fig. 5.8. Since we know the equivalent number of cycles for each bump or pothole, we can obtain the equivalent number of cycles for a truck (or pan) pass by cumulating the effects of each bump or pothole. For example, when d = 3m, s/d = 0.5, and n = 4, then A_n/A_0 = 0.7 (using Fig. 2.7 and Eqn. 5.4). For this 4th pothole, 10 cycles with amplitude between 80 to 100% of A_4 equal 10 cycles with amplitude 0.7 x (80 to 100%) of A_0 or approximately 50 to 80% of

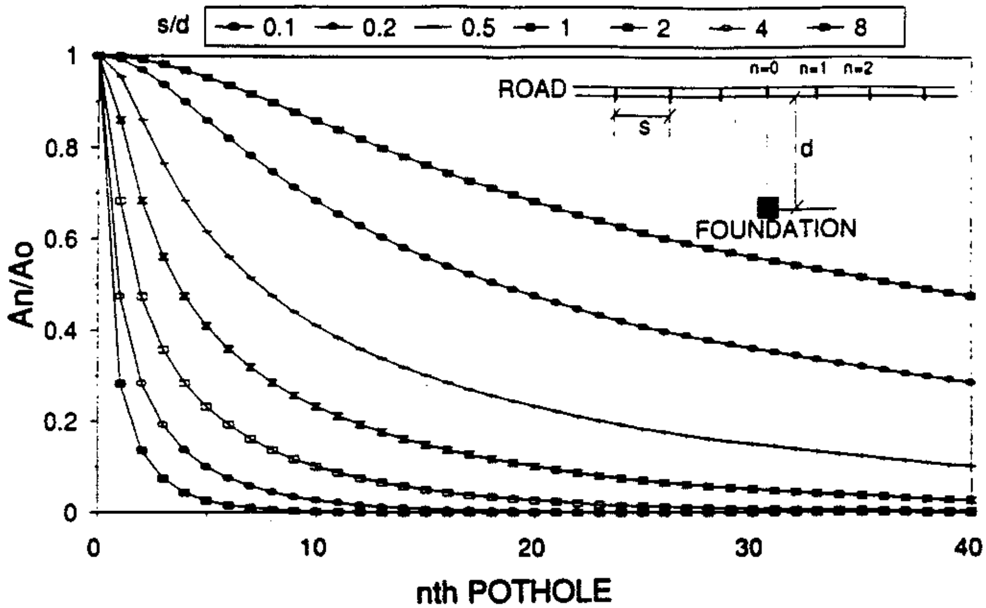


Figure 5.8 The Normalized Amplitude of Vibration for a Truck Passing Over the nth Pothole at Different s/d Ratios

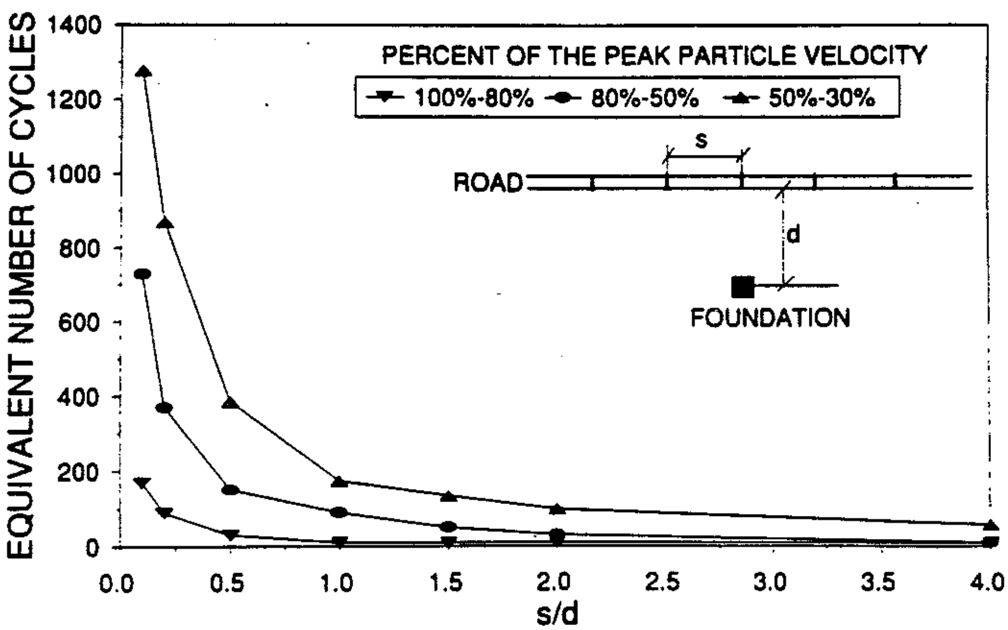


Figure 5.9 Estimated Equivalent Number of Cycles for a Truck Pass

A_0. When one truck travels over all the potholes along the road, the cumulative effect or equivalent number of cycles, is equal to 30 cycles with amplitude between 80 to 100% of A_0, 150 cycles between 50 to 80% of A_0 and 386 cycles between 30 to 50% of A_0.

The effect of s/d was analyzed by a parametric study and the results are presented in Fig. 5.9. Since the vibration attenuates quickly with distance, the pothole far away from the foundation has little effect on the foundation. A FORTRAN program, TRUCKPAS is attached with this report to calculate the equivalent number of cycles for each truck pass. Similarly, program BULLD calculates the equivalent number of cycles for each bulldozer pass. It is needed to emphasize that construction induced vibrations are very complicated and depend on type of equipment, road condition, operating condition of equipment, and soil profile. The best way to estimate the equivalent number of cycles is from field measurement and the above simplified method only provides a preliminary estimate when field records are not available.

5.3 Modeling of Residual Soil Settlement Under Cyclic Torsional Shear

After the peak particle velocity as a function of horizontal and vertical distance is obtained as described before, the soil profile can be divided into several layers and shear strain amplitude can be calculated as a function of depth. The resultant ground surface settlement will be calculated as the cumulated settlement of each of the layers. The relationship between densification and shear strain amplitude, number of cycles, and confining pressure needs to be determined from the data base of resonant column and torsional shear tests.

As described in Chapter 1, one of the objectives of this research effort was to investigate the dynamic settlement of various residual soils as a function of confining pressure, shear strain amplitude, number of cycles, and vibration frequency. The effect of the degree of saturation on the dynamic settlement was also considered. All of these dynamic settlement data were obtained from torsional shear tests using the SBEL Stokoe device at NCSU.

As discussed in Chapter 4, the volume change caused by static isotropic consolidation and that resulting from dynamic torsional shear are considered separately. Figure 5.10 provides the relation between the dynamic volumetric strain and number of cycles under different shear strain amplitudes for specimen 3ST#11B. This relation can be modeled by regression method as :

$$\Delta\varepsilon_{vol} = c(\log N)^{b} \tag{5.5}$$

where $\Delta\varepsilon_{vol}$ is the dynamic volumetric strain under N cycles of torsional shear, b is the constant which depends only on the confining pressure and type of soil, and c is the parameter controlled by the shear strain amplitude, confining pressure and type of soil. Figures 5.11 and 5.12 show the same relation for silty sand specimen 4ST#4 and silt with high liquid limit 5ST#2, respectively. A very important observation from these results is that the dynamic settlement for large number of cycles (up to 1 million) appears to fall along the same curve with number of cycles less than 1000. This suggests that after 1000 cycles, the dynamic settlement still follows the same relation described by Eqn. 5.5, i.e., b and c values remain the same. Accepting that this function is appropriate for large number of cycles, torsional shear tests up to 1000 cycles can be performed, and b and c value can be determined from the settlement data of 1 to 1000 cycles.

The factor c is a function of shear strain amplitude. Figure 5.13 shows c value variation as a function of shear strain amplitude for specimen 3ST#11B at 25 kPa. The relationship between c and shear strain amplitude can be modeled by regression method as :

$$c = a(\gamma - \gamma_c) \tag{5.6}$$

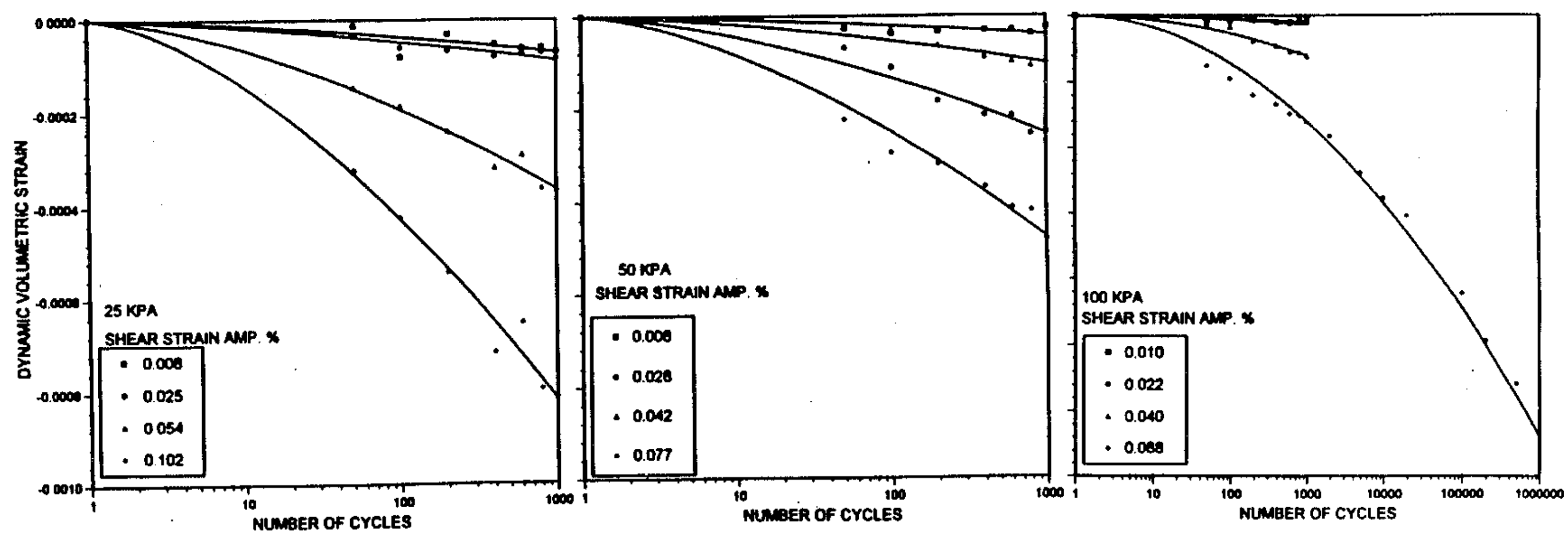


Figure 5.10 Dynamic Volumetric Strain as a Function of Number of Cycles. (Test results for specimen 3ST#11B are shown by points. The results from the model are shown by the curves)

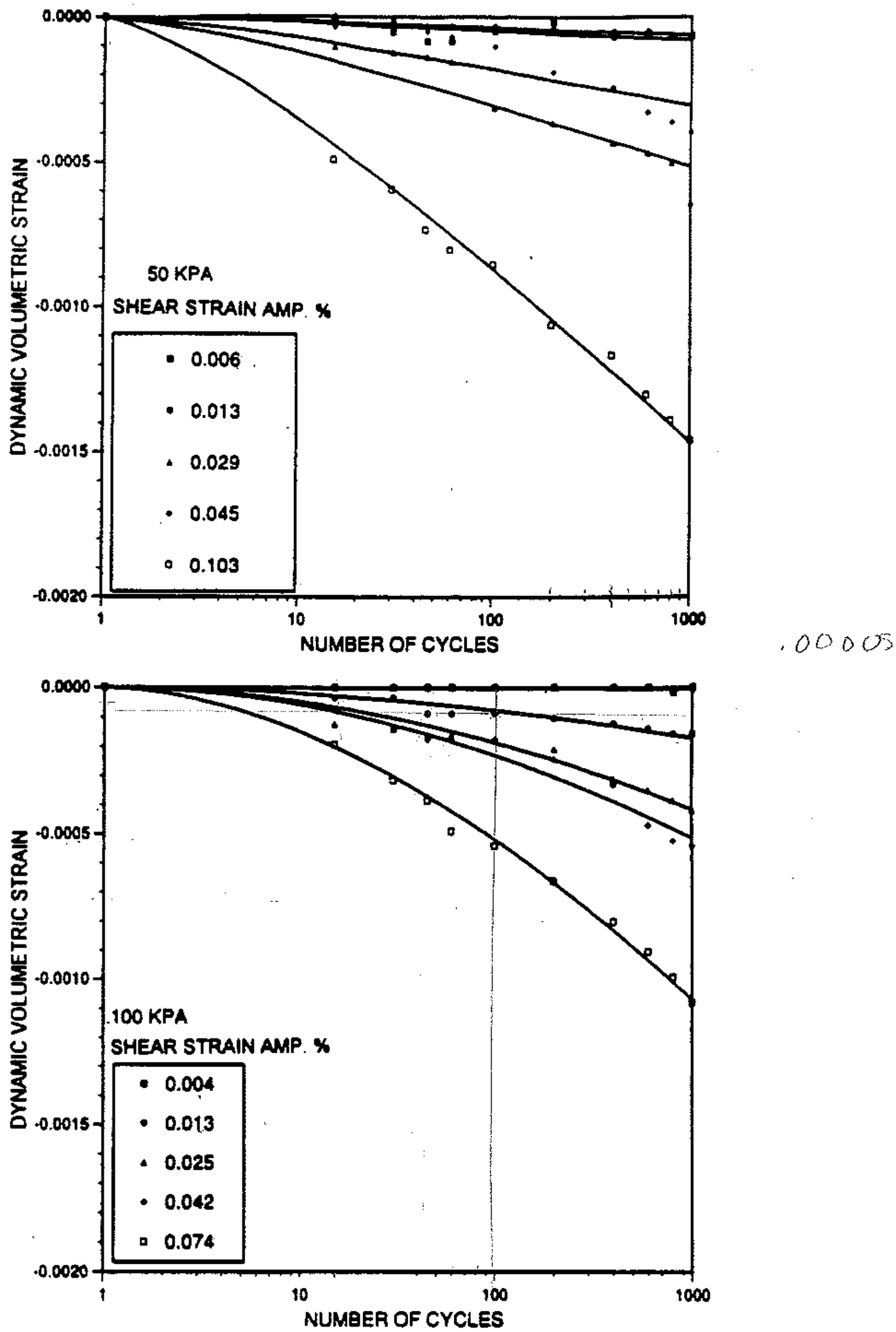


Figure 5.11 Dynamic Volumetric Strain as a Function of Number of Cycles. (Test results for specimen 4ST#4 are shown by points. The results from the model are shown by the curves).

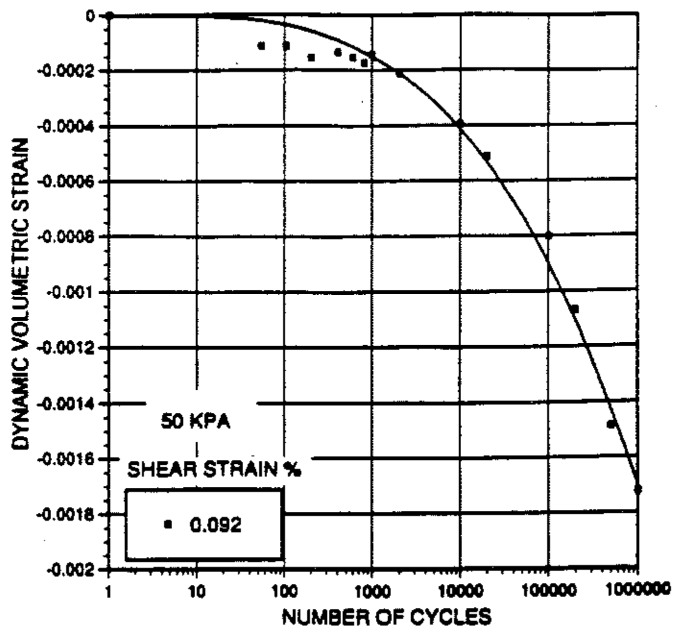


Figure 5.12 Dynamic Volumetric Strain as a Function of Number of Cycles. (Test results for specimen 5ST#2 are shown by points. The results from the model are shown by the curves)

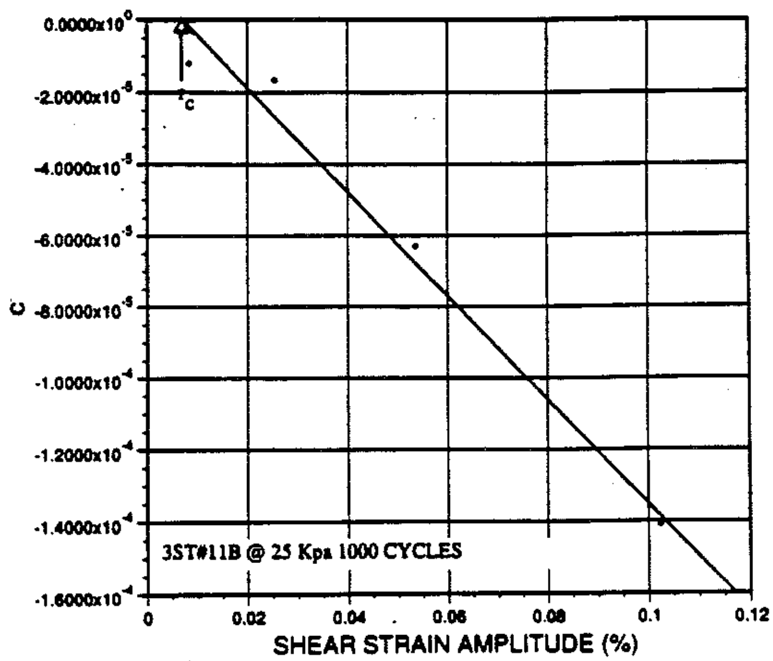


Figure 5.13 Dynamic Volumetric Strain as a Function of Number of Cycles. (The c values were obtained from the curve fitting of test data for specimen 3ST#11B at 25 kPa)

where factor a is only influenced by type of soil and confining pressure, γ_c is the threshold shear strain amplitude (in %) of the specimen at each confining pressure and γ is the current shear strain amplitude (in %). If the shear strain amplitude is below γ_c, dynamic settlement is unlikely to happen. Combining Eqns. 5.5 and 5.6, one can obtain :

$$\Delta\varepsilon_{vol} = a(\gamma - \gamma_c)(\log N)^b \qquad (5.7)$$

This model for dynamic settlement incorporates the influence of shear strain amplitude, number of cycles, factors a, b and threshold shear strain amplitude, which is controlled by confining pressure and soil type. When N = 1000, Eqn. 5.7 can be written as :

$$a(\lambda - \lambda_c) = \frac{\Delta\varepsilon_{vol@N=1000}}{(\log 1000)^b} \qquad (5.8)$$

One can determine a and γ_c values by regression analysis on the settlement data at 1000 cycles. Figure 5.14 shows the example for 3ST#11B at 100 kPa confining pressure. By using the model (Eqn. 5.7), one can predict the settlement caused by cyclic torsional shear. Figure 5.15 compares the measured volumetric strain for 3ST#11B and that calculated using Eqn. 5.7. The model represents the test data very well.

As discussed in Sections 4.5.2 and 4.5.4, it has been suggested that the dynamic settlement is not controlled by the vibration frequency and the degree of saturation of soil specimens.

From above discussion, it is clear that for the same kind of dynamic load (shear strain amplitude and number of cycles), the dynamic settlement is controlled by the soil properties and confining pressure. The finer the particle size, the smaller is the settlement observed. Figure 5.16 provides the best fit lines for the dynamic volumetric strain at 1000 cycles for the silty soils with high liquid limit, sandy silt and silty sand. The data comes from the torsional shear tests results of specimens 3ST#11A, 3ST#11B, 3ST#12, 4ST#1,

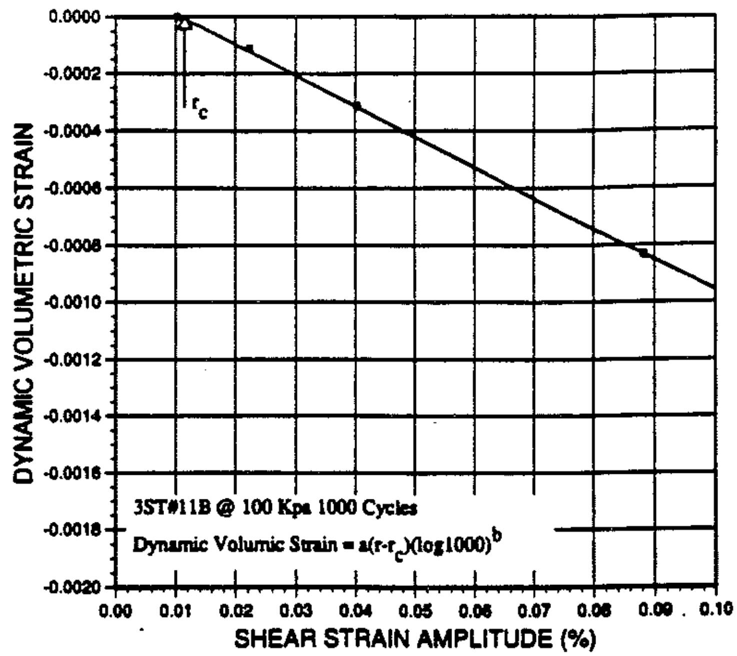


Figure 5.14 Dynamic Volumetric Strain (for 1000 Cycles) as a Function of Shear Strain Amplitude for Specimen 3ST#11B at 100 kPa

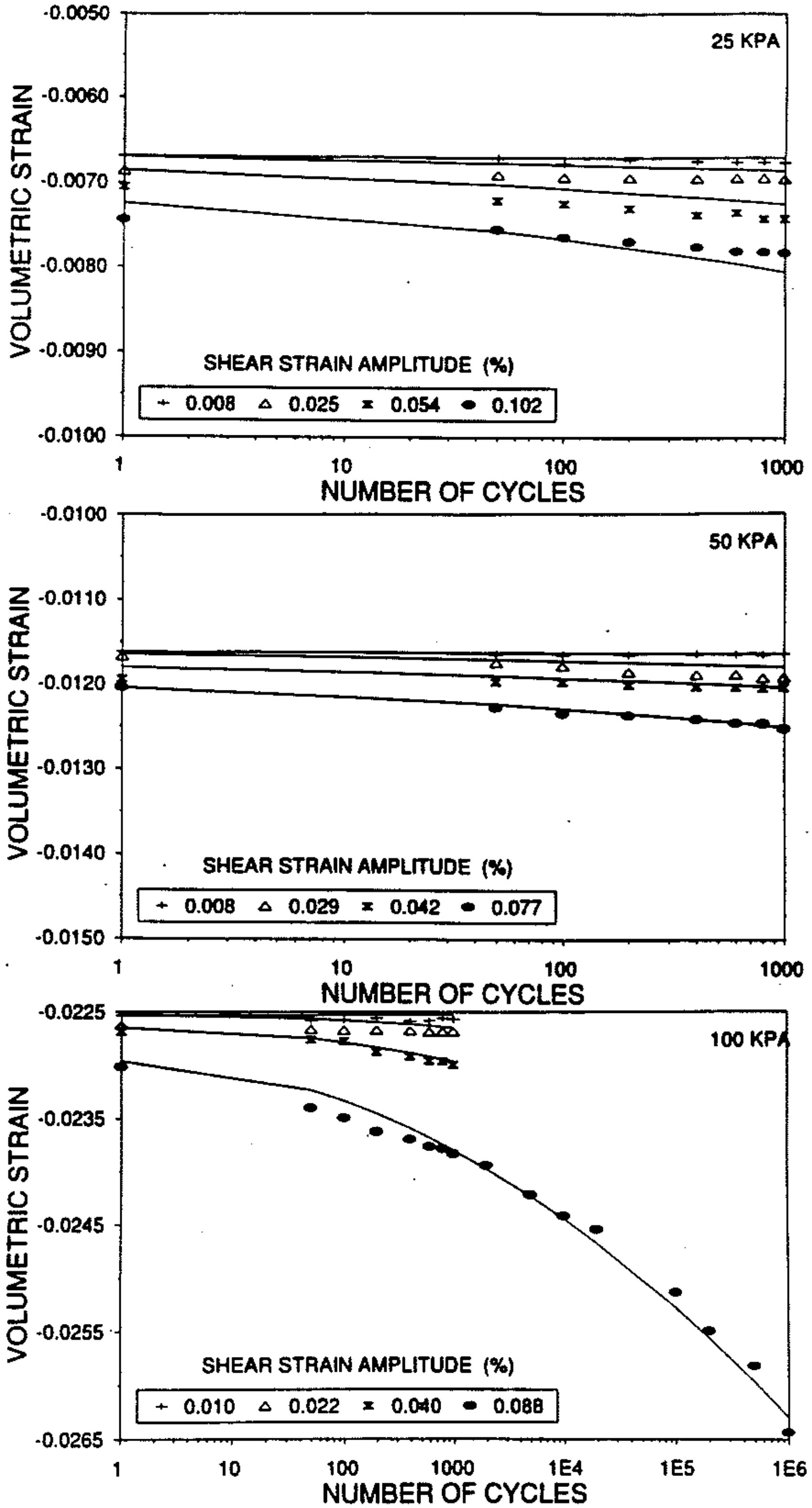


Figure 5.15 Comparison Between Measured and Predicted Volumetric Strain. (Test results for specimen 3ST#11B are shown by points. The results from the model are shown by the curves)

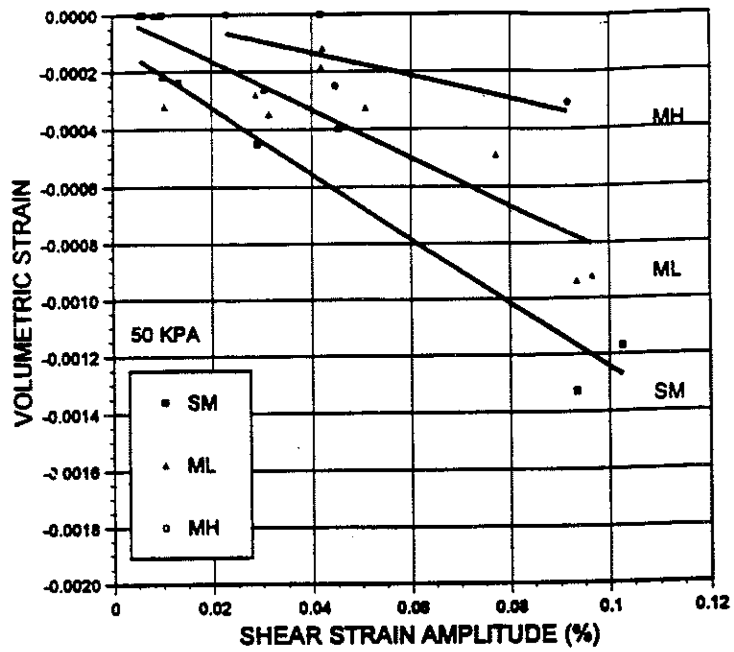


Figure 5.16 Effect of Soil Type on Dynamic Settlement (1000 Cycles)

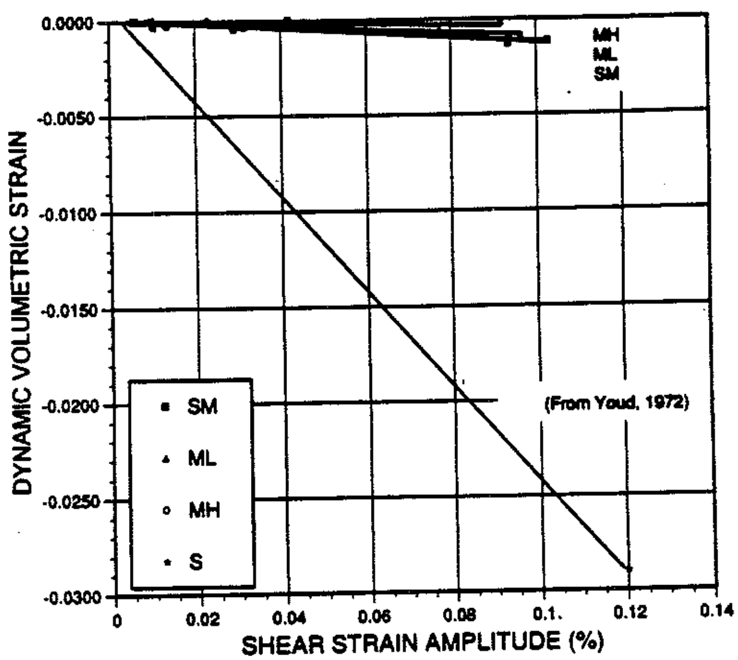


Figure 5.17 Comparison Between Dynamic Volumetric Strain as a Function of Shear Strain Amplitude for Dry Sand (Youd, 1972) and Residual Soils for 1000 Cycles

4ST#4, and 5ST#2. Table 5.1 lists factor a, b, and γ_C of different classifications of residual soil under confining pressures 25 kPa, 50 kPa, and 100 kPa. For preliminary purposes when site-specific data is not available, one can match the soil at different depths to Table 5.1 by the nearest soil classification and grain size distribution, and then select values for factors a, b, and γ_c. By using Eqn. 5.7, the settlement induced by construction vibration can be calculated.

Figure 5.17 compares the dynamic settlement for the tests results on dry sand obtained by Youd (1972) and the residual soils tested in this project. It is clear that the residual soil settles much lesser than dry sand.

5.4 Modeling of Shear Modulus of Residual Soil

As discussed in Chapter 4 and in Section 5.1, the shear modulus of residual soil decreases with increasing shear strain amplitude. The normalized shear modulus, G/G_{max}, of test phase I is shown in Fig. 5.18. It is observed that at very small shear strain amplitudes, the soil behaves as a linear elastic material, i.e., G/G_{max} equals 1.0, and the shear modulus reaches its maximum value, G_{max}. From the shear wave velocity measured in the field, we can find the maximum shear wave velocity, and then calculate the G_{max} according to Eqn. 2.7. When the shear strain increases above a certain level, the shear modulus decreases. This effect is presented in Fig. 5.19, and can be modeled by equation as :

$$\frac{G}{G_{max}} = 1 \qquad (\text{if } \gamma \le \gamma_g) \qquad (5.9a)$$

$$\frac{G}{G_{max}} = 1 - G_1 \log\left(\frac{\gamma}{\gamma_g}\right) \qquad (\text{if } \gamma > \gamma_g) \qquad (5.9b)$$

where γ_g is the limiting shear strain amplitude. Below γ_g, shear modulus remains G_{max}. Factor G_1 and γ_g depend on soil properties and the confining pressure. For tests

Table 5.1 Factors for Soil Dynamic Densification Modeling

Type of Soil	SM			ML			ML		
Specimen Number	4ST#4			3ST#3			3ST#8		
Factors	a	b	rc (%)	a	b	rc (%)	a	b	rc (%)
Confining Pressure (Kpa)									
25							0.002812	1	0.00683
50	0.00344	1.3	0.0052	0.00597	1.75	0.00725	0.00113	1.5	0.00375
100	0.00333	1.7	0.0023	0.00242	2.5	0.003			

Type of Soil	ML			MH			MH		
Specimen Number	2ST#3			3ST#11B			5ST#2		
Factors	a	b	rc (%)	a	b	rc (%)	a	b	rc (%)
Confining Pressure (Kpa)									
25	0.00534	1.5	0.0071	0.00144	1.6	0.00705			
50	0.00232	1.8	0.003	0.00111	1.6	0.00449	9.9E-05	3.5	0.01692
100	0.00112	3	0.0121	0.0012	2	0.0109			

Type of Soil	SM-ML		ML	
Specimen Number	RC-1,2		RC-3,4,5	
Factors	G1	rg (%)	G1	rg (%)
Confining Pressure (Kpa)				
25	0.382	0.00136	0.416	0.00412
50	0.400	0.00134	0.400	0.00405
100	0.409	0.00192	0.384	0.00448

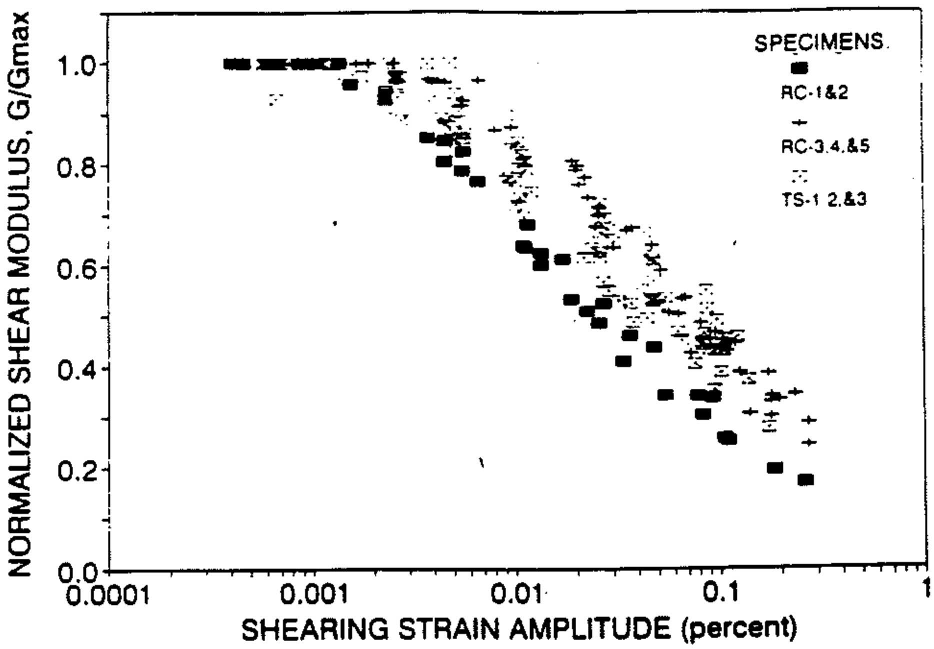


Figure 5.18 Normalized Shear Modulus as a Function of Shear Strain Amplitude

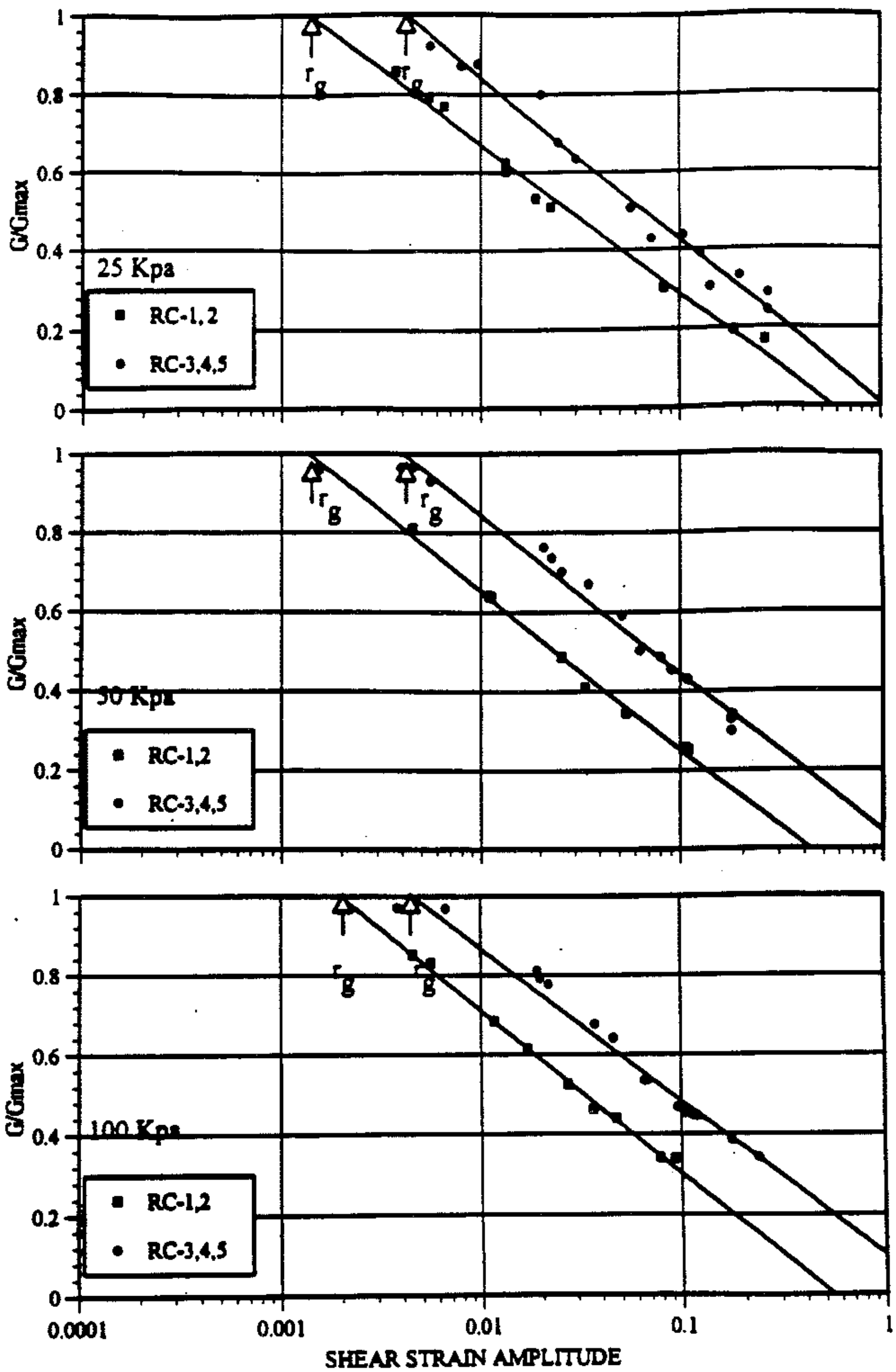


Figure 5.19 G/Gmax as a Function of Shear Strain Amplitude for Confining Pressures of 25, 50, and 100 kPa. (Test results are shown by points. The results from the model are shown by lines)

conducted in this experimental program, these factors are listed in Table 5.1. One can select values of G_1 and γ_g by matching his soil with similar classification groups as listed in the table. By using this model (Eqn. 5.9), one can obtain an estimate of the actual shear strain amplitude by the method provided in Section 5.1.

5.5 Procedure for Dynamic Settlement Evaluation and Examples

In the above sections, the attenuation of construction induced vibrations, the evaluation of equivalent number of cycles, and the modeling of dynamic settlement and shear modulus of residual soil from our experimental data base were discussed. Based on these considerations, we can evaluate the construction vibration induced settlement using the following procedure :

1. Determine the source characteristics of the construction induced vibration from field measurement or literature, such as presented in Fig. 2.1;
2. Determine the peak particle velocity on the ground surface at the site of the building foundation by field measurement, or surface wave attenuation theory from Eqn. 2.1 or 2.3;
3. Estimate the equivalent number of cycles of each event by field time history records or by the simplified method proposed in Section 5.2 (For truck pass or bulldozer pass, one can use the attached programs TRUCKPAS or BULLD);
4. Calculate the particle velocity amplitude at different depths(about 1.5 m, 3.0 m and 6.0 m) by the Rayleigh wave attenuation theory using Eqn. 5.1;
5. Find the shear strain amplitude at different depths by the method provided in Sections 5.1 and 5.4;
6. Calculate the dynamic settlement by Eqn. 5.7 for the equivalent number of cycles for the appropriate shear strain amplitude in each layer, (The factors a, b, and γ_c

can be obtained from cyclic torsional shear test or selected from Table 5.1 by matching existing soils to those with most similar properties); and finally,

7. Obtain the total vibration induced settlement by adding the settlement from each layer. One could evaluate the differential settlement of a building by repeating procedures 1 to 7 for different locations under the building. (i.e., different distances from the vibration source and different confining pressures).

Wahls (1994) has presented a comprehensive review of criteria for tolerable movements of buildings and bridges. There are basically three criteria which have to be satisfied when considering limiting settlements: (i) visual appearance, (ii) serviceability or function, and (iii) stability. Most of the researches have emphasized that it is impossible to lay down specific guidelines for limiting differential settlements in relation to damage and that each structure must be treated on its merits. The engineers need to use their judgment based on building type and soil profile.

The popularly used recommendations on allowable differential settlement of structures were initially proposed by Skempton and MacDonald (1956) and later systematically reviewed by Burland et al. (1977). Table 5.2 is provided following their recommendations. It needs to be emphasized that the tolerable foundation settlement in this table is total settlement, i.e., settlement during and after construction. The construction vibration induced settlement is one of the post-construction settlement and the design criteria must be based on engineering judgment.

For dynamic settlement analysis, above mentioned steps 4 to 7 are written into a FORTRAN program CVIS (Construction Vibration Induced Settlement). The user inputs dynamic soil properties, equivalent number of cycles, and surface peak particle velocity, and the program calculates the total dynamic settlement based on the above procedures. Programs TRUCKPAS and BULLD help users to estimate the equivalent number of

Table 5.2 Guidelines for tolerable foundation settlement

	Sands	Clayey Soils
Isolated Foundation:		
Total Settlement	40 mm	65 mm
Differential Settlement	25 mm	40 mm
Relative Rotation	1/500	1/500
Tilt	Determined in Design	Determined in Design
Raft Foundation:		
Total Settlement	40 - 65 mm	65 mm - 100 mm

cycles for truck and bulldozer passes respectively if field records are not available. Appendices 1, 2.1 and 2.2 provide these programs instructions, input data and results of example problems, and source codes of computer programs. The program CVIS (Version 1.0) only estimates the dynamic settlement for free ground surface. In the soil profile, the vertical stress is less than that under building foundations. Therefore, the soil settles more than that under building foundations. The result obtained by CVIS is conservative to evaluate the foundation settlement under construction induced vibrations.

For better understanding of the above procedure, three example problems will be discussed. They are settlement caused by truck passing , bulldozer passing and weight dropping.

Example 1

Since we don't have the time history of the truck passing on an unpaved road, here we just estimate this case by assuming the equivalent pothole spacing on a paved road.

For each pothole, we use the data for a loaded truck (11,500 kg) hitting one 7.5 cm x 20 cm bump at speed 38.3 km/hour (23.8 mph) on paved road (see Fig. 5.5). This record came from NCDOT investigation reports for Corning Glass Works, in Wilmington, NC in 1981.

In this NCDOT record, there are 10 cycles with amplitude between 80 to 100% of the peak particle velocity, 10 cycles between 50 to 80%, and 18 cycles between 30 to 50% when the loaded truck hit the bump. The dominant frequency of the ground vibration is 15 Hz.

Assuming the building foundation is located three meters form a unpaved road. When the truck hit the nearest bump, the resultant peak particle velocity is 6.38 mm/sec (from NCDOT record). Assuming the truck rolls over bumps with 0.6 m spacing along the road (Fig. 5.9), then s/d = 0.2. Following the procedure in Section 5.2, the equivalent number of cycles are 30 cycles between 80 to 100% of peak particle velocity, A_0, 150 cycles between 50 to 80% of A_0 and 386 cycles between 30 to 50% of A_0. Program TRUCKPAS can do this calculation. Supposing there are 10,000 truck passes along the road and the soil properties are the same as specimen 3ST#8, the cumulative settlement calculated by program CVIS is only 0.0025 mm. The input data file and output result are provided in Appendix 2.1.1. If we change the soil properties to specimen 3ST#11B, the shear strain amplitude throughout the soil profile is less than the threshold value, therefore, there is no settlement. If the user wants to evaluate the dynamic settlement at different distance from the road, the method discussed in Section 2.2 can be used to find the peak particle velocity, and then repeat program CVIS.

Example 2

The D-9G bulldozer working pass generates quit uniform waves at 19 Hz (Fig. 5.6). The peak particle velocity is 14.7 mm/sec when the bulldozer passes 1.2 m from the foundation. The bulldozer passes at 4.34 km/hour and the equivalent number of cycles for each pass are estimated by program BULLD as 71 cycles between 100% to 80% of the peak particle velocity, 162 between 80% to 50%, and 150 between 50% to 30% respectively. If we use the test result of specimen 3ST#3 in our data base, the cumulative settlement generated by 10,000 passes is 1.27 mm. The input and output files of the program CVIS is provided in Appendix 2.1.2.

Example 3

The record of a 136 kg weight dropping from 1.7 m height (Figure 5.7) has 1 cycle between 100% to 80% of peak particle velocity, 1 cycle between 80% to 50%, and 1 cycle between 50% to 30%. This record obtained from NCDOT field test in Wilmington, NC in 1981. Three meters from the source, the peak particle velocity is 100.8 mm/sec at the dominant frequency of 30 Hz. It is important to emphasize that the energy of pile driving could be higher than this example. Assuming the soil is the same as our specimen 3ST#11B, and the maximum shear wave velocity is 139 m/sec. The Rayleigh wave length is around 4.2 m. If we consider the extremely condition, for 1 million strikes, the cumulated settlement is 11.4 mm. The input and output files are listed in Appendix 2.1.3. If we change the soil type to specimen 3ST#3, the cumulated settlement for this case reaches 88.4 mm. The peak particle velocity in this example is 100.8 mm/sec, which is much higher than 50.8 mm/sec recommended by the US Bureau of Mines for residential structures. This vibration amplitude can damage the building structure directly before any settlement of the foundation.

5.6 Summary

From above discussion, it is clear that the construction induced settlement is controlled by the vibration amplitude, distance from the source and dynamic properties of soils. The modeling of dynamic settlement as a function of shear strain amplitude and number of cycles at each confining pressure is provided. The effect of shear strain amplitude on the shear modulus of residual soils is analyzed in this chapter. Following the procedure proposed in this chapter, one can use the model developed to estimate the construction induced settlement.

CHAPTER 6

CONCLUSIONS

Based on the results of laboratory resonant column and torsional shear tests, a critical analysis of the literature related to construction induced vibrations, and the analytical work performed in this study, the following observations and conclusions are noted :

1. Fundamental concepts and literature show that cyclic shear strain is the primary factor causing dynamic densification of granular soils.
2. Resonant column and torsional shear tests were conducted on 33 specimens of residual soil obtained from 8 different sites. These specimens were tested at confining pressures of 25, 50 and 100 kPa with the aim to study the change in shear modulus, damping ratio, and the dynamic densification. A data base was developed for dynamic densification of these residual soils as a function of confining pressure, shear strain amplitude, cyclic frequency and number of cycles.
3. The shear modulus of the residual soils was observed to decrease and the damping ratio was observed to increase with increasing shear strain amplitude. No significant effect of number of cycles was observed on the shear modulus or damping ratio of residual soils.
4. The dynamic settlement of the residual soils tested was observed to be small, especially in comparison to that reported in the literature for sands. This dynamic densification was found to mainly depend on the soil type, confining pressure, shear strain amplitude, and number of cycles applied. The following general trends were observed :

(a) Dynamic settlement was greatest for the most granular specimen with decreasing settlement associated with increasing fines content;

(b) Dynamic settlement decreased with increasing confining pressures;

(c) Dynamic densification of residual soils increased with increasing shear strain amplitude. Further, the results of the cyclic torsional shear test on residual soils tested showed that the threshold shear strain, that value below which there is essentially no volume change, is in the range of 0.005% to 0.01%.

(d) The dynamic settlement was found to increase monotonically with increasing number of loading cycles.

5. It was observed from the cyclic torsional shear test results that the frequency of the vibrations and the degree of saturation of the specimen did not have a significant effect on the dynamic densification of the residual soils tested.

6. Based on the results of the various residual soils tested in this project, a model to predict the construction induced settlement has been proposed. The concept of equivalent number of cycles has been used to estimate the construction induced settlement.

7. The effects of shear strain amplitude on the shear modulus and damping ratio of residual soil were also evaluated. A model was developed to estimate the decrease in shear modulus with increasing shear strain amplitude.

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APPENDIX 1

INSTRUCTIONS FOR USE OF COMPUTER PROGRAMS

Appendix 1.1 CVIS

The program CVIS (Construction Vibration Induced Settlement) has the functions to calculate the wave attenuation through the depth, to find shear strain amplitude in three layers, and to predict the settlement of free ground surface under the equivalent number of cycles. The dynamic factors which describe the settlement of soil under cyclic load were obtained from torsional shear tests. The program divides the soil profile into three layers, which are 2.1m, 2.4m, and 3.0m respectively. The user needs to provide the surface peak particle velocity at the site of interest under construction induced vibrations.

Using the program CVIS is easy and straight forward. The input data file and output file can have any name. The user just answers the questions asked by the program and can run multiple problems at same time. The format of the input data file is provided as:

```
TITLE
PPV,FREQ,VS
NE,NN90,NN65,NN40
A(1),B(1),RC(1),G1(1),RG(1)
A(2),B(2),RC(2),G1(2),RG(2)
A(3),B(3),RC(3),G1(3),RG(3)
```

Following is explanation for each of the variables in the input data file:

TITLE:	Title of the problem, could be any thing in a single line.
PPV:	Peak particle velocity on the site ground surface (mm/sec).
FREQ:	Dominant frequency of the vibration.
VS:	Shear wave velocity (m/sec)
NE:	Number of events (i.e., truck passing, pile driving)
NN90:	Equivalent number of cycles between 80 to 100% of PPV.

NN65: Equivalent number of cycles between 50 to 80% of PPV.

NN40: Equivalent number of cycles between 30 to 50% of PPV.

A(I), B(I), RC(I), G1(I), RG(I) (I=1,2,3)

Soil dynamic properties obtained from resonant column / torsional shear tests.

This program is written in FORTRAN language and the CVIS.exe file is provided for IBM compatible computers. The source code needs to be compiled if the program is to be used on a UNIX system Apple computer.

Appendix 1.2 TRUCKPAS

The program TRUCKPAS estimates the equivalent number of cycles for a truck passing by the site. No input file needed, just answer the questions asked by the program.

Program ask	INPUT NN90,NN65,NN40
User input	NN90,NN65,NN40
Program ask	INPUT D,S/D,DWHEEL,ALFA
User input	D,SD,DWHEEL,ALFA

where:

NN90:	Equivalent number of cycles between 80 to 100% of PPV, 1 bump.
NN65:	Equivalent number of cycles between 50 to 80% of PPV, 1 bump.
NN40:	Equivalent number of cycles between 30 to 50% of PPV, 1 bump.
D:	Distance from the site to the road (m).
SD:	S/D ratio (see Sector 5.4).
DWHEEL:	Wheel base of the truck (m).
ALFA	Attenuation factor (see Section 5.1 and 2.3)

Appendix 1.3 BULLD

The program BULLD estimates the equivalent number of cycles for a bulldozer passing by the site. No input file needed, just answer the questions asked by the program.

Program ask	INPUT D,FREQ,V,DWHEEL,ALFA
User input	D,FREQ,V,DWHEEL,ALFA

where:

D:	Distant from the site to the bulldozer passing by (m).
FREQ:	Vibration frequency induced by bulldozer (Hz).
V:	Bulldozer velocity (m/sec).
DWHEEL:	Length of bulldozer (m).
ALFA	Attenuation factor (see Section 5.1 and 2.3)

APPENDIX 2

APPENDIX 2.1

EXAMPLES FOR CALCULATING CONSTRUCTION VIBRATION INDUCED SETTLEMENT

Appendix 2.1.1 Example 1

Input File

```
TRUCK PASS @ 3 M, (BASED ON SPECIMEN 3ST#8)
6.375,15.0,141.1
10000,30,150,386
0.00281,1.0,0.00683,0.382,0.00136
0.00113,1.5,0.00375,0.400,0.00134
0.00113,1.5,0.00375,0.409,0.00194
```

Output File of the Program CVIS

```
TRUCK PASS @ 3 M, (BASED ON SPECIMEN 3ST#8)

  ### INPUT DATA ###

 PEAK PARTICAL VELOCITY (MM/SEC)= 6.3750
 VIBRATION FREQUENCY (HZ)       = 15.000
 SHEAR WAVE VELOCITY ( M/SEC)   =141.100
 NUMBER OF EVENTS               =  10000
 # OF CYCLES PER EVENT 100-80%  =     30
 # OF CYCLES PER EVENT 80-50%   =    150
 # OF CYCLES PER EVENT 50-30%   =    386

 LAYER    A(I)      B(I)       RC(I)      G1(I)      RG(I)
  1     .00281    1.00000    .00683     .38200     .00136
  2     .00113    1.50000    .00375     .40000     .00134
  3     .00113    1.50000    .00375     .40900     .00194

   ### RESULTS ###


 SETTLEMENT IN LAYER  1  =    .0000E+00(MM)
 SHEAR STRAIN AMPLITUDE IN THIS LAYER =.55187E-02%


 SETTLEMENT IN LAYER  2  =  -.2566E-02(MM)
 SHEAR STRAIN AMPLITUDE IN THIS LAYER =.42474E-02%


 SETTLEMENT IN LAYER  3  =    .0000E+00(MM)
 SHEAR STRAIN AMPLITUDE IN THIS LAYER =.18792E-02%


 TOTAL SETTLEMENT DUE TO CONSTRUCTION VIBRATION =  -.2566E-02MM
```

Appendix 2.1.2 Example 2

Input File

```
D9G BULLDOZER @1.22 M, (BASED ON SPECIMEN 3ST#3)
14.68,19.0,167.0
10000,71,162,150
0.00597,1.75,0.00725,0.382,0.00136
0.00597,1.75,0.00725,0.400,0.00134
0.00242,2.50,0.00300,0.409,0.00194
```

Output File of the Program CVIS

```
D9G BULLDOZER @1.22 M, (BASED ON SPECIMEN 3ST#3)


  ### INPUT DATA ###

 PEAK PARTICAL VELOCITY (MM/SEC)=14.6800
 VIBRATION FREQUENCY (HZ)       = 19.000
 SHEAR WAVE VELOCITY ( M/SEC)   =167.000
 NUMBER OF EVENTS               =  10000
 # OF CYCLES PER EVENT 100-80%  =     71
 # OF CYCLES PER EVENT 80-50%   =    162
 # OF CYCLES PER EVENT 50-30%   =    150

 LAYER    A(I)       B(I)        RC(I)       G1(I)       RG(I)
  1      .00597    1.75000     .00725      .38200      .00136
  2      .00597    1.75000     .00725      .40000      .00134
  3      .00242    2.50000     .00300      .40900      .00194


   ### RESULTS ###


 SETTLEMENT IN LAYER  1  =  -.1032E+01(MM)
 SHEAR STRAIN AMPLITUDE IN THIS LAYER =.11703E-01%


 SETTLEMENT IN LAYER  2  =  -.1808E+00(MM)
 SHEAR STRAIN AMPLITUDE IN THIS LAYER =.86823E-02%


 SETTLEMENT IN LAYER  3  =  -.5532E-01(MM)
 SHEAR STRAIN AMPLITUDE IN THIS LAYER =.34340E-02%


 TOTAL SETTLEMENT DUE TO CONSTRUCTION VIBRATION =  -.1268E+01MM
```

Appendix 2.1.3 Example 3

Input File

```
2033.6 J DROPPED WEIGHT @3.0 M (BASED ON 3ST#11B)
100.8,30.0,138.7
1000000,1,1,1
0.00144,1.6,0.00705,0.416,0.00412
0.001105,1.6,0.0045,0.400,0.00405
0.001196,2.0,0.0109,0.384,0.00448
```

Output File of the Program CVIS

```
2033.6 J DROPPED WEIGHT @3 M (BASED ON 3ST#11B)


  ### INPUT DATA ###

 PEAK PARTICAL VELOCITY (MM/SEC)= 100.8000
 VIBRATION FREQUENCY (HZ)       = 30.000
 SHEAR WAVE VELOCITY ( M/SEC)   =138.700
 NUMBER OF EVENTS               =1000000
 # OF CYCLES PER EVENT 100-80%  =      1
 # OF CYCLES PER EVENT 80-50%   =      1
 # OF CYCLES PER EVENT 50-30%   =      1

 LAYER    A(I)      B(I)        RC(I)      G1(I)       RG(I)
  1      .00144    1.60000     .00705     .41600      .00412
  2      .00111    1.60000      00450     .40000      .00405
  3      .00120    2.00000      01090     .38400      .00448

   ### RESULTS ###


 SETTLEMENT IN LAYER  1  =  -.8575E+01(MM)
 SHEAR STRAIN AMPLITUDE IN THIS LAYER =.92259E-01%


 SETTLEMENT IN LAYER  2  =  -.2828E+01(MM)
 SHEAR STRAIN AMPLITUDE IN THIS LAYER =.37541E-01%


 SETTLEMENT IN LAYER  3  =   .0000E+00(MM)
 SHEAR STRAIN AMPLITUDE IN THIS LAYER =.54280E-02%


 TOTAL SETTLEMENT DUE TO CONSTRUCTION VIBRATION =  -.1140E+02MM
```

APPENDIX 2.2

SOURCE CODE OF PROGRAMS

Appendix 2.2.1 CVIS.FOR

```
$DEBUG
C
C*********************************************************************
C
C                        CVIS  VERSION 1.0
C CALCULATION OF THE CONSTRUCTION INDUCED SETTLEMENT
C                         MAY, 1994
C                   WRITTEN BY LISHENG SHAO
C
C*********************************************************************
      CHARACTER*12 IN,OUT
      CHARACTER*80 TITLE
      DIMENSION DL(3),A(3),B(3),RC(3),G1(3),R(3),SS(3),Z(3)
      DIMENSION VA(3),RG(3)
    4   WRITE(*,*) 'PLEASE TYPE YOUR INPUT FILE NAME'
      READ(*,'(A)')IN
      WRITE(*,*) 'PLEASE TYPE OUTPUT FILE NAME'
      READ(*,'(A)')OUT
      OPEN(5,FILE=IN,STATUS='OLD')
      OPEN(6,FILE=OUT,STATUS='NEW')
      READ(5,1)TITLE
    1   FORMAT(A)
C
C  READ INPUT DATA
C
      READ(5,*) PPV,FREQ,VS
      READ(5,*) NE,NN90,NN65,NN40
      DO 10 I=1,3
   10   READ(5,*) A(I),B(I),RC(I),G1(I),RG(I)
      WRITE(6,1) TITLE
      WRITE(6,20) PPV,FREQ,VS
   20   FORMAT(1X//,'  ### INPUT DATA ###',/
     *            /1X,'PEAK PARTICAL VELOCITY (MM/SEC)=',F9.4,
     *            /1X,'VIBRATION FREQUENCY (HZ)       =',F7.3,
     *            /1X,'SHEAR WAVE VELOCITY ( M/SEC)   =',F7.3)
      WRITE(6,30) NE,NN90,NN65,NN40
   30   FORMAT(1X,'NUMBER OF EVENTS                  =',I7,
     *        /1X,'# OF CYCLES PER EVENT 100-80%   =',I7,
     *        /1X,'# OF CYCLES PER EVENT 80-50%    =',I7,
     *        /1X,'# OF CYCLES PER EVENT 50-30%    =',I7,/)
      WRITE(6,32)
   32   FORMAT(1X,'LAYER    A(I)      B(I)       RC(I)       G1(I)',
     *          '       RG(I)')
      DO 35 I=1,3
   35   WRITE(6,36) I,A(I),B(I),RC(I),G1(I),RG(I)
   36   FORMAT(1X,I2,5(1X,F10.5))
      WRITE(6,38)
   38   FORMAT(//1X,'  ### RESULTS ###',/)
      PI=3.14159
      PPV=PPV/25.4
      VS=VS*3.281
C
C DIVIDING INTO 3 LAYERS
C
      Z(1)=5.0
      Z(2)=10.0
      Z(3)=20.0
```

```
      DL(1)=7.0
      DL(2)=8.0
      DL(3)=10.0
      VRM=0.919*VS
      WAVEL=VRM/FREQ
      DO 500 L=1,3
C
C  CALCULATING SHEAR STRAIN AMPLITUDE IN EACH LAYER
C
      ZMR=Z(L)/WAVEL
      W=-EXP(-0.8475*2.*PI*ZMR)+1.7321*EXP(-0.3933*2.*PI*ZMR)
      WW0=W/0.7321
      VA(L)=PPV*WW0
      VR=VRM
      RII=0.0
   50   R(L)=VA(L)*100.0/(12.0*VR)
      IF(ABS(R(L)-RII).LT.0.001) GOTO 70
      IF(R(L).LE.RG(L)) GOTO 60
      GGM=1-G1(L)*LOG10(R(L)/RG(L))
      GOTO 65
   60   GGM=1.0
   65   CONTINUE
      VR=SQRT(GGM)*VRM
      RII=R(L)
      GOTO 50
   70   E90=0.0
      E65=0.0
      E40=0.0
C
C  CALCULATING DYNAMIC STRAIN IN EACH LAYER
C
      R90=R(L)*0.9
      IF(R90.LT.RC(L)) GOTO 200
      NN=NE*NN90
      AAL=LOG10(FLOAT(NN))
      E90=-A(L)*(R90-RC(L))*(AAL**B(L))
      E65=0.0
      R65=R(L)*0.65
      IF(R65.LT.RC(L)) GOTO 200
      NN=NE*NN65
      AAL=LOG10(FLOAT(NN))
      E65=-A(L)*(R65-RC(L))*(AAL**B(L))
      E40=0.0
      R40=R(L)*0.4
      IF(R40.LT.RC(L)) GOTO 200
      NN=NE*NN40
      AAL=LOG10(FLOAT(NN))
      E40=-A(L)*(R40-RC(L))*(AAL**B(L))
200   CONTINUE
      E=E90+E65+E40
C
C  CALCULATING DYNAMIC SETTLEMENT
C
      SS(L)=E*DL(L)*12.0*25.4
C
C  OUTPUT RESULTS
C
      WRITE(6,220) L,SS(L),R(L)
  220   FORMAT(//1X,'SETTLEMENT IN LAYER ',I2,'  =',
     *  E12.4,'(MM)',
```

```
     *  /1X,'SHEAR STRAIN AMPLITUDE IN THIS LAYER =',E10.5,'%')
500     CONTINUE
      TTS=SS(1)+SS(2)+SS(3)
      WRITE(6,520) TTS
520     FORMAT(//1X,'TOTAL SETTLEMENT DUE TO CONSTRUCTION',
     *   ' VIBRATION =',E12.4,'MM')
      CLOSE(5)
      CLOSE(6)
      WRITE(*,*) 'IF YOU WANT TO CALCULATE OTHER CASE, INPUT 1'
      WRITE(*,*) 'IF NOT, INPUT 0'
      READ(*,*) NEXT
      IF(NEXT.EQ.1) GOTO 4
      STOP
      END
```

Appendix 2.2.2 TRUCKPAS.FOR

```
$DEBUG
C
C***********************************************************************
C
C                   TRUCKPAS  VERSION 1.0
C CALCULATE THE EQUIVALENT NUMBER OF CYCLES FOR TRUCKPASS
C                       MAY, 1994
C                 WRITTEN BY LISHENG SHAO
C
C***********************************************************************
      NCY90=0
      NCY65=0
      NCY40=0
      PI=3.14159
      WRITE(*,*) 'INPUT NN90,NN65,NN40'
      READ(*,*) NN90,NN65,NN40
      WRITE(*,*) 'INPUT D,S/D,DWHEEL,ALFA'
      READ(*,*) D,SD,DWHEEL,ALFA
      D=D*3.281
      DWHEEL=DWHEEL*3.281
      DO 100 N=-40,40
      RN=D*SQRT(FLOAT(N)*FLOAT(N)*SD*SD+1)
      DP=DWHEEL/PI
      ANA0=(SQRT(DP+D)/SQRT(DP+RN))*EXP(ALFA*(D-RN))
      A90=0.9*ANA0
      A65=0.65*ANA0
      A40=0.4*ANA0
      IF(A90.GE.0.8) NCY90=NCY90+NN90
      IF(A90.LT.0.8.AND.A90.GE.0.5) NCY65=NCY65+NN90
      IF(A90.LT.0.5.AND.A90.GE.0.3) NCY40=NCY40+NN90
      IF(A65.GE.0.5) NCY65=NCY65+NN65
      IF(A65.LT.0.5.AND.A65.GE.0.3) NCY40=NCY40+NN65
      IF(A40.GE.0.3) NCY40=NCY40+NN40
 100    CONTINUE
      WRITE(*,200) NCY90,NCY65,NCY40
 200    FORMAT(1X//,1X,'NUMBER OF CYCLES BETWEEN 80-100%',I5,/
     *            1X,'NUMBER OF CYCLES BETWEEN 50-80% ',I5,/
     *            1X,'NUMBER OF CYCLES BETWEEN 50-30% ',I5)
      STOP
      END
```

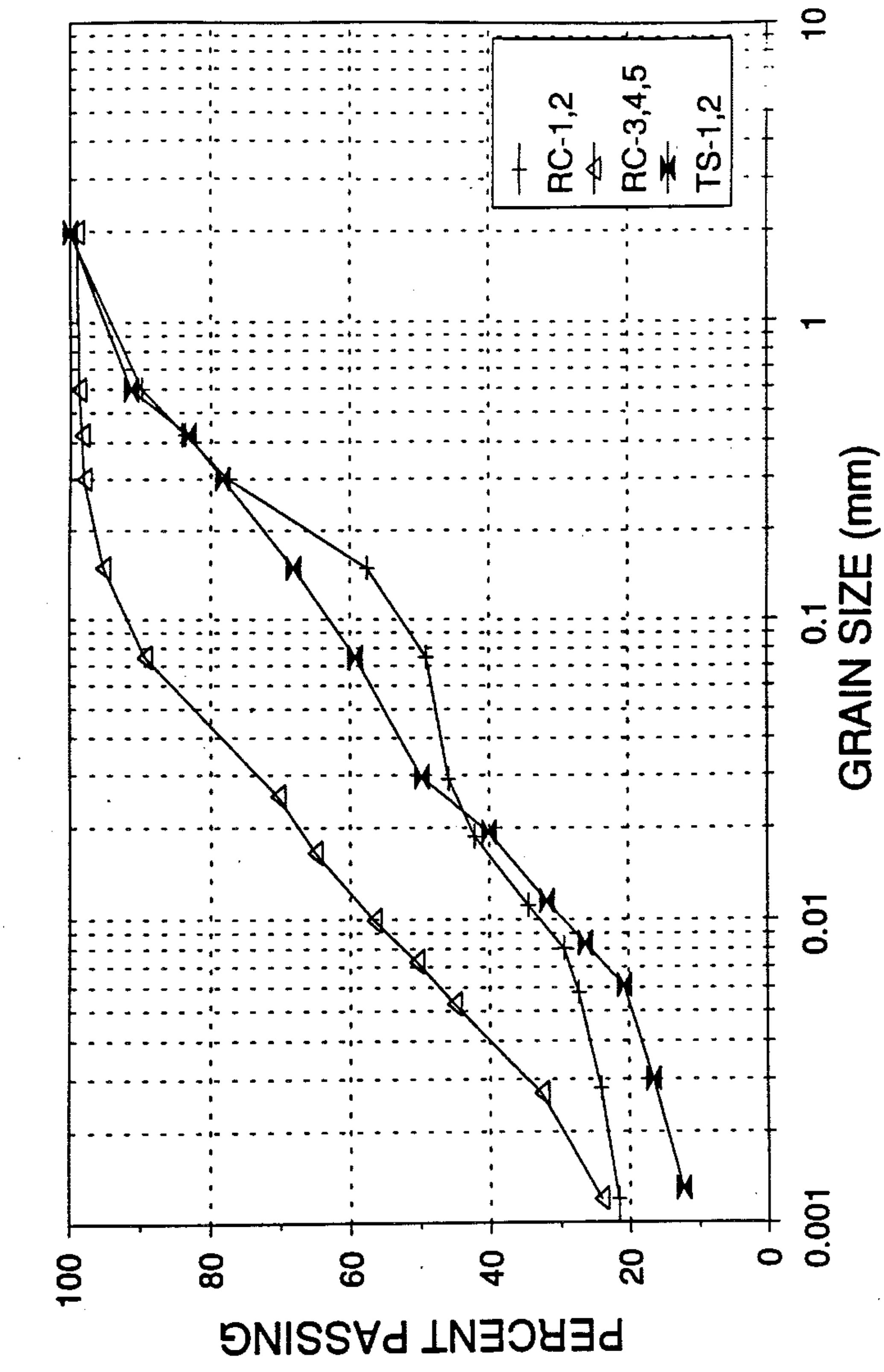
Appendin 2.2.3 BULLD.FOR

```
$DEBUG
C
C***********************************************************************
C
C                    BULLD  VERSION 1.0
C CALCULATE THE EQUIVALENT NUMBER OF CYCLES FOR BULLDOZER
C                        MAY, 1994
C                  WRITTEN BY LISHENG SHAO
C
C***********************************************************************
      NCY90=0
      NCY65=0
      NCY40=0
      PI=3.14159
      WRITE(*,*) 'INPUT D,FREQ,V,DWHEEL,ALFA'
      READ(*,*) D,FREQ,V,DWHEEL,ALFA
      D=D*3.281
      V=V*3.281
      DWHEEL=DWHEEL*3.281
      MM=INT(10*D*FREQ/V)
      DO 100 N=-MM,MM
      RN=SQRT(D*D+(V*FLOAT(N)/FREQ)**2)
      DP=DWHEEL/PI
      ANA0=(SQRT(DP+D)/SQRT(DP+RN))*EXP(ALFA*(D-RN))
      IF(ANA0.GE.0.8) NCY90=NCY90+1
      IF(ANA0.LT.0.8.AND.ANA0.GE.0.5) NCY65=NCY65+1
      IF(ANA0.LT.0.5.AND.ANA0.GE.0.3) NCY40=NCY40+1
  100   CONTINUE
      WRITE(*,200) NCY90,NCY65,NCY40
  200   FORMAT(1X//,1X,'NUMBER OF CYCLES BETWEEN 80-100%',I5,./
     *           1X,'NUMBER OF CYCLES BETWEEN 50-80% ',I5,/
     *           1X,'NUMBER OF CYCLES BETWEEN 50-30% ',I5)
      STOP
      END
```

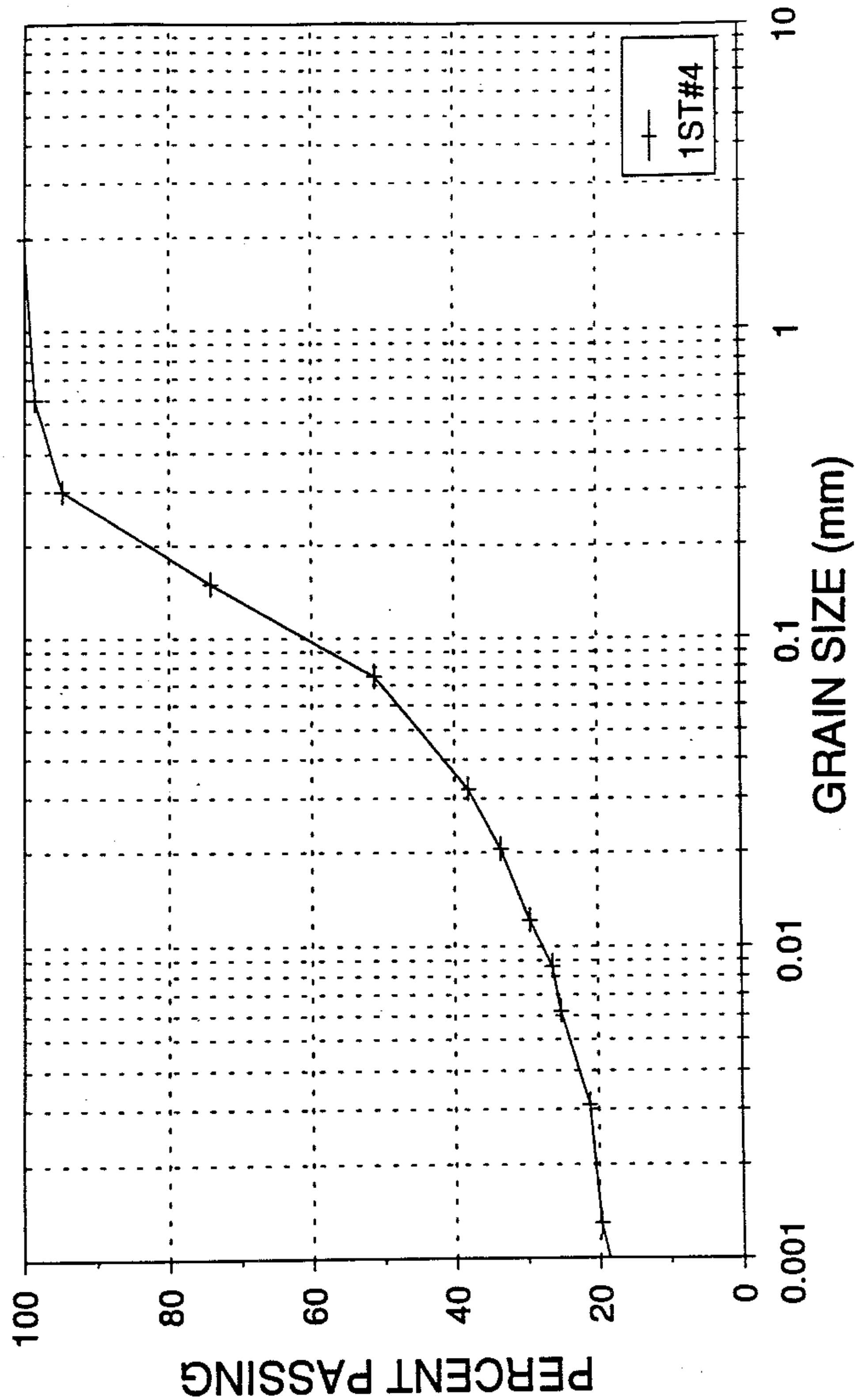
APPENDIX 3

APPENDIX 3.1

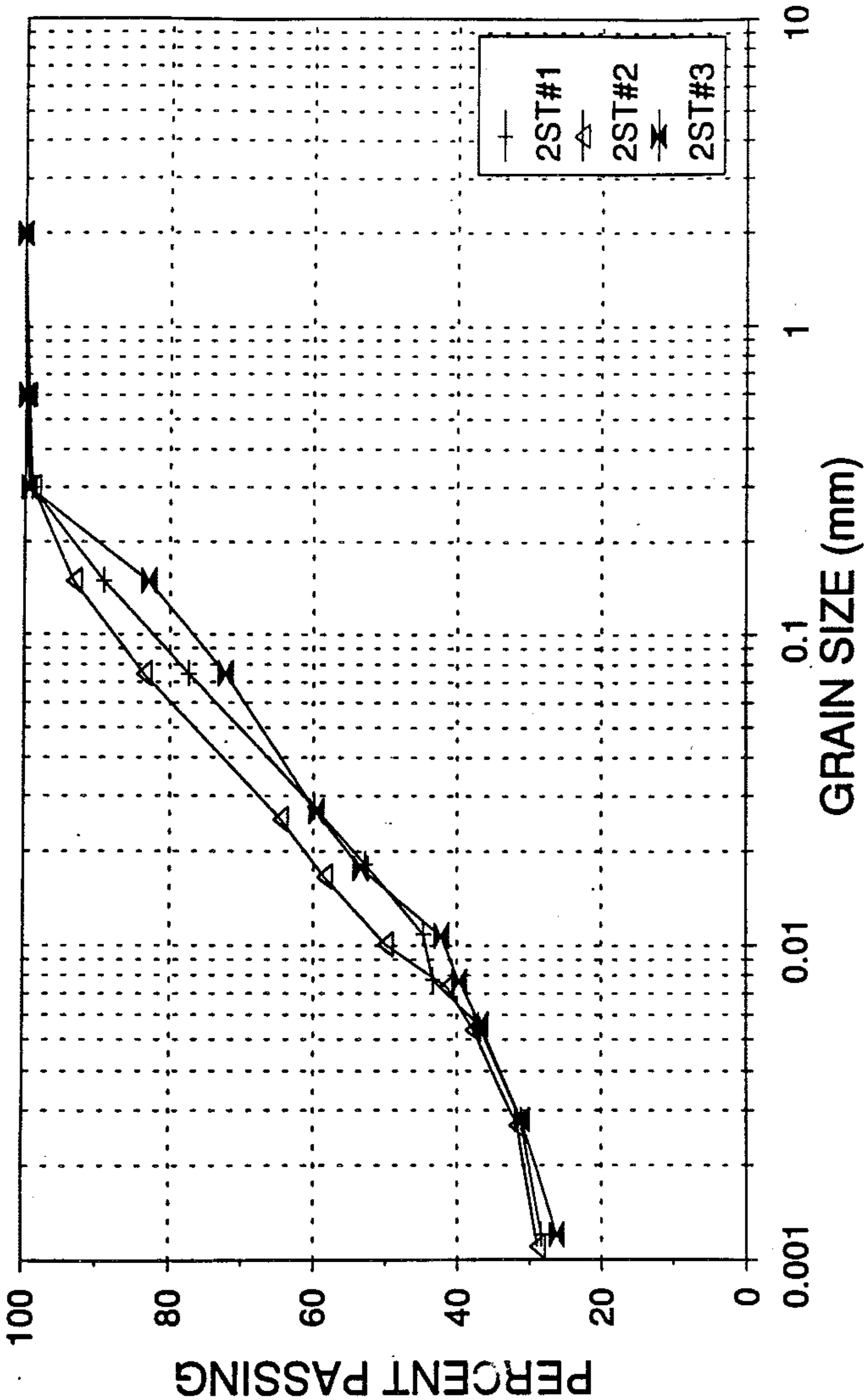
GRAIN SIZE DISTRIBUTION CURVES

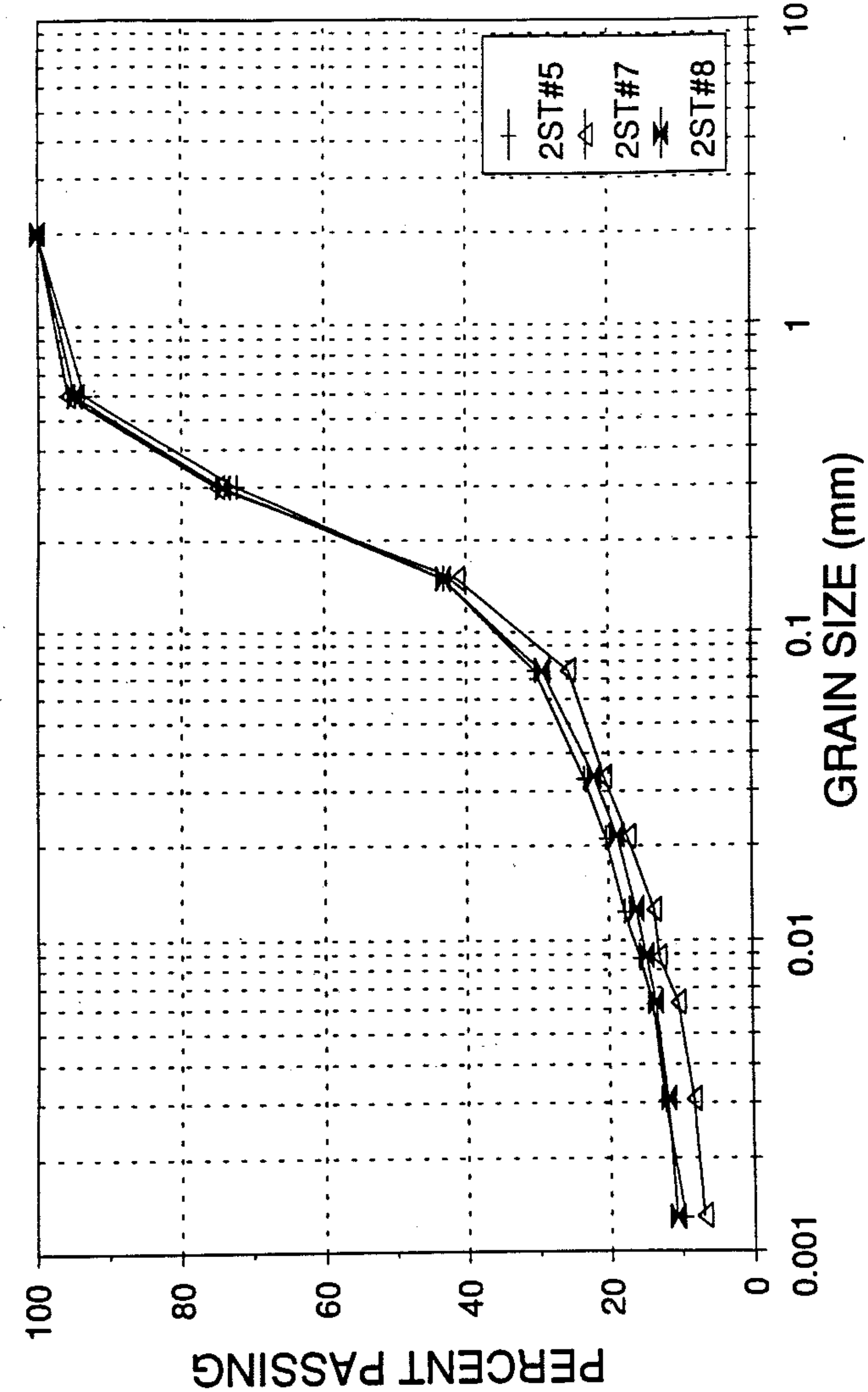


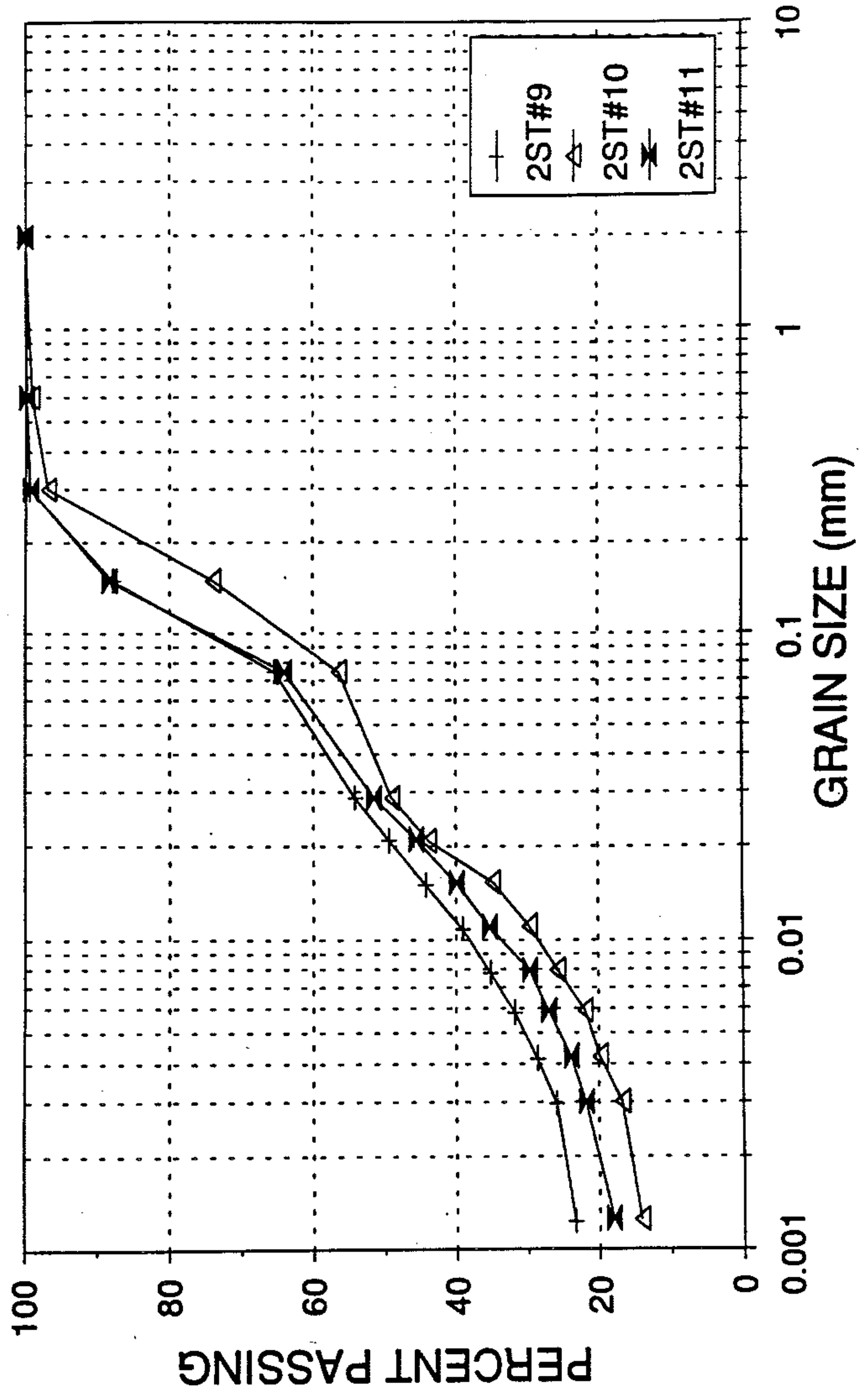
PERCENT PASSING
100
80
60
40
20
0
0.001
0.01
0.1
1
10
GRAIN SIZE (mm)
RC-1,2
RC-3,4,5
TS-1,2

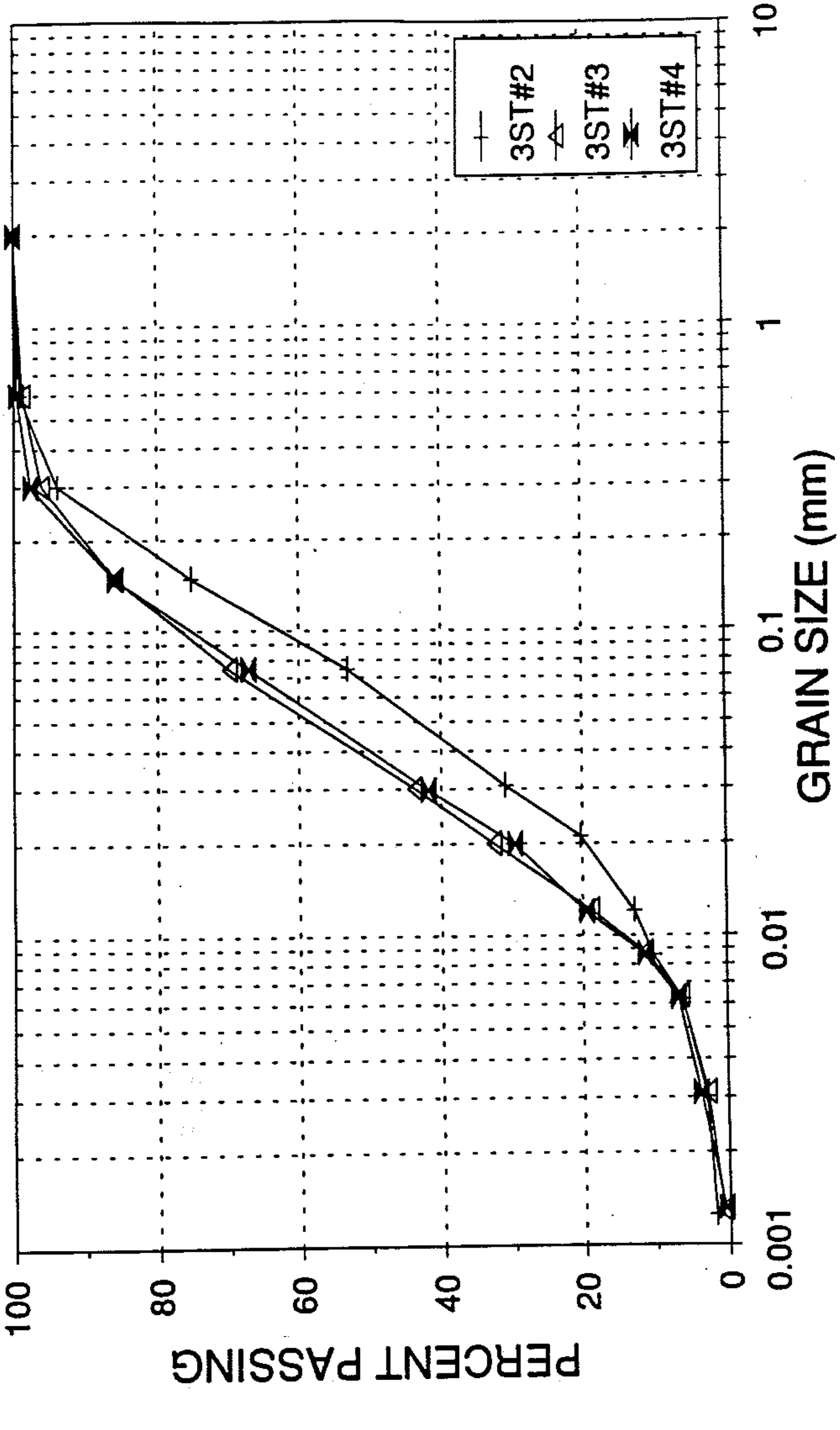


PERCENT PASSING
100
80
60
40
20
0
GRAIN SIZE (mm)
0.001
0.01
0.1
1
10
1ST#4

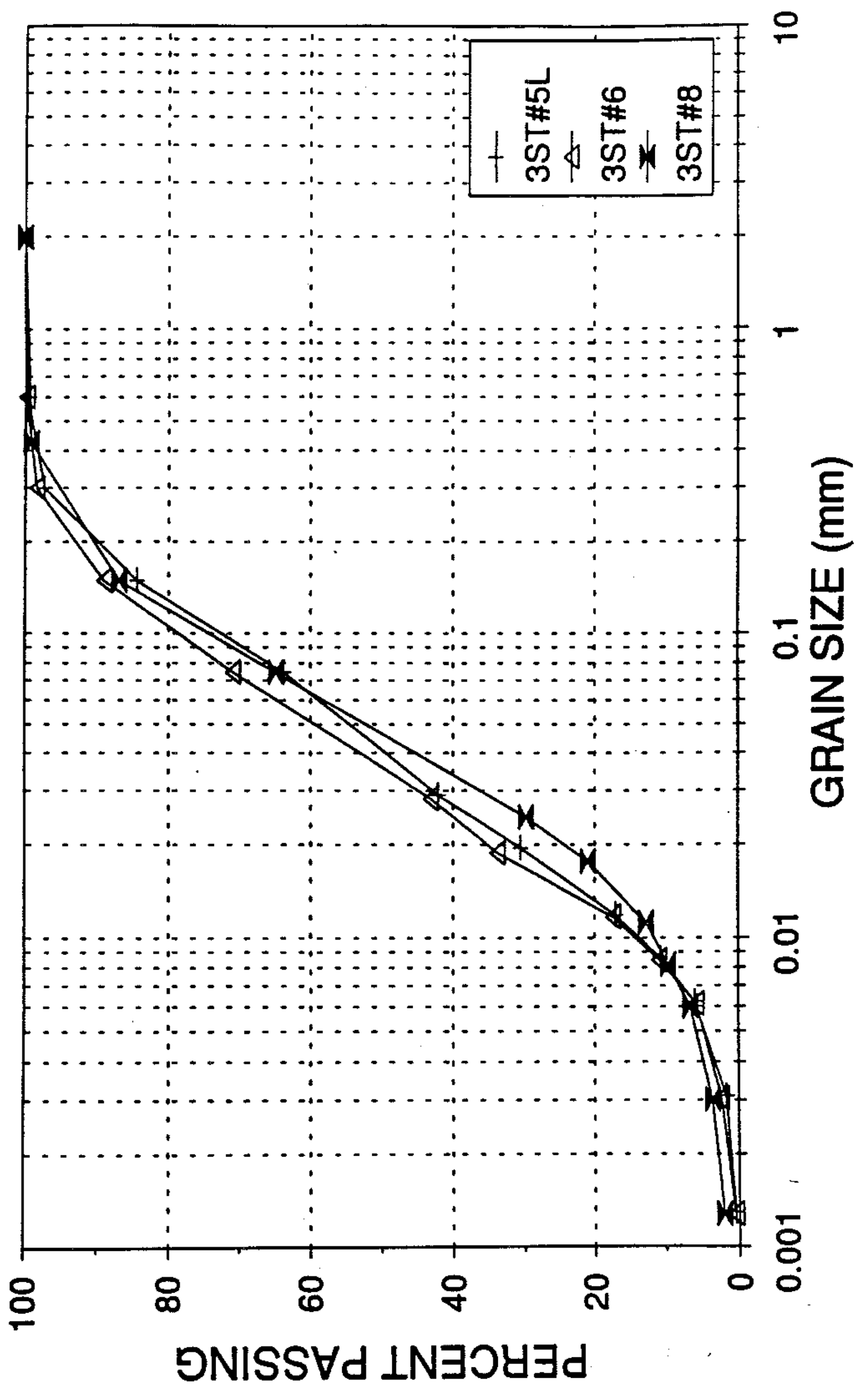

PERCENT PASSING
100
80
60
40
20
0
0.001
0.01
0.1
1
10
GRAIN SIZE (mm)
2ST#1
2ST#2
2ST#3

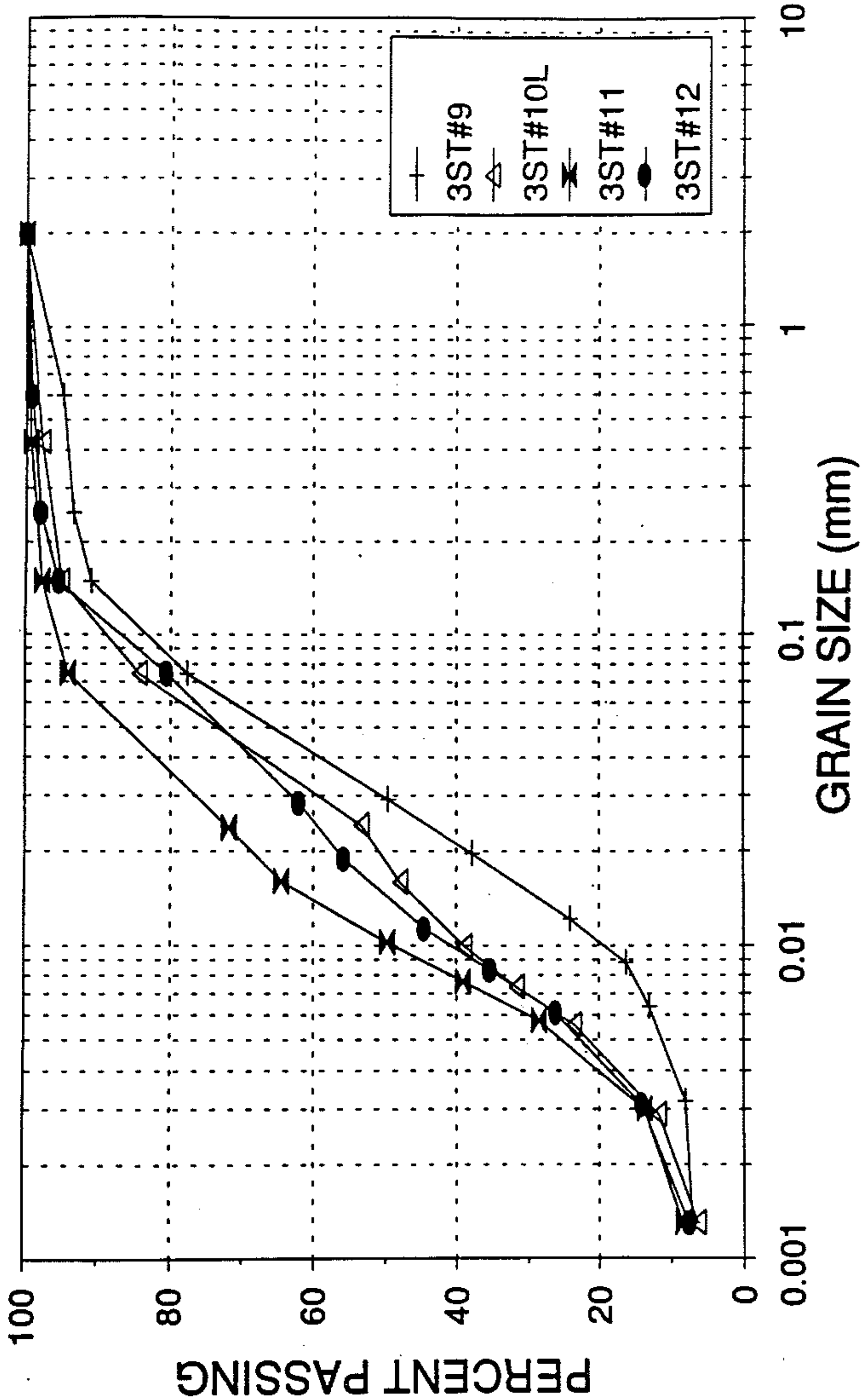

PERCENT PASSING
GRAIN SIZE (mm)
100
80
60
40
20
0
0.001
0.01
0.1
1
10
2ST#5
2ST#7
2ST#8


PERCENT PASSING
100
80
60
40
20
0
0.001
0.01
0.1
1
10
GRAIN SIZE (mm)
2ST#9
2ST#10
2ST#11

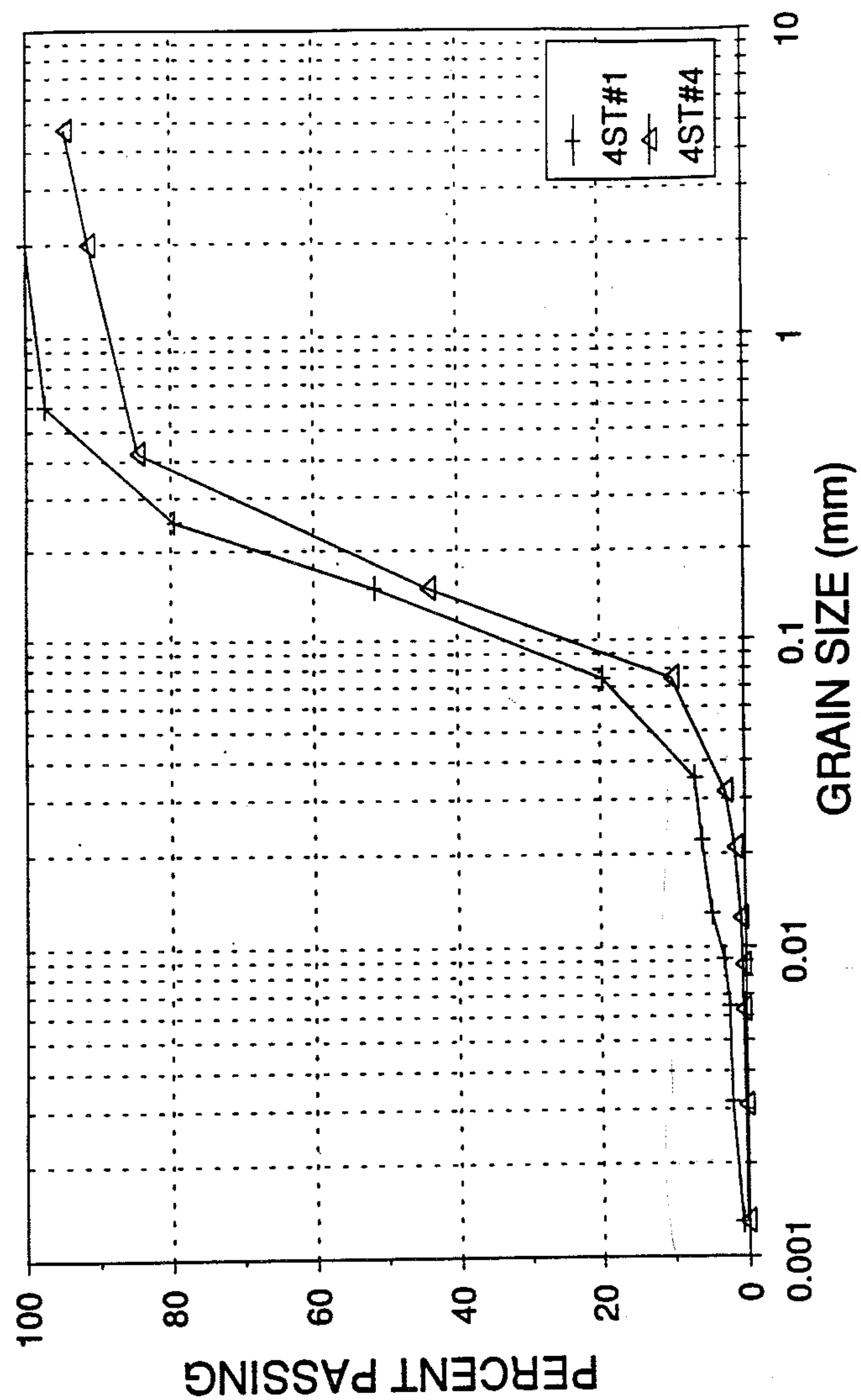


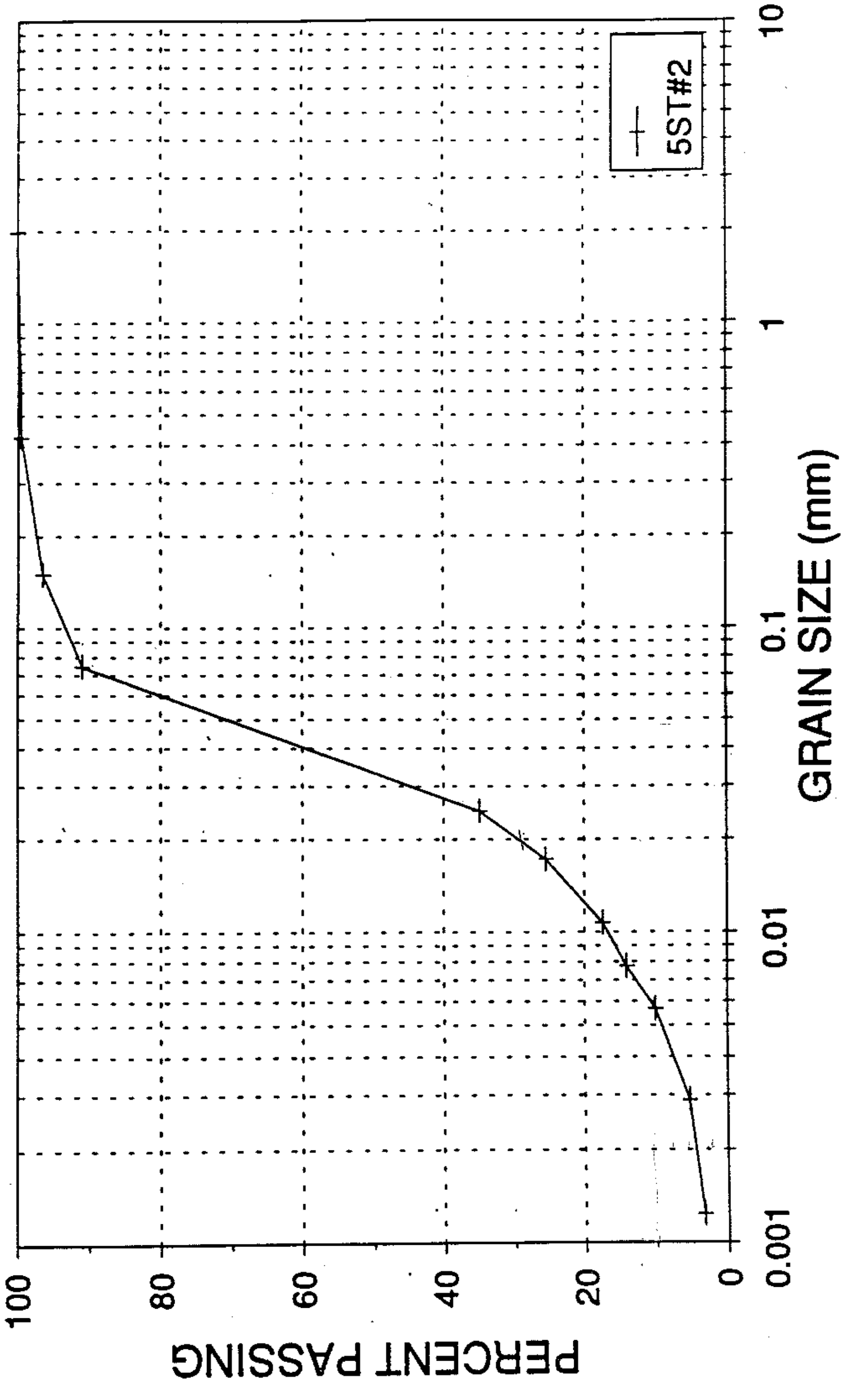
PERCENT PASSING
100
80
60
40
20
0
0.001
0.01
0.1
1
10
GRAIN SIZE (mm)
3ST#2
3ST#3
3ST#4


PERCENT PASSING
100
80
60
40
20
0
0.001
0.01
0.1
1
10
GRAIN SIZE (mm)
3ST#5L
3ST#6
3ST#8



PERCENT PASSING
GRAIN SIZE (mm)
0
20
40
60
80
100
0.001
0.01
0.1
1
10
3ST#9
3ST#10L
3ST#11
3ST#12


PERCENT PASSING
100
80
60
40
20
0
GRAIN SIZE (mm)
0.001
0.01
0.1
1
10
4ST#1
4ST#4



PERCENT PASSING
100
80
60
40
20
0
GRAIN SIZE (mm)
0.001
0.01
0.1
1
10
5ST#2

APPENDIX 3.2

CALCULATIONS FOR RESONANT COLUMN AND TORSIONAL SHEAR TEST

Both the resonant column and torsional shear tests are fairly calculation intensive. Calculations must be made both for the initial state of the specimen and for the state of the specimen during the test. Before testing, the initial state of the specimen is described by the following parameters (Note: each variable is defined at the end of this section) :

$$\text{Volume } (V_i)\ (\text{ft}^3) = \frac{\pi d^2}{4} l_i \qquad \text{(A3.2.1)}$$

$$\text{Dry Weight } (Wt_{dry})\ (\text{lb}) = \frac{Wt_i}{1+w} \qquad \text{(A3.2.2)}$$

$$\text{Dry Density } (\rho_d)\ (\text{pcf}) = \frac{Wt_{dry}}{V_i} \qquad \text{(A3.2.3)}$$

$$\text{Volume of Solids } (V_{solid})\ (\text{ft}^3) = \frac{Wt_{dry}}{G_s \gamma_w} \qquad \text{(A3.2.4)}$$

$$\text{Void Ratio } (e_o) = \frac{G_s \gamma_w}{\rho_d} - 1 \qquad \text{(A3.2.5)}$$

$$\text{Degree of Saturation (S)} = \frac{wG_s}{e_o} \qquad \text{(A3.2.6)}$$

For the resonant column test, the following calculations were used to describe what was occurring during the test:

$$\text{Length (l) (ft)} = l_i [V_{lvdti} - V_{lvdt}] f_{lvdt} \qquad \text{(A3.2.7)}$$

$$\text{Diameter (d) (ft)} = d_i [V_{probesi} - V_{probes}] f_{probes} \qquad \text{(A3.2.8)}$$

$$\text{Volume (V) } (\text{ft}^3) = \frac{\pi d^2}{4} l \qquad \text{(A3.2.9)}$$

$$\text{Weight (Wt) (lb)} = Wt_i \qquad \text{(A3.2.10)}$$

$$\text{Void Ratio (e)} = \frac{V - V_{solid}}{V_{solid}} \qquad \text{(A3.2.11)}$$

$$\text{Mass Polar Moment (I) } (\text{ft-lb/sec}^2) = \frac{Wtd^2}{8g} \qquad \text{(A3.2.12)}$$

$$\text{Beta } (\beta) = \frac{\omega_n l}{V_s} \quad \text{(A3.2.13)}$$

$$\beta \tan\beta = \frac{I}{I_O} \quad \text{(A3.2.14)}$$

$$\text{Shear Wave Velocity } (V_S) \text{ (ft/sec)} = \frac{2\pi l}{p\beta} \quad \text{(A3.2.15)}$$

$$\text{Shear Modulus (G) (psf)} = V_s^2 \frac{Wt}{gV} \quad \text{(A3.2.16)}$$

Shear Strain Amplitude (γ) (%) =

$$1.1067\,1.1067 \times 10^{-9}\, ap^2 \frac{d}{l} \times 100 \quad \text{(A3.2.17)}$$

$$\text{Viscous Damping Ratio (D)} = \sqrt{\frac{\delta^2}{4\pi^2 + \delta^2}} \times 100 \quad \text{(A3.2.18)}$$

For the torsional shear test, the same calculations were made for the length, diameter, volume, weight, and void ratio as in the resonant column test. In addition to these calculations, the following calculations were made :

$$\text{Angle of Twist } (\alpha) \text{ (radians)} = \text{VpKp} \quad \text{(A3.2.19)}$$

$$\text{Shear Strain } (\gamma)\ (\%) = 0.4\alpha \frac{d}{l} \times 100 \quad \text{(A3.2.20)}$$

$$\text{Torque (T) (ft-lb)} = V_T K_T \quad \text{(A3.2.21)}$$

$$\text{Area Moment (Jp) } (\text{ft}^4) = \frac{\pi d^4}{32} \quad \text{(A3.2.22)}$$

$$\text{Shear Stress } (\tau) \text{ (psf)} = \frac{0.4dT}{J_P} \quad \text{(A3.2.23)}$$

$$\text{Shear Modulus (G) (psf)} = \frac{\tau}{\gamma} \quad \text{(A3.2.24)}$$

$$\text{Hysteretic Damping } (\lambda)\ (\%) = \sqrt{\frac{X^2 + Y^2}{2XY}} \times 100 \quad \text{(A3.2.25)}$$

where:

A	=	area
a	=	accelerometer output in millivolts (RMS)
d	=	diameter of solid soil specimen
d_i	=	initial specimen diameter
f_{lvdt}	=	LVDT calibration factor (1 inch/20000 increments)
f_{probes}	=	calibration factor for the 3 proximity probes used for radial strain measurements (inch/volt)
G_s	=	sample specific gravity
g	=	acceleration due to gravity (32.17 ft/sec^2)
I_o	=	mass polar moment of inertia of drive system
K_P	=	proximitor calibration factor (radians/volt)
K_T	=	torque calibration factor (ft-lb/volt)
l	=	length of soil specimen
p	=	period of vibration in milliseconds
V_T	=	torsional drive system input voltage
V_P	=	proximitor output voltage
Wt_i	=	initial specimen weight (Note: weight remained constant for the unsaturated specimens tested)
w	=	specimen water content
γ_w	=	unit weight of water (62.4 pcf)
δ	=	logarithmic decrement
ω_n	=	undamped natural circular frequency

APPENDIX 4

APPENDIX 4.1

DATA SUMMARY OF PHASE I(a) & I(b) RESULTS

Table A4.1.1: Summary of Resonant Column Test Results

Specimen #	Test #	Pressure	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
RC-1	1.	0.5 ksf	.0014	906.8	3.9
			.0055	716.5	5.4
			.0065	696.7	6.7
			.0134	566.1	7.5
			.0189	481.6	8.2
			.2585	150.8	11.9
			.0019	765.3	5.3
	2.	1.0 ksf	.0004	1402.4	3.4
			.0015	1346.9	3.9
			.0045	1136.0	5.0
			.0110	897.6	6.9
			.0334	574.4	12.5
			.1095	350.7	16.4
	3.	2.0 ksf	.0005	1867.4	4.0
			.0045	1586.5	4.3
			.0116	1274.3	6.8
			.0170	1144.1	7.6
			.0364	859.8	10.6
			.0781	634.9	11.9
RC-2	4.	0.5 ksf	.0009	898.2	4.5
			.0037	768.5	5.6
			.0133	539.5	8.7
			.0224	456.4	9.9
			.0826	272.1	15.2
			.1834	172.8	16.3
	5.	1.0 ksf	.0006	1392.9	3.7
			.0045	1125.7	4.8
			.0112	886.9	6.7
			.0255	676.6	11.5
			.0536	478.2	13.2
			.1058	355.5	16.5

Table A4.1.1: Continued

Specimen #	Test #	Pressure	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
RC-2	6.	2.0 ksf	.0007	1793.1	3.4
			.0056	1487.2	4.3
			.0271	937.9	9.6
			.0475	783.2	11.3
			.0923	604.7	13.7
RC-3	7.	0.5 ksf	.0025	316.0	4.5
			.0096	276.9	5.7
			.0201	252.3	6.3
			.1037	137.5	10.3
			.1952	104.6	14.3
	8.	1.0 ksf	.0010	439.5	5.6
			.0056	408.1	4.9
			.0207	334.7	5.9
			.0350	294.2	6.5
			.1090	188.3	10.5
			.1777	130.8	11.4
	9.	2.0 ksf	.0008	529.6	4.9
			.0066	512.1	4.8
			.0192	429.0	5.4
			.0460	338.9	8.1
			.1193	235.5	10.6
			.2328	180.5	12.9
RC-4	10.	0.5 ksf	.0019	286.0	5.4
			.0079	249.1	6.3
			.0246	193.4	8.1
			.0567	144.7	10.6
			.1255	110.9	12.5
			.2679	81.7	18.1
	11.	1.0 ksf	.0016	449.0	4.7
			.0046	433.1	4.8
			.0227	330.0	6.7
			.0512	264.8	8.8
			.0802	217.8	10.2
			.1770	146.7	13.4

Table A4.1.1: Continued

Specimen #	Test #	Pressure	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
RC-4	12.	2.0 ksf	.0014	574.6	4.7
			.0042	556.5	4.4
			.0197	454.0	5.9
			.0656	306.5	9.5
			.0957	268.0	10.2
			.1137	255.9	10.7
			.1739	220.7	11.6
RC-5	13.	0.5 ksf	.0019	332.9	4.5
			.0055	306.2	4.7
			.0302	210.9	7.7
			.0719	142.0	10.7
			.1399	101.2	13.0
			.2680	80.2	16.7
	14.	1.0 ksf	.0010	424.7	4.1
			.0039	409.4	4.7
			.0256	297.1	7.7
			.0631	213.6	10.4
			.0901	192.3	11.2
			.1801	143.9	13.0
	15.	2.0 ksf	.0008	636.8	4.0
			.0038	618.0	4.0
			.0218	493.8	5.8
			.0372	429.1	7.3
			.0682	340.6	9.0
			.1043	287.3	9.9
TS-1	16.	0.5 ksf	.0009	798.1	
			.0010	798.3	2.1
			.0024	798.3	2.5
			.0027	776.9	2.8
			.0104	635.2	4.2
			.0258	490.9	6.5
			.0393	441.7	7.9
			.0828	351.6	9.4
			.1393	296.8	11.0

Table A4.1.1: Continued

Specimen #	Test #	Pressure	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
TS-1	17.	1.0 ksf	.0007	989.0	
			.0011	1062.7	5.4
			.0023	989.0	6.1
			.0040	894.9	5.7
			.0110	741.6	6.2
			.0271	602.7	7.5
			.0656	478.2	8.3
			.0758	429.4	8.5
	18.	2.0 ksf	.0008	1279.7	
			.0013	1252.3	3.5
			.0023	1198.5	3.8
			.0049	1094.3	3.9
			.0093	995.0	4.4
			.0235	810.7	6.1
			.0498	665.2	7.1
			.0813	570.9	8.0
TS-2	19.	0.5 ksf	.0008	630.5	
			.0015	611.6	2.8
			.0023	593.0	3.0
			.0051	521.2	3.8
			.0101	454.3	5.5
			.0321	334.1	8.6
			.0375	307.2	8.7
			.0952	221.6	11.7
	20.	1.0 ksf	.0007	801.3	
			.0011	801.3	2.2
			.0023	758.6	2.6
			.0043	716.8	3.1
			.0090	618.1	4.0
			:0217	492.4	6.7
			.0443	396.0	8.1
			.1016	310.5	10.0

Table A4.1.1: Continued

Specimen #	Test #	Pressure	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
TS-2	21.	2.0 ksf	.0006	968.4	
			.0011	968.4	
			.0018	944.7	2.7
			.0038	898.1	2.9
			.0096	808.5	4.1
			.0260	643.7	5.7
			.0472	550.5	7.2
			.0838	448.7	8.2
TS-3	22.	2.0 ksf	.0006	966.7	
			.0008	966.7	2.2
			.0031	874.3	2.8
			.0045	851.9	3.0
			.0100	743.6	4.4
			.0261	604.7	6.5
			.0469	514.4	7.8
			.0893	416.2	9.4

Table A4.1.2: Summary of Torsional Shear Test Results

Specimen: TS-1
Confining Pressure: 0.5 ksf

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
1.	.0037	1	.0037	739.3	2.9
		7	.0037	743.1	2.3
		15	.0037	740.3	2.3
		20	.0037	742.5	2.3
		30	.0037	742.5	2.3
		40	.0038	730.7	2.2
		60	.0038	735.4	2.2
		80	.0038	734.3	2.2
2.	.0049	3	.0048	739.6	2.1
		7	.0049	725.0	2.1
		10	.0049	725.0	2.1
		15	.0049	721.4	2.3
		20	.0049	726.8	2.3
		30	.0049	721.4	2.3
		40	.0049	719.4	2.3
		50	.0049	721.1	2.3
		60	.0050	715.7	2.4
		70	.0050	715.7	2.4
		100	.0050	715.7	2.4
3.	.0094	1	.0092	665.7	3.2
		4	.0093	653.1	3.3
		7	.0093	653.1	3.6
		10	.0092	664.7	3.7
		15	.0093	657.6	3.6
		20	.0095	643.6	3.7
		30	.0095	643.6	3.7
		40	.0094	648.8	3.8
		60	.0096	636.8	3.7
		80	.0096	636.8	3.7
		100	.0097	631.8	3.7

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
4.	.0263	1	.0253	523.0	6.9
		5	.0262	506.6	6.5
		8	.0262	503.8	6.5
		10	.0264	500.2	6.4
		15	.0265	499.0	6.4
		20	.0265	500.6	6.4
		30	.0265	497.9	6.3
		40	.0261	507.9	6.2
		50	.0265	500.6	6.0
		65	.0265	500.6	6.0
		80	.0267	494.3	6.0
		100	.0263	505.4	5.9
5.	.0435	2	.0424	457.5	5.3
		4	.0426	452.3	5.9
		7	.0429	455.0	6.0
		10	.0433	451.0	6.1
		15	.0435	449.7	6.3
		20	.0441	442.4	6.4
		30	.0440	444.6	6.6
		50	.0441	443.3	6.6
		75	.0442	441.1	6.6
		100	.0442	440.2	6.6
6.	.0996	1	.1052	318.1	11.4
		3	.1040	323.6	9.7
		7	.1032	324.3	9.8
		10	.1014	330.0	9.5
		15	.1002	334.2	9.2
		20	.0992	337.6	8.9
		30	.0979	342.0	8.6
		50	.0964	347.4	8.1
		75	.0948	353.0	7.8
		100	.0941	355.8	7.9

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
7.	.1229	1	.1227	338.0	6.3
		3	.1239	334.6	6.8
		7	.1233	337.7	6.9
		10	.1233	336.3	7.1
		15	.1239	334.6	7.1
		20	.1233	336.3	7.4
		30	.1239	334.6	7.4
		50	.1227	338.0	7.4
		75	.1214	342.9	7.5
		100	.1208	344.0	7.5

Specimen: TS-1
Confining Pressure: 1 ksf

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
1.	.0009	1	.0009	987.4	1.5
		3	.0009	987.4	1.5
		7	.0009	987.4	1.5
		10	.0009	987.4	1.5
		15	.0009	987.4	1.5
		20	.0009	987.4	1.5
		25	.0009	987.4	1.5
		30	.0009	987.4	1.5
		50	.0009	987.4	1.5
		75	.0009	987.4	1.5
		100	.0009	987.4	1.5
2.	.0023	1	.0023	902.4	3.5
		3	.0023	907.3	3.0
		7	.0023	904.8	3.0
		10	.0023	902.4	3.0
		15	.0023	902.4	3.0
		20	.0023	902.4	3.0
		30	.0023	902.4	3.0
		40	.0023	902.4	3.0
		50	.0023	902.4	3.0
		75	.0023	902.4	2.8
		100	.0023	902.4	2.8

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
3.	.0051	1	.0050	841.6	4.9
		3	.0050	839.5	4.8
		7	.0050	875.3	4.8
		10	.0050	870.9	4.8
		15	.0051	862.2	4.7
		20	.0050	835.3	4.8
		25	.0050	841.6	4.9
		30	.0051	862.2	4.7
		40	.0051	862.2	4.7
		51	.0054	771.2	4.6
		75	.0051	817.4	4.8
		100	.0054	758.8	4.6
4.	.0108	1	.0105	727.3	4.2
		3	.0107	711.4	4.2
		7	.0108	710.2	4.3
		10	.0107	715.8	4.3
		15	.0108	714.1	4.5
		20	.0108	714.1	4.5
		30	.0108	716.1	4.3
		40	.0108	708.8	4.3
		50	.0108	706.9	4.3
		75	.0109	707.5	4.5
		100	.0109	704.2	4.3
5.	.0289	1	.0287	541.9	7.6
		3	.0290	535.8	6.4
		8	.0287	544.8	6.4
		10	.0287	541.7	6.4
		15	.0290	537.2	6.4
		20	.0290	537.2	6.2
		25	.0290	537.2	6.2
		30	.0289	539.6	6.2
		40	.0289	538.1	6.1
		50	.0290	537.2	5.9
		75	.0290	537.2	5.9
		100	.0290	537.2	5.7

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
6.	.0475	1	.0467	522.3	5.3
		3	.0474	516.2	5.4
		7	.0474	514.4	5.7
		10	.0476	515.2	5.7
		15	.0476	513.5	5.8
		20	.0477	511.2	5.8
		25	.0477	513.0	6.0
		30	.0477	511.2	6.0
		40	.0477	511.2	6.0
		50	.0475	513.1	6.0
		75	.0475	513.9	6.0
		100	.0475	513.1	6.0
7.	.0939	1	.0959	424.3	6.4
		3	.0964	422.1	6.3
		7	.0959	427.8	6.3
		10	.0954	428.3	6.4
		15	.0948	430.6	6.4
		20	.0941	434.1	6.4
		25	.0938	435.3	6.4
		30	.0933	437.6	6.5
		40	.0931	440.6	6.5
		50	.0921	443.7	6.5
		75	.0913	447.4	6.6
		100	.0910	448.6	6.6

Table A4.1.2: Continued
Specimen: TS-1
Confining Pressure: 2 ks

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
1.	.0011	1	.0011	1116.9	1.8
		3	.0011	1116.9	2.5
		7	.0011	1110.4	2.1
		10	.0011	1118.8	2.2
		15	.0011	1113.0	2.2
		20	.0011	1116.9	2.2
		25	.0011	1130.2	2.2
		30	.0011	1116.9	1.5
		40	.0011	1103.9	2.1
		50	.0011	1116.9	1.5
		80	.0011	1110.4	1.8
		100	.0011	1103.9	1.8
2.	.0026	1	.0026	1072.1	1.7
		3	.0026	1080.4	1.8
		7	.0026	1073.4	2.0
		10	.0026	1066.9	1.8
		15	.0026	1066.9	1.8
		20	.0026	1070.1	2.0
		25	.0027	1042.1	1.8
		30	.0026	1070.1	1.8
		40	.0027	1052.8	1.4
		50	.0026	1075.3	2.0
		70	.0027	1059.4	1.8
		100	.0027	1057.8	2.0
3.	.0053	1	.0051	990.9	2.3
		3	.0053	986.7	2.2
		7	.0053	999.4	2.2
		10	.0053	1002.6	2.2
		15	.0053	994.6	2.2
		20	.0053	994.6	2.4
		25	.0053	989.9	2.4
		30	.0053	989.9	2.3
		40	.0053	989.9	2.4
		50	.0053	987.5	2.4
		70	.0053	994.6	2.4
		100	.0054	986.8	2.4

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
4.	.0111	1	.0109	918.8	3.1
		3	.0110	904.3	3.1
		7	.0110	908.3	3.1
		10	.0110	908.1	3.1
		20	.0111	902.1	3.1
		25	.0111	899.9	3.1
		30	.0111	898.0	3.3
		40	.0112	891.9	3.2
		50	.0112	889.9	3.2
		75	.0112	889.9	3.2
		100	.0112	891.7	3.1
5.	.0281	1	.0274	775.3	4.7
		5	.0279	761.3	4.8
		7	.0279	761.3	4.8
		10	.0280	757.9	4.9
		15	.0281	754.5	4.9
		20	.0282	752.8	4.9
		25	.0282	751.1	4.9
		30	.0283	749.4	4.9
		40	.0284	747.8	4.9
		50	.0284	747.8	4.9
		70	.0284	747.8	4.9
		100	.0284	747.8	4.9
6.	.0471	1	.0467	682.2	5.5
		3	.0472	671.3	5.3
		7	.0475	666.0	5.3
		10	.0474	669.5	5.5
		15	.0472	674.9	5.4
		20	.0472	673.1	5.3
		30	.0470	674.9	5.5
		40	.0470	673.1	5.5
		50	.0470	678.5	5.6
		75	.0471	676.7	5.5
		100	.0466	682.2	5.5

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
7.	.0849	1	.0867	572.1	6.7
		3	.0867	572.1	6.4
		7	.0862	575.5	6.5
		10	.0860	580.1	6.6
		15	.0855	588.5	6.5
		20	.0852	591.2	6.5
		25	.0847	595.8	6.5
		30	.0842	600.4	6.5
		35	.0842	603.3	6.5
		40	.0842	605.3	6.5
		50	.0839	611.2	6.5
		70	.0837	613.0	6.2
		100	.0822	624.4	6.3

Specimen: TS-2
Confining Pressure: 0.5 ksf

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
1.	.0012	1	.0011	592.0	2.3
		3	.0013	509.2	2.0
		7	.0013	509.2	2.0
		10	.0011	606.1	2.4
		15	.0011	592.0	2.3
		20	.0013	507.9	2.0
		25	.0013	507.9	2.0
		30	.0011	606.1	2.4
		40	.0011	590.5	2.3
		50	.0011	591.3	2.3
		70	.0011	590.5	2.3
		100	.0011	592.8	2.3

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
2.	.0027	1	.0027	553.5	2.4
		3	.0027	548.2	2.4
		7	.0027	549.0	2.4
		10	.0027	553.5	2.4
		15	.0027	553.5	2.4
		20	.0027	548.2	2.4
		25	.0027	548.2	2.4
		30	.0027	549.0	2.4
		40	.0027	554.2	2.4
		50	.0027	548.2	2.4
		70	.0027	554.2	2.4
		100	.0027	543.0	2.4
3.	.0058	1	.0056	511.6	3.2
		3	.0057	501.0	3.2
		7	.0057	501.0	3.5
		10	.0057	498.8	3.5
		15	.0057	503.9	3.5
		20	.0057	507.6	3.5
		25	.0057	506.2	3.5
		30	.0058	493.6	3.4
		40	.0058	492.2	3.4
		50	.0059	490.1	3.4
		70	.0059	492.9	3.4
		100	.0059	492.9	3.4
4.	.0127	1	.0121	442.6	5.1
		3	.0125	429.9	5.0
		7	.0126	425.5	5.4
		10	.0127	421.3	5.3
		15	.0128	420.4	5.3
		20	.0128	418.8	5.3
		25	.0128	418.8	5.3
		30	.0128	417.9	5.3
		40	.0129	417.1	5.3
		50	.0129	416.3	5.2
		70	.0129	416.3	5.0
		100	.0129	416.3	5.0

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
5.	.0359	1	.0365	309.8	8.5
		3	.0367	309.3	9.2
		7	.0364	312.6	8.7
		10	.0368	308.2	8.6
		15	.0360	314.7	8.3
		20	.0360	315.9	8.0
		25	.0358	317.6	8.0
		30	.0357	318.1	8.1
		40	.0355	320.4	7.7
		50	.0353	321.6	7.6
		70	.0352	323.9	7.5
		100	.0349	325.1	7.2
6.	.0626	1	.0620	276.8	8.8
		3	.0631	267.2	8.9
		7	.0630	270.3	8.9
		10	.0634	268.7	8.9
		15	.0631	269.8	8.9
		20	.0630	270.3	8.9
		25	.0630	270.3	8.7
		30	.0626	272.0	8.8
		40	.0623	273.1	8.6
		50	.0620	274.8	8.5
		70	.0620	274.8	8.1
		100	.0617	275.9	8.0
7.	.1449	1	.1724	163.2	17.7
		3	.1624	172.8	15.6
		7	.1526	183.8	14.6
		10	.1488	189.1	14.1
		15	.1447	194.2	13.4
		20	.1421	198.0	13.1
		25	.1403	200.2	12.7
		30	.1390	202.4	13.6
		40	.1367	205.8	12.1
		50	.1349	208.2	11.9
		70	.1331	210.7	11.3
		100	.1316	213.5	11.0

Table A4.1.2: Continued
Specimen: TS-2
Confining Pressure: 1 ksf

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
1.	.0011	1	.0011	745.2	1.9
		3	.0011	745.2	1.9
		7	.0011	736.2	1.9
		10	.0011	736.2	1.9
		15	.0011	736.2	1.9
		20	.0011	736.2	1.9
		25	.0011	736.2	1.9
		30	.0011	736.2	1.9
		40	.0011	736.2	1.9
		50	.0011	736.2	1.9
		70	.0011	736.2	1.9
		100	.0011	727.4	1.8
2.	.0026	1	.0026	723.4	1.6
		3	.0026	719.9	1.6
		7	.0026	716.4	1.6
		10	.0026	716.4	1.6
		15	.0026	716.4	1.6
		20	.0026	716.4	1.6
		25	.0027	712.9	1.6
		30	.0027	709.5	1.6
		40	.0027	709.5	1.6
		50	.0027	709.5	1.6
		70	.0027	709.5	1.6
		100	.0027	709.5	1.6
3.	.0054	1	.0053	676.9	2.5
		3	.0054	665.6	2.4
		7	.0054	664.0	2.3
		10	.0054	662.4	2.3
		15	.0054	659.3	2.3
		20	.0054	659.3	2.3
		25	.0054	657.8	2.3
		30	.0054	657.8	2.3
		50	.0054	657.8	2.3
		70	.0055	653.2	2.3
		100	.0055	653.2	2.3

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
4.	.0117	1	.0112	602.7	3.5
		3	.0116	584.1	3.5
		7	.0116	584.1	3.8
		10	.0116	581.5	3.8
		15	.0117	579.0	3.9
		20	.0117	577.7	3.9
		25	.0118	575.2	3.9
		30	.0118	574.0	3.9
		40	.0118	572.7	3.9
		50	.0119	571.5	3.9
		70	.0119	570.3	3.9
		100	.0120	566.6	3.8
5.	.0313	1	.0300	480.9	6.5
		3	.0310	464.1	6.4
		7	.0312	461.3	6.4
		10	.0314	459.4	6.4
		15	.0315	457.6	6.4
		20	.0315	457.6	6.4
		25	.0315	457.6	6.4
		30	.0316	456.6	6.2
		40	.0316	456.6	6.2
		50	.0316	456.6	6.1
		70	.0316	456.6	6.1
		100	.0316	455.7	6.0
6.	.0549	1	.0542	399.2	7.3
		3	.0551	392.7	7.3
		7	.0551	392.7	7.3
		10	.0551	392.7	7.3
		15	.0549	393.6	7.3
		20	.0551	392.7	7.1
		25	.0549	393.6	7.1
		30	.0549	393.6	7.1
		40	.0549	393.6	7.0
		50	.0549	393.6	7.0
		70	.0547	395.4	7.0
		100	.0546	396.4	6.8

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
7.	.1104	1	.1067	336.8	7.7
		3	.1129	318.5	8.5
		7	.1131	317.7	8.8
		10	.1131	317.7	8.8
		15	.1129	318.5	8.6
		20	.1116	322.1	8.5
		25	.1108	324.4	8.4
		30	.1103	325.9	8.4
		40	.1095	328.2	8.3
		50	.1090	329.7	8.1
		70	.1077	333.6	8.0
		100	.1067	336.8	7.9

Specimen: TS-2
Confining Pressure: 2 ksf

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
1.	.0010	1	.0010	927.7	1.6
		3	.0010	933.5	1.7
		7	.0010	933.5	1.3
		10	.0010	933.5	1.3
		15	.0010	927.7	1.3
		20	.0010	933.5	1.3
		25	.0010	933.5	1.3
		30	.0010	927.7	1.3
		40	.0010	927.7	1.3
		50	.0010	927.7	1.3
		70	.0010	927.7	1.3
		100	.0010	927.7	1.3

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
2.	.0026	1	.0026	905.8	1.9
		3	.0026	905.8	1.9
		7	.0026	905.8	1.9
		10	.0026	905.8	1.9
		15	.0026	905.8	1.9
		20	.0026	905.8	1.9
		25	.0026	905.8	1.9
		30	.0026	905.8	1.9
		40	.0026	905.8	1.9
		50	.0026	905.8	1.9
		70	.0026	905.8	1.9
		100	.0026	905.8	1.6
3.	.0051	1	.0051	874.0	2.5
		3	.0051	865.3	2.2
		7	.0051	863.1	2.2
		10	.0051	861.0	2.2
		15	.0051	861.0	2.2
		20	.0051	861.0	2.2
		25	.0052	856.7	2.2
		30	.0052	856.7	2.2
		40	.0052	856.7	2.2
		50	.0052	854.6	2.2
		70	.0052	854.6	2.2
		100	.0052	852.5	2.2
4.	.0105	1	.0103	786.4	3.4
		3	.0104	786.7	3.2
		7	.0104	782.9	3.2
		10	.0104	782.9	3.2
		17	.0105	779.1	3.2
		20	.0105	779.1	3.2
		25	.0105	775.3	3.2
		30	.0105	775.3	3.2
		40	.0105	775.3	3.2
		50	.0105	775.3	3.2
		70	.0106	771.5	3.2
		100	.0106	771.5	3.2

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
5.	.0265	1	.0259	670.2	5.4
		3	.0263	660.4	5.3
		7	.0263	660.4	5.3
		10	.0264	657.2	5.3
		15	.0265	655.7	5.3
		20	.0266	652.5	5.3
		25	.0266	652.5	5.3
		30	.0266	652.5	5.3
		40	.0266	651.0	5.3
		50	.0266	651.0	5.3
		70	.0266	651.0	5.3
		100	.0267	649.4	5.1
6.	.0441	1	.0423	616.2	5.3
		3	.0434	599.9	5.5
		7	.0440	592.9	5.8
		10	.0441	591.2	5.8
		15	.0443	587.8	6.0
		20	.0443	587.8	6.0
		25	.0446	584.5	6.1
		30	.0443	587.8	6.1
		40	.0442	589.5	6.1
		50	.0445	586.1	6.1
		70	.0443	587.8	6.1
		100	.0443	587.8	6.1
7.	.0859	1	.0854	510.1	6.6
		3	.0872	499.6	7.1
		7	.0872	499.6	7.4
		10	.0867	502.5	7.6
		15	.0872	499.6	7.8
		20	.0872	499.6	7.8
		25	.0862	505.5	7.7
		30	.0859	507.0	7.7
		40	.0852	511.6	7.5
		50	.0852	511.6	7.5
		70	.0844	516.3	7.4
		100	.0831	524.2	7.3

Table A4.1.2: Continued
Specimen: TS-3
Confining Pressure: 0.5 ksf

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
1.	.0011	1	.0011	914.5	1.2
		3	.0011	914.5	1.2
		7	.0011	914.5	1.2
		10	.0011	909.4	1.2
		15	.0011	914.5	1.2
		20	.0011	914.5	1.2
		25	.0011	899.2	1.2
		30	.0011	914.5	1.2
		40	.0011	909.4	1.2
		50	.0011	909.4	1.2
		70	.0011	904.3	1.2
		100	.0011	899.2	1.2
2.	.0028	1	.0028	814.4	3.8
		3	.0028	792.4	3.2
		7	.0028	814.4	3.0
		10	.0028	814.4	2.8
		15	.0028	814.4	2.8
		20	.0028	814.4	2.8
		25	.0028	814.4	2.8
		30	.0028	814.4	2.8
		40	.0028	814.4	2.8
		50	.0027	822.0	2.5
		70	.0027	825.8	2.3
		100	.0027	825.8	2.3
3.	.0055	1	.0056	780.9	3.7
		3	.0056	774.8	3.2
		7	.0056	774.8	3.0
		10	.0055	782.0	3.0
		15	.0055	778.4	3.0
		20	.0055	782.0	3.0
		25	.0055	785.0	3.0
		30	.0056	776.3	3.0
		40	.0056	777.8	3.0
		50	.0056	776.3	2.7
		70	.0055	779.9	2.8
		100	.0055	785.0	2.8

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
4.	.0117	1	.0113	724.7	4.6
		3	.0115	716.7	4.6
		7	.0115	716.7	4.3
		10	.0115	716.7	4.3
		15	.0117	704.9	4.2
		20	.0117	701.1	4.2
		25	.0117	701.1	4.2
		30	.0118	697.3	4.2
		40	.0118	697.3	4.2
		50	.0118	697.3	3.9
		70	.0118	697.3	3.9
		100	.0118	697.3	3.9
5.	.0294	1	.0284	612.7	7.4
		3	.0295	588.8	6.7
		7	.0295	588.8	6.7
		10	.0295	588.8	6.7
		15	.0295	588.8	6.7
		20	.0295	588.8	6.7
		25	.0295	588.8	6.5
		30	.0295	588.8	6.5
		40	.0295	588.8	6.5
		50	.0295	588.8	6.2
		70	.0295	588.8	6.2
		100	.0295	588.8	6.0
6.	.0488	1	.0472	553.3	6.8
		3	.0477	547.4	7.0
		7	.0493	530.2	7.1
		10	.0493	530.2	7.4
		15	.0493	530.2	7.4
		20	.0493	530.2	7.4
		25	.0493	530.2	7.4
		30	.0493	530.2	7.6
		40	.0493	530.2	7.6
		50	.0493	530.2	7.4
		70	.0487	535.8	7.4
		100	.0482	541.5	7.8

Table A4.1.2: Continued

Series	Average Shear Strain (%)	Cycle	Shear Strain (%)	Shear Modulus (ksf)	Damping Ratio (%)
7.	.0977	1	.0970	447.8	8.2
		3	.0985	442.5	8.8
		7	.0990	441.9	9.2
		10	.0993	440.8	9.2
		15	.0993	440.8	9.2
		20	.0993	439.1	9.0
		25	.0985	442.5	9.3
		30	.0980	444.8	9.1
		40	.0975	447.2	9.0
		50	.0962	453.1	8.9
		70	.0959	454.3	8.8
		100	.0939	464.3	8.4

APPENDIX 4.2

GRAPHICAL REPRESENTATION OF PHASE I(a) & I(b) DATA

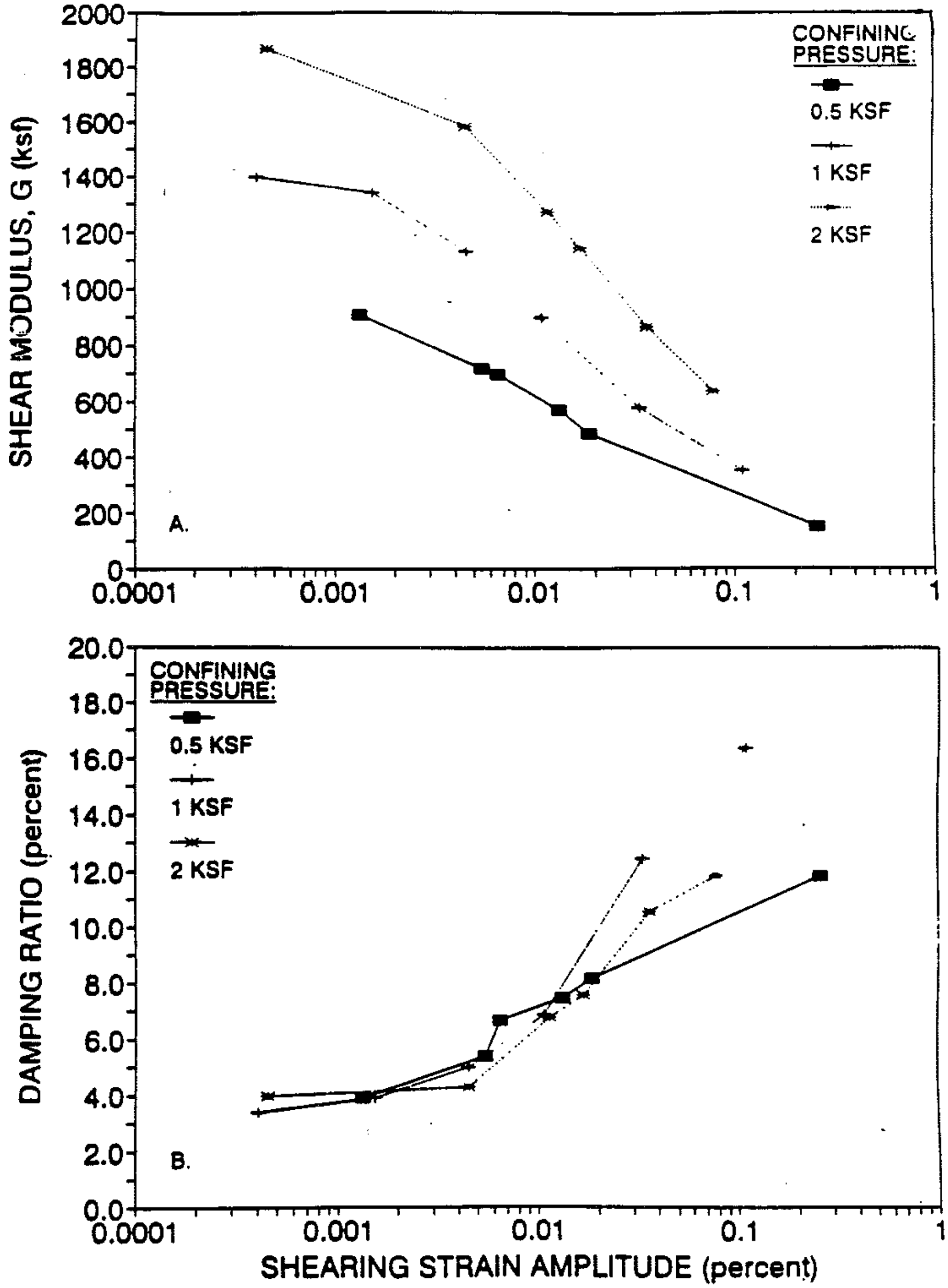


Figure A4.2.1 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-1

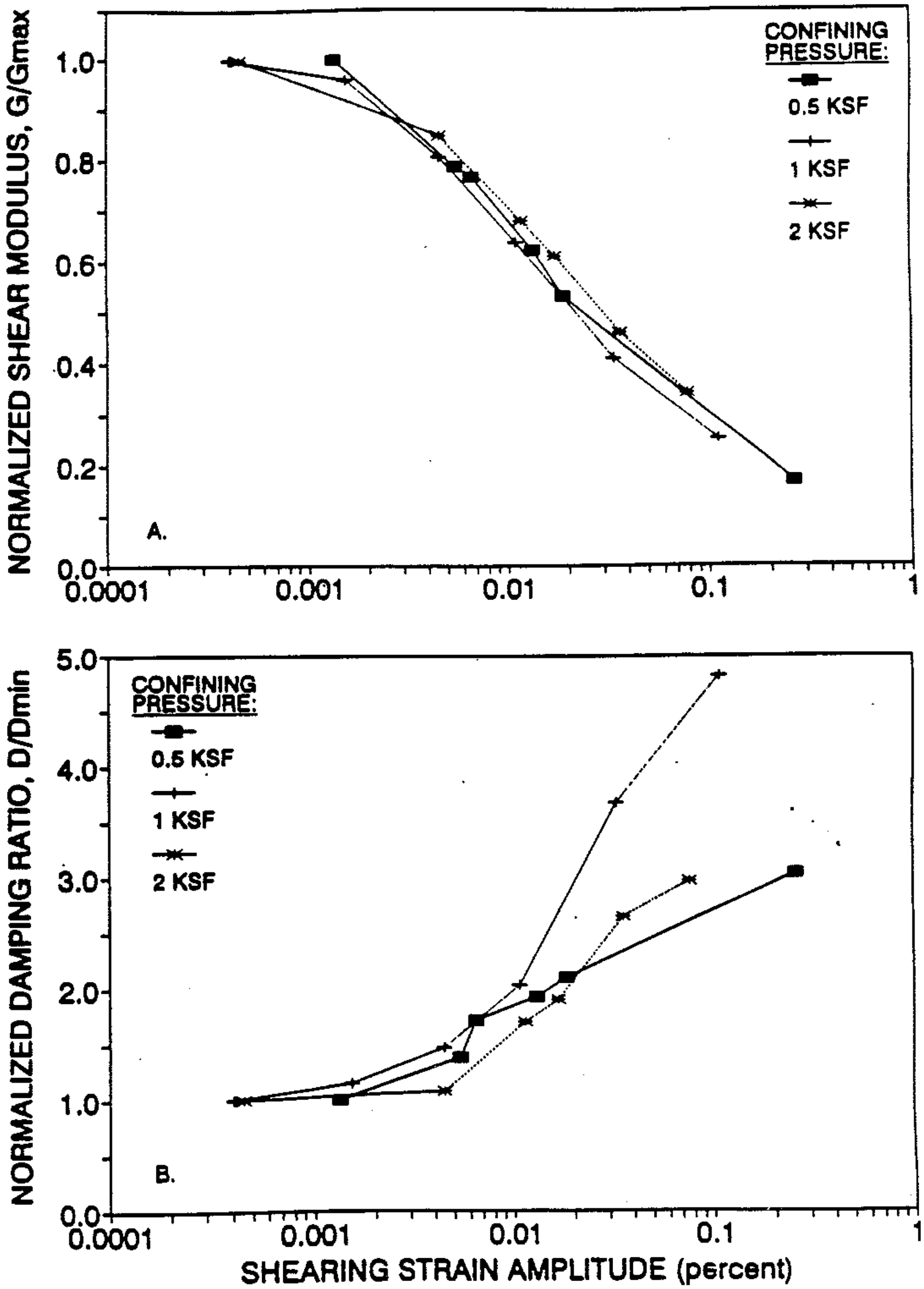


Figure A4.2.2 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-1

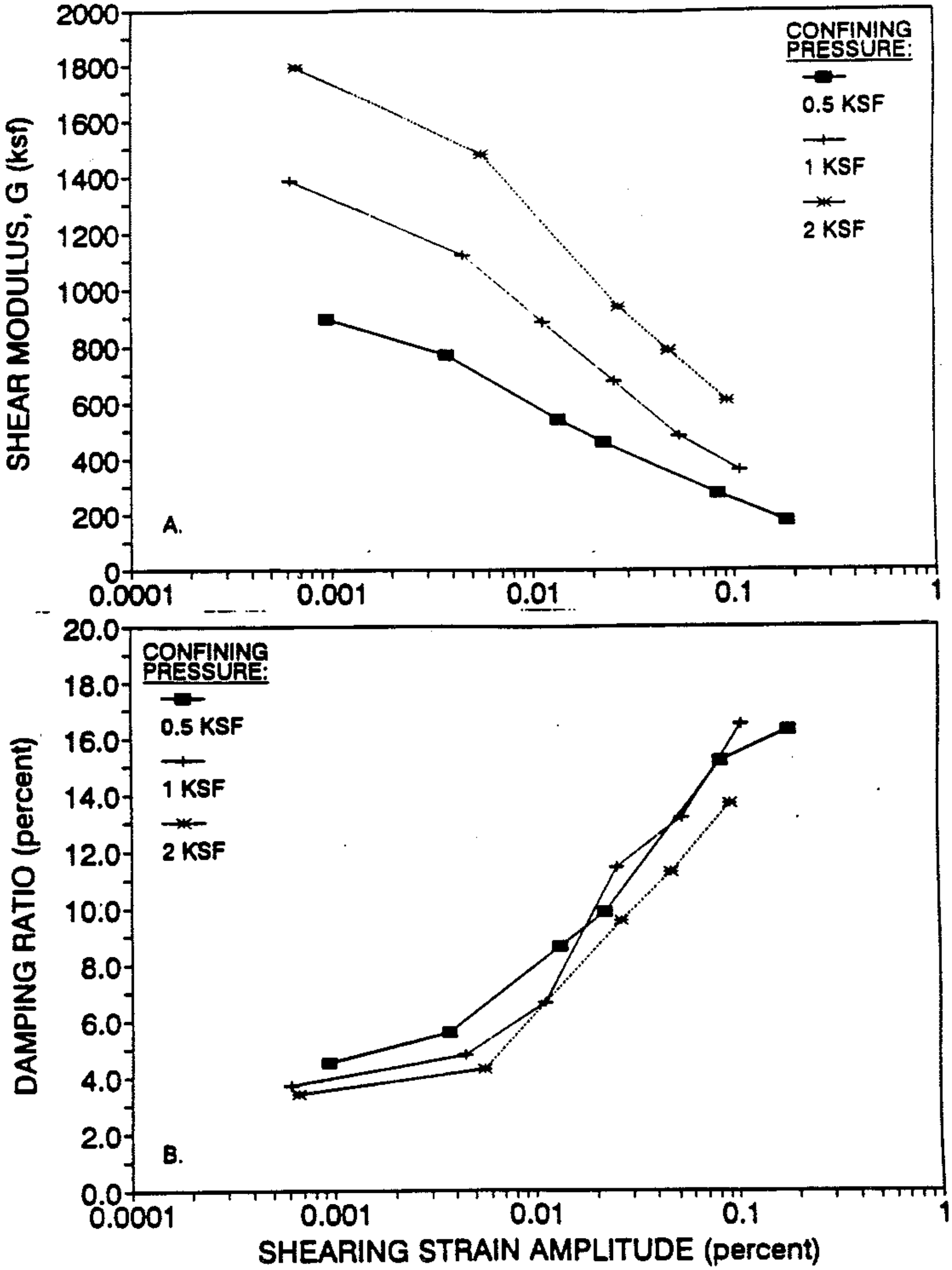


Figure A4.2.3 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-2

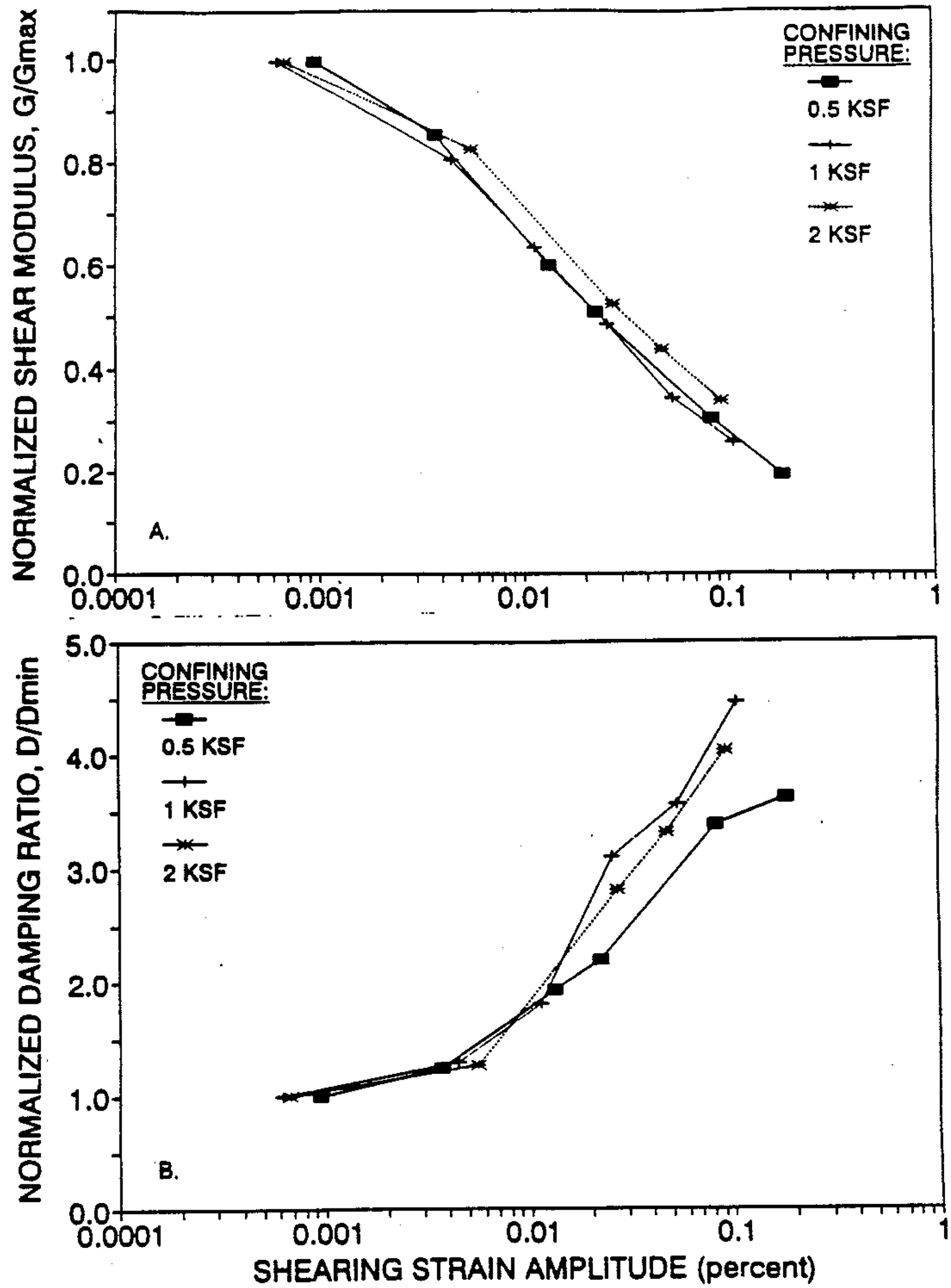


Figure A4.2.4 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-2

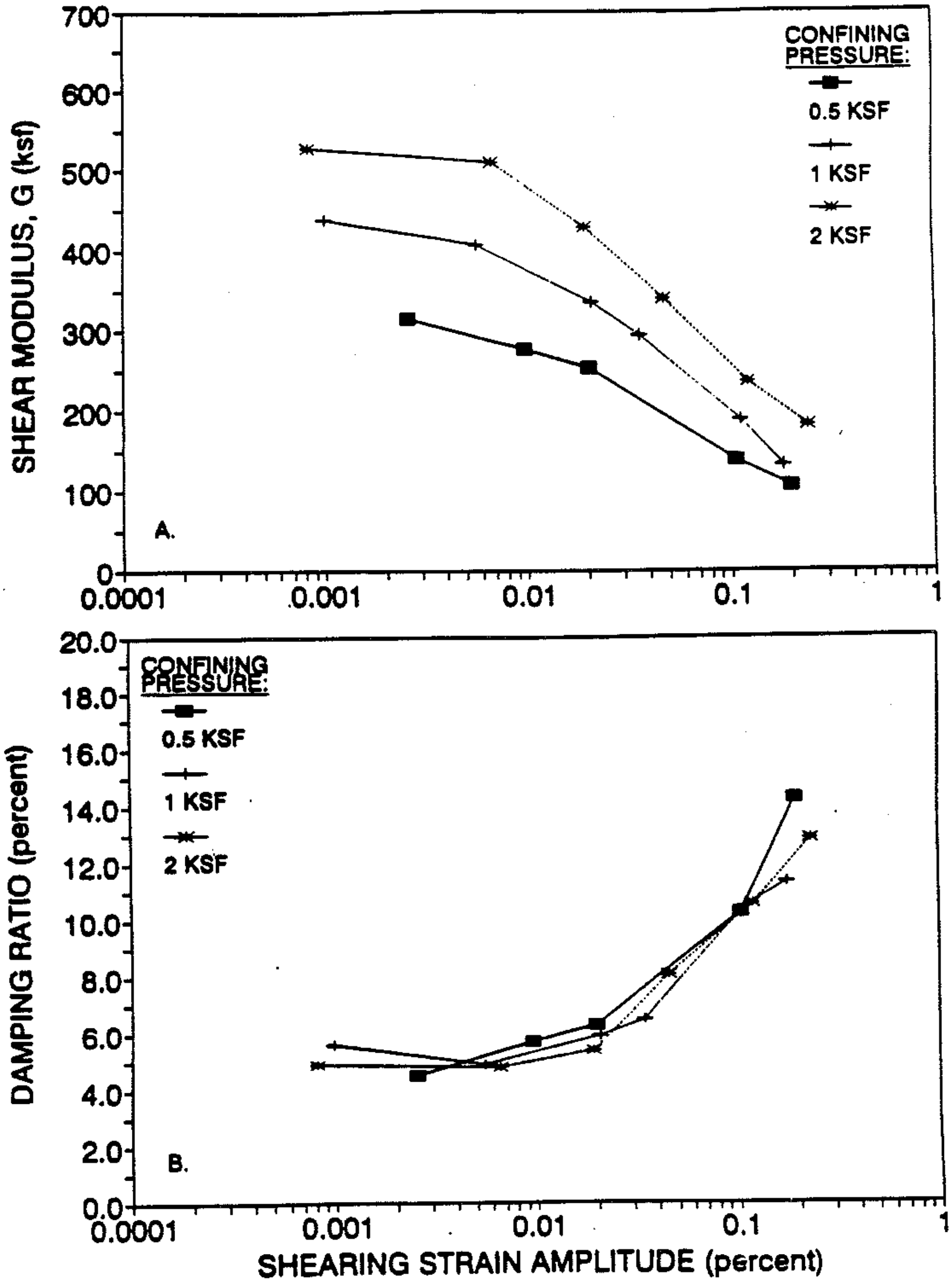


Figure A4.2.5 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-3

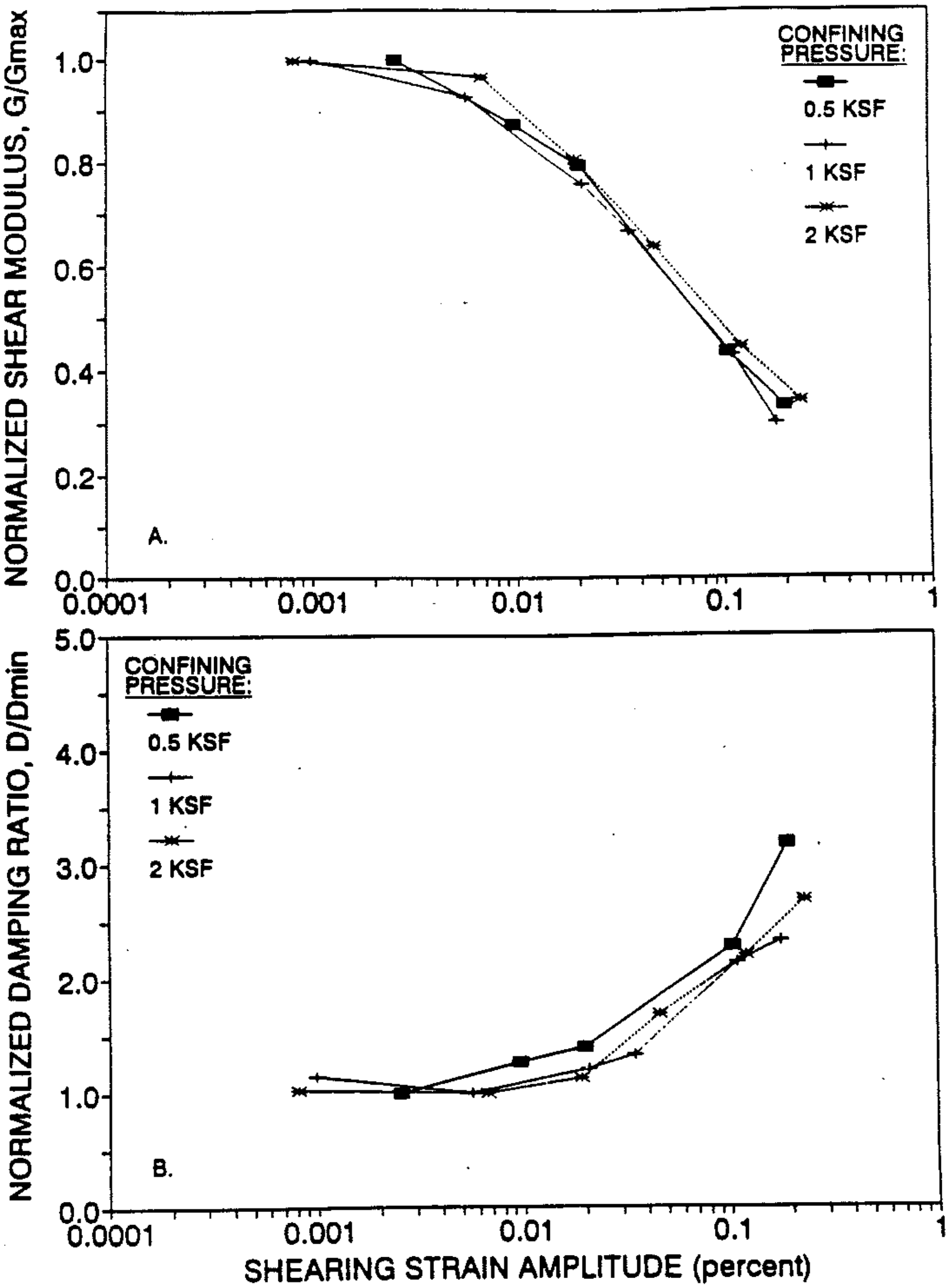


Figure A4.2.6 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-3

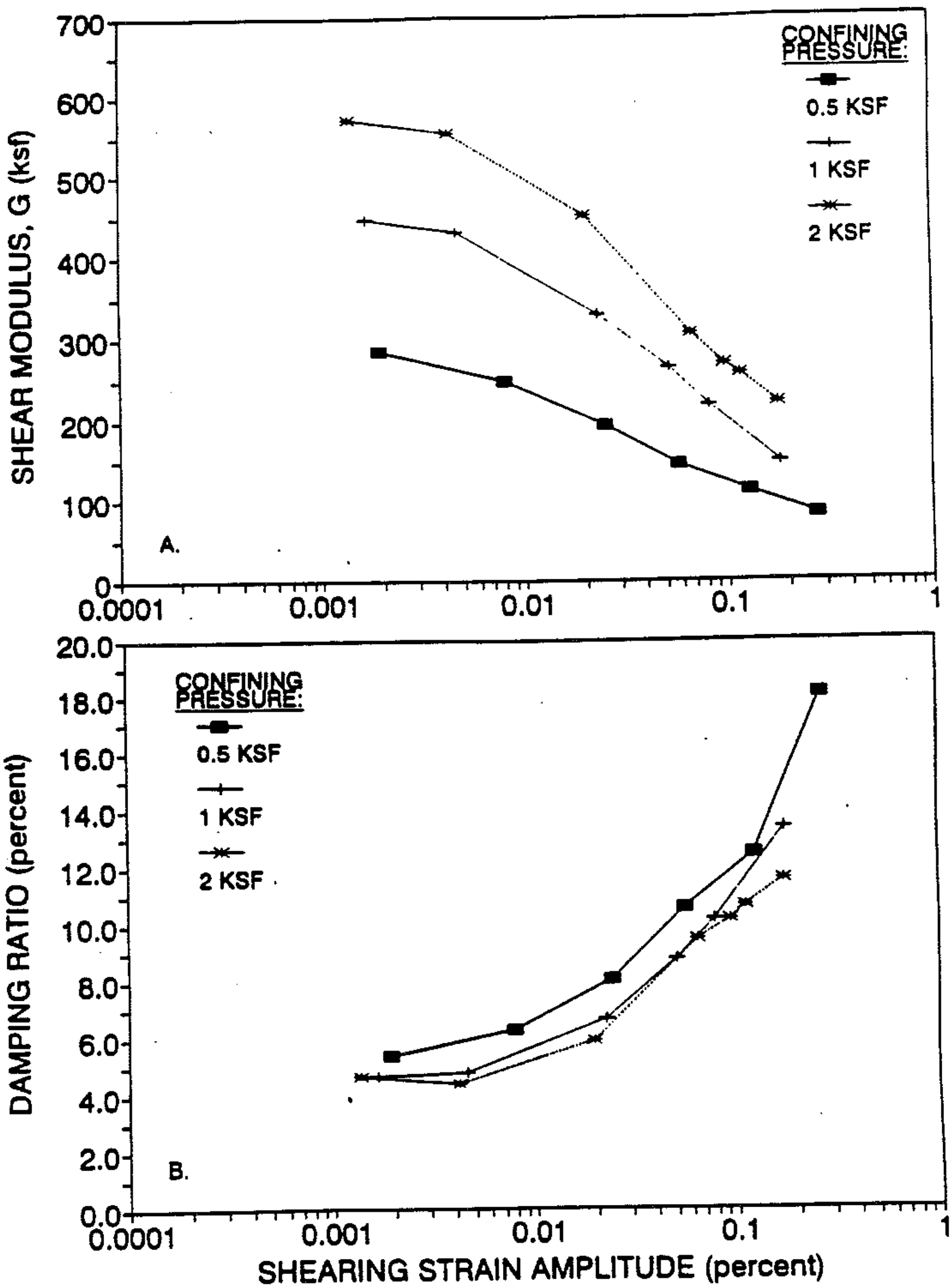


Figure A4.2.7 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-4

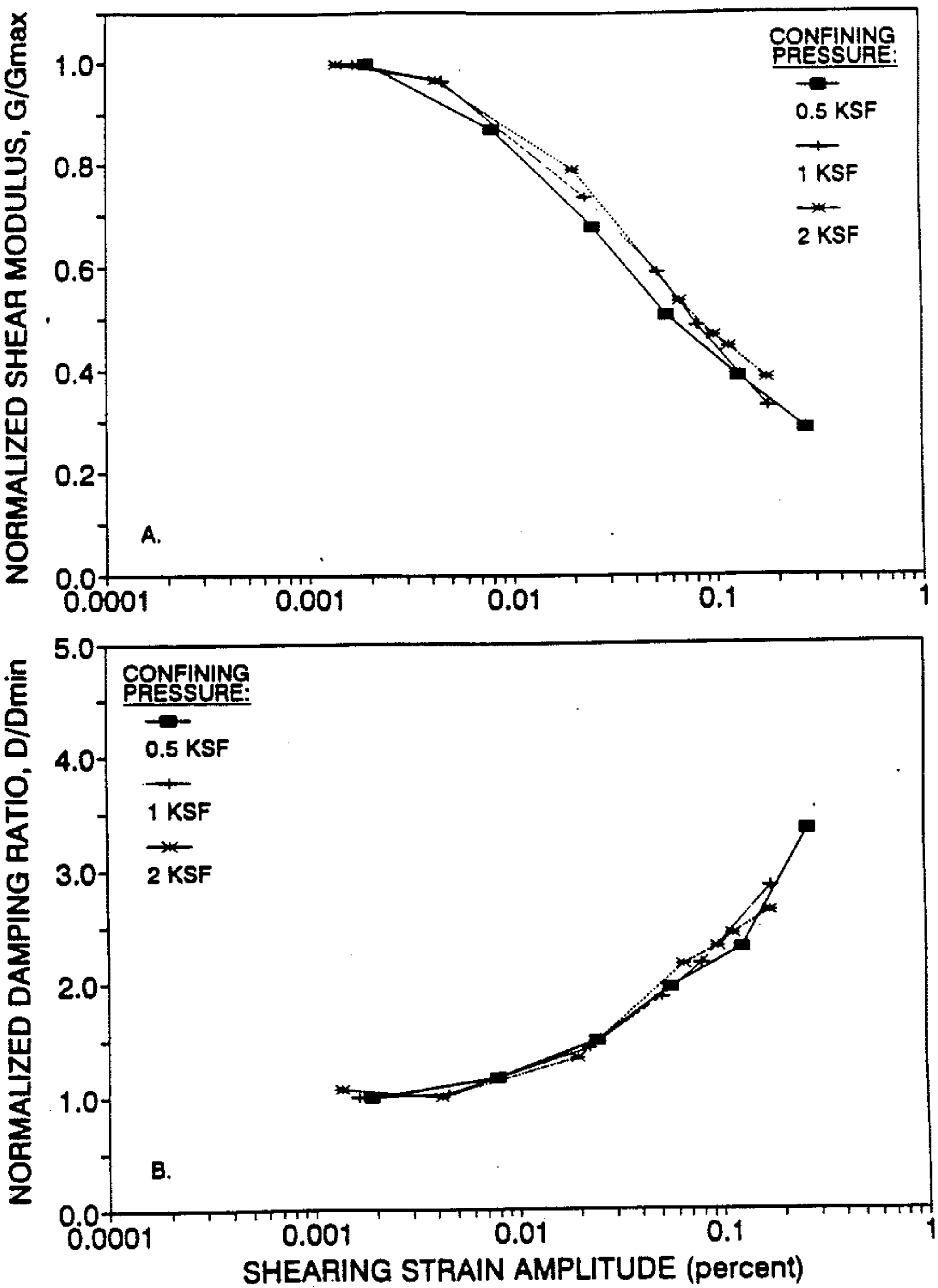


Figure A4.2.8 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-4

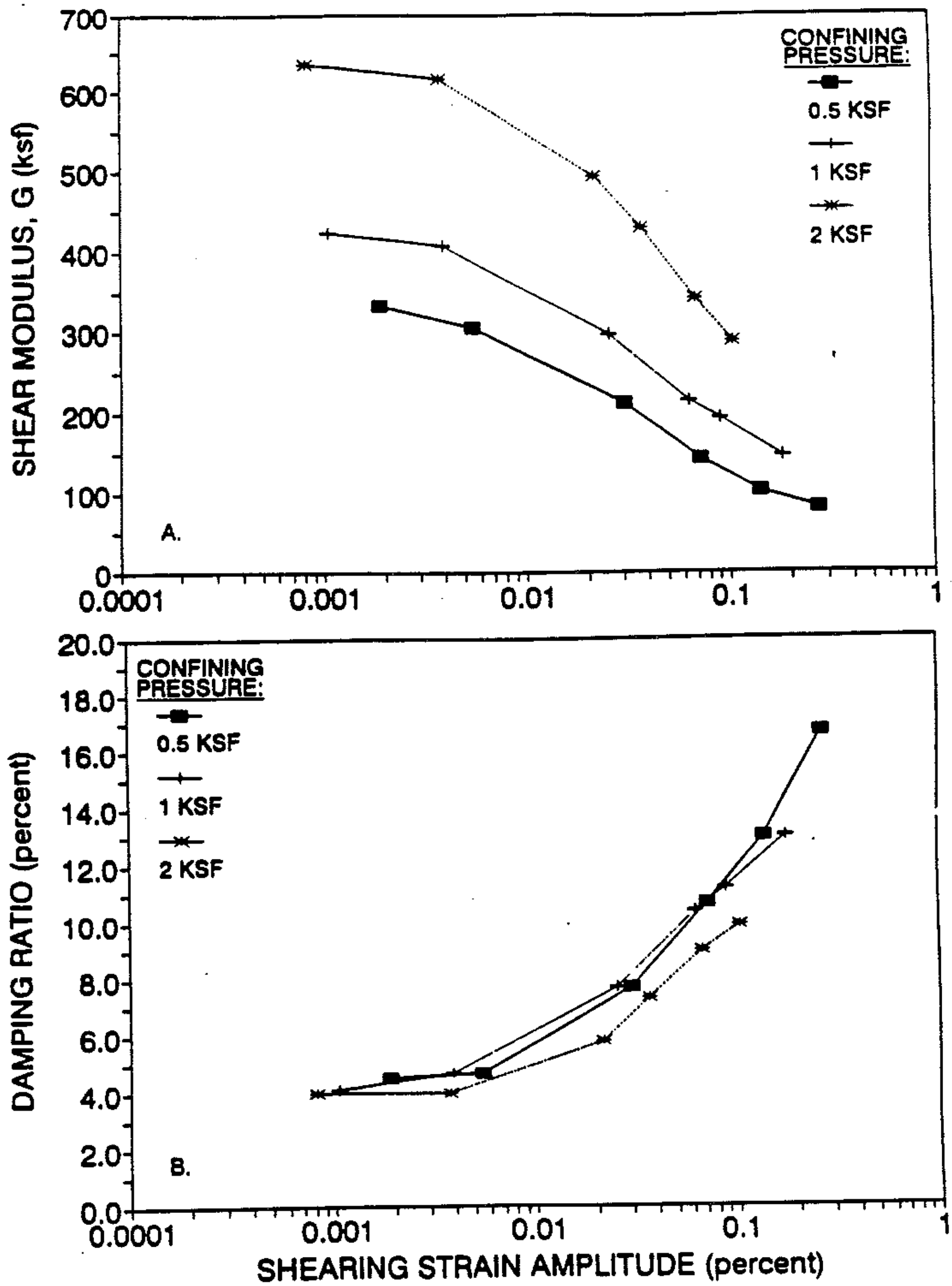


Figure A4.2.9 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-5

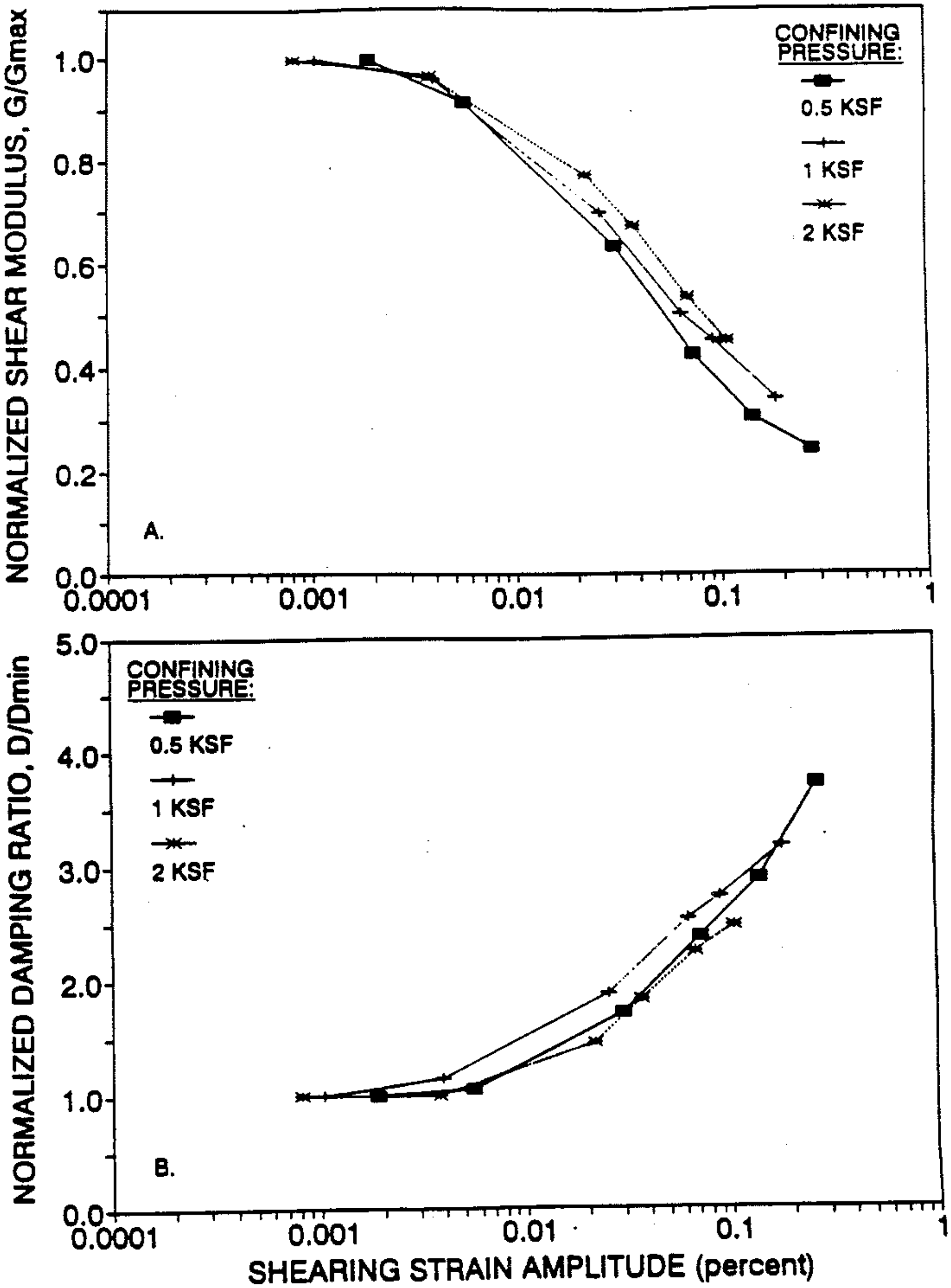


Figure A4.2.10 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimen RC-5

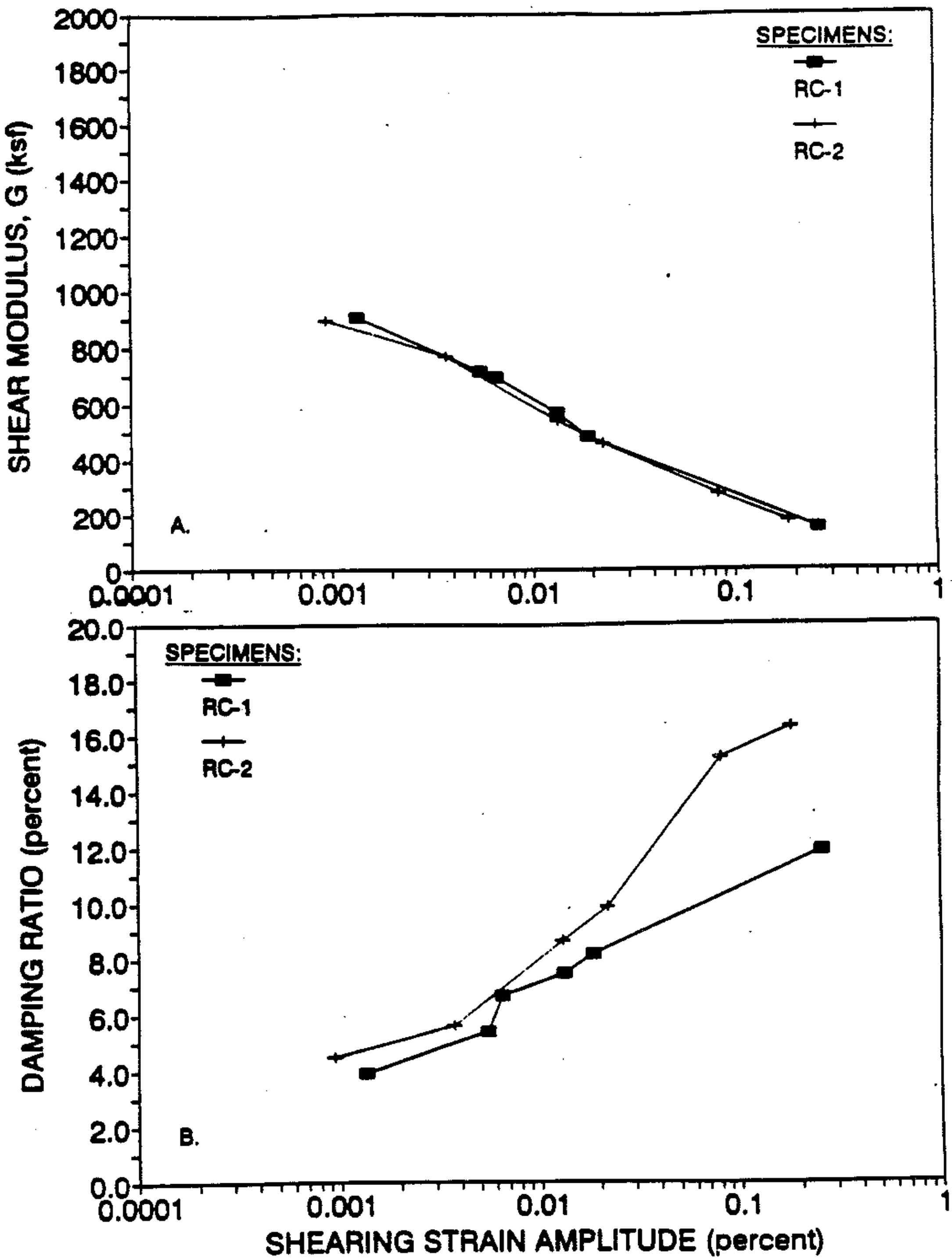


Figure A4.2.11 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens RC-1 and RC-2 at 0.5 ksf Confining Pressure

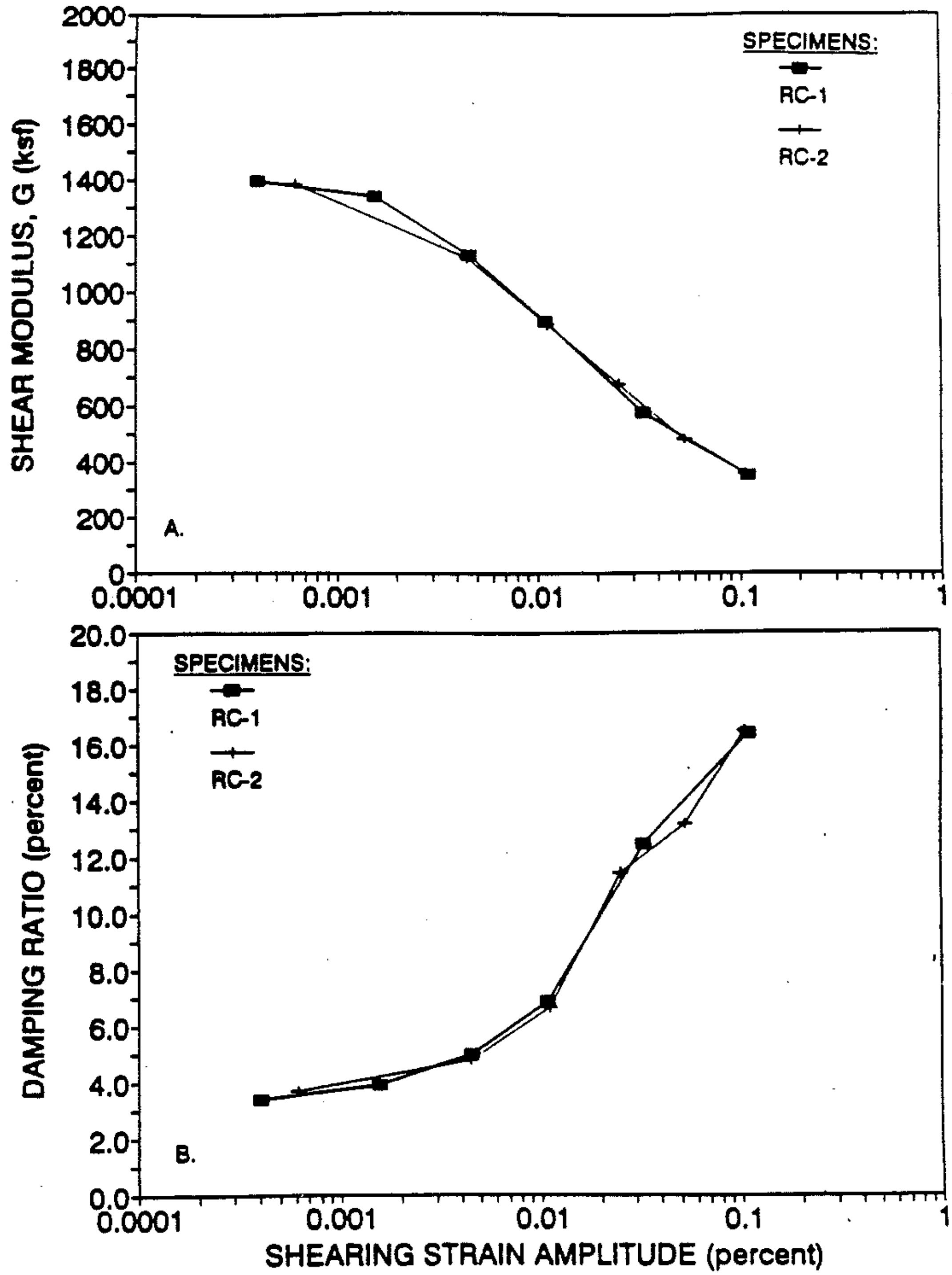


Figure A4.2.12 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens RC-1 and RC-2 at 1 ksf Confining Pressure

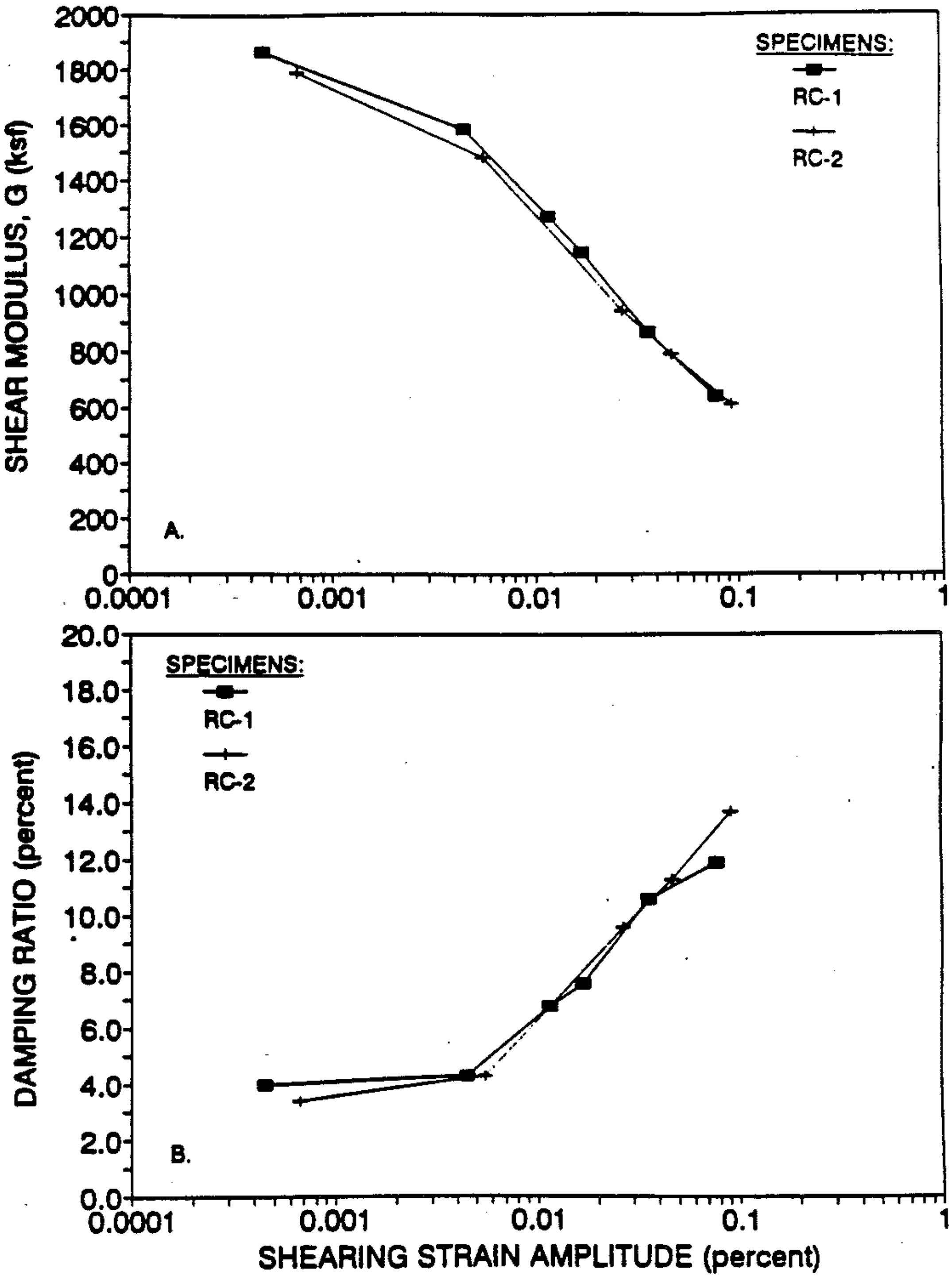


Figure A4.2.13 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens RC-1 and RC-2 at 2 ksf Confining Pressure

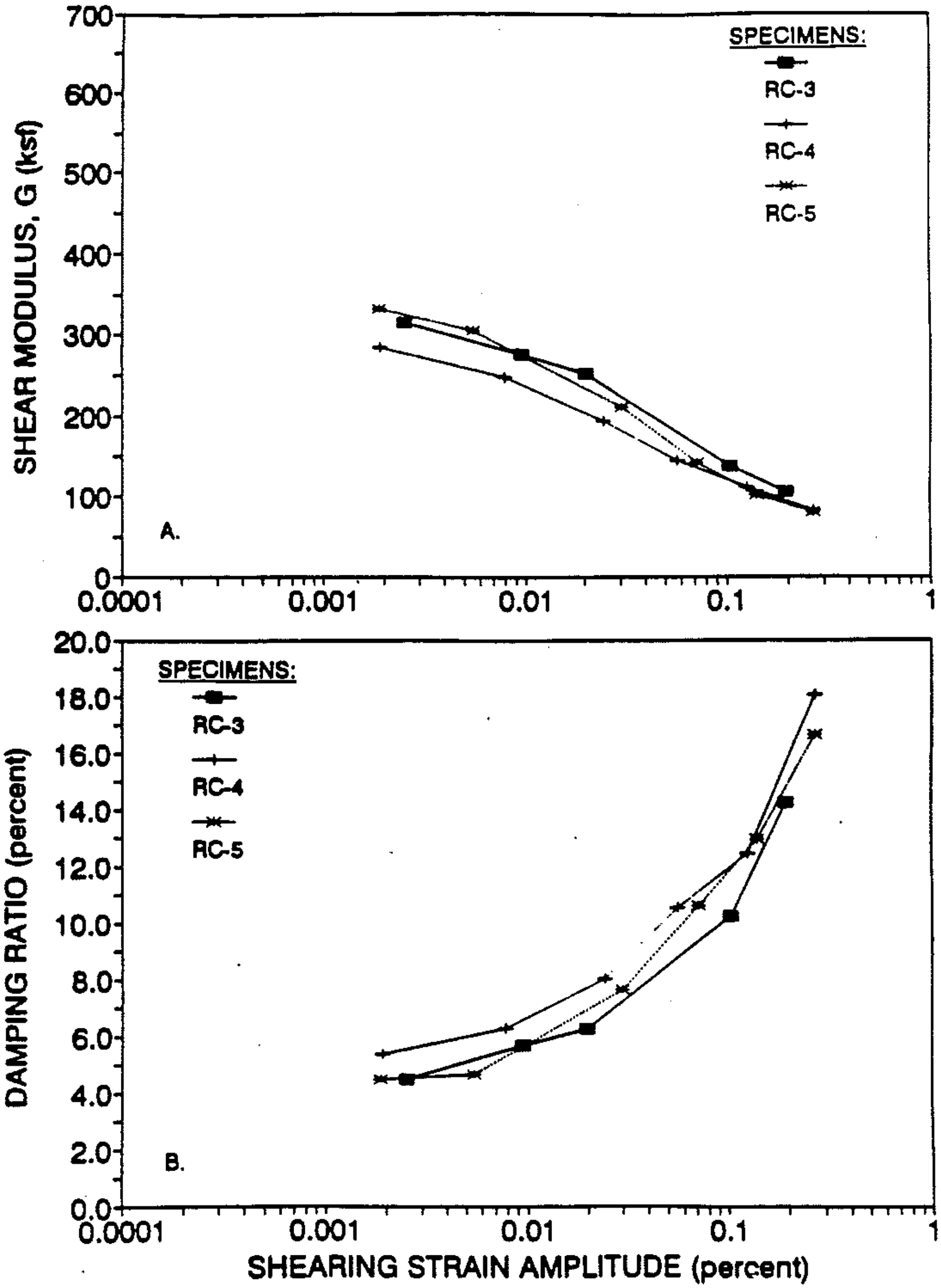


Figure A4.2.14 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens RC-3, RC-4, and RC-5 at 0.5 ksf Confining Pressure

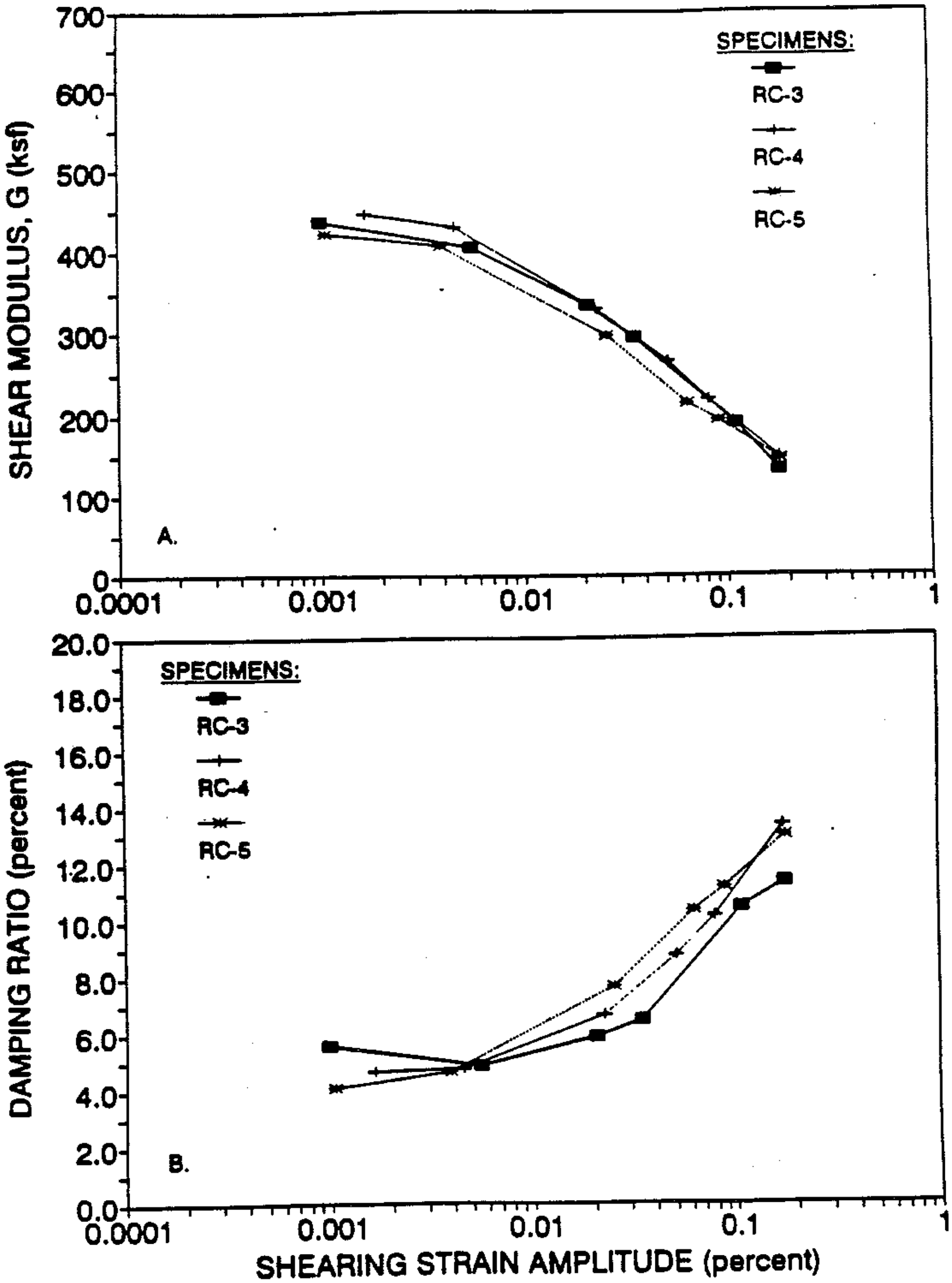


Figure A4.2.15 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens RC-3, RC-4, and RC-5 at 1 ksf Confining Pressure

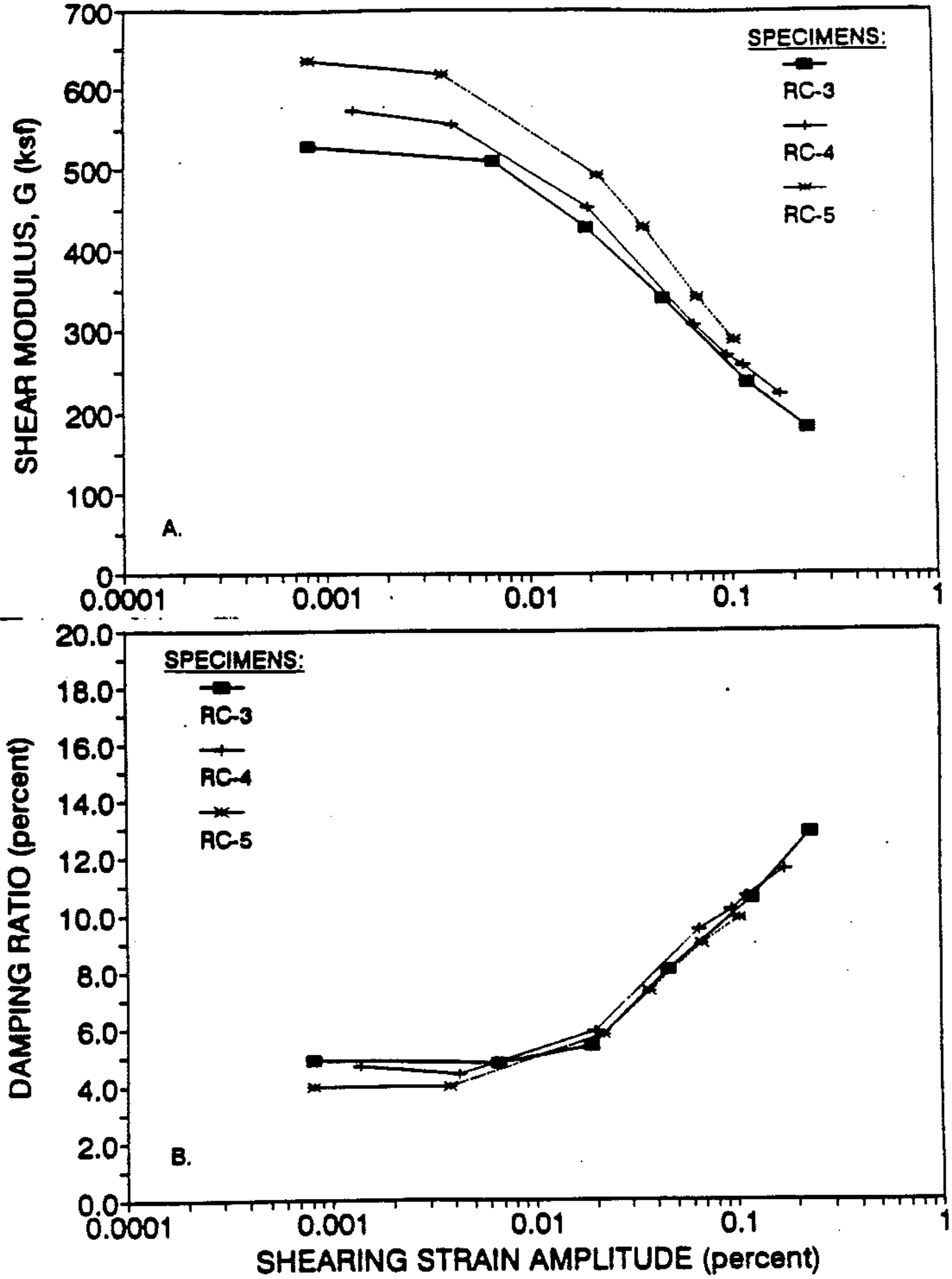


Figure A4.2.16 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens RC-3, RC-4, and RC-5 at 2 ksf Confining Pressure

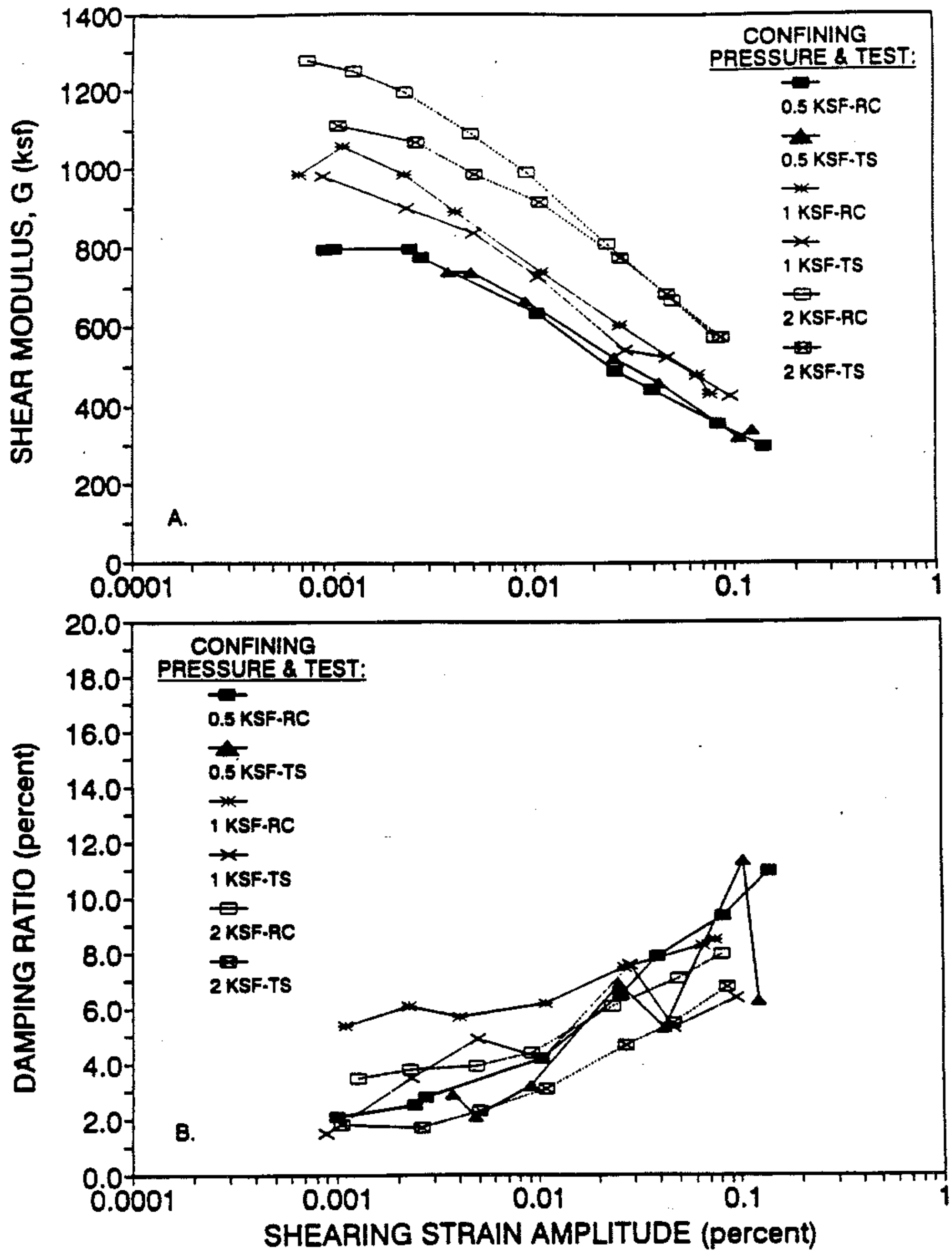


Figure A4.2.17 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimen TS-1

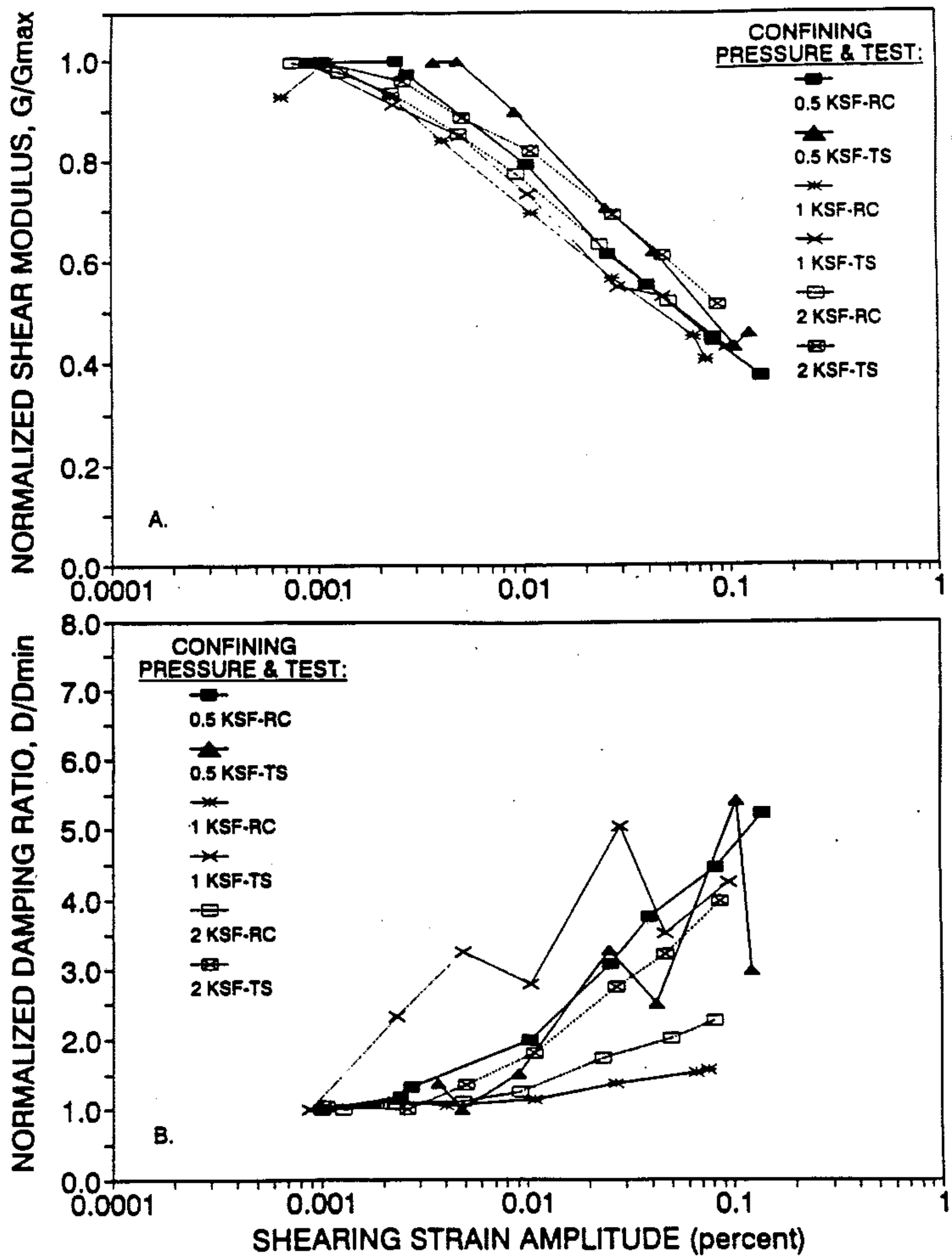


Figure A4.2.18 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimen TS-1

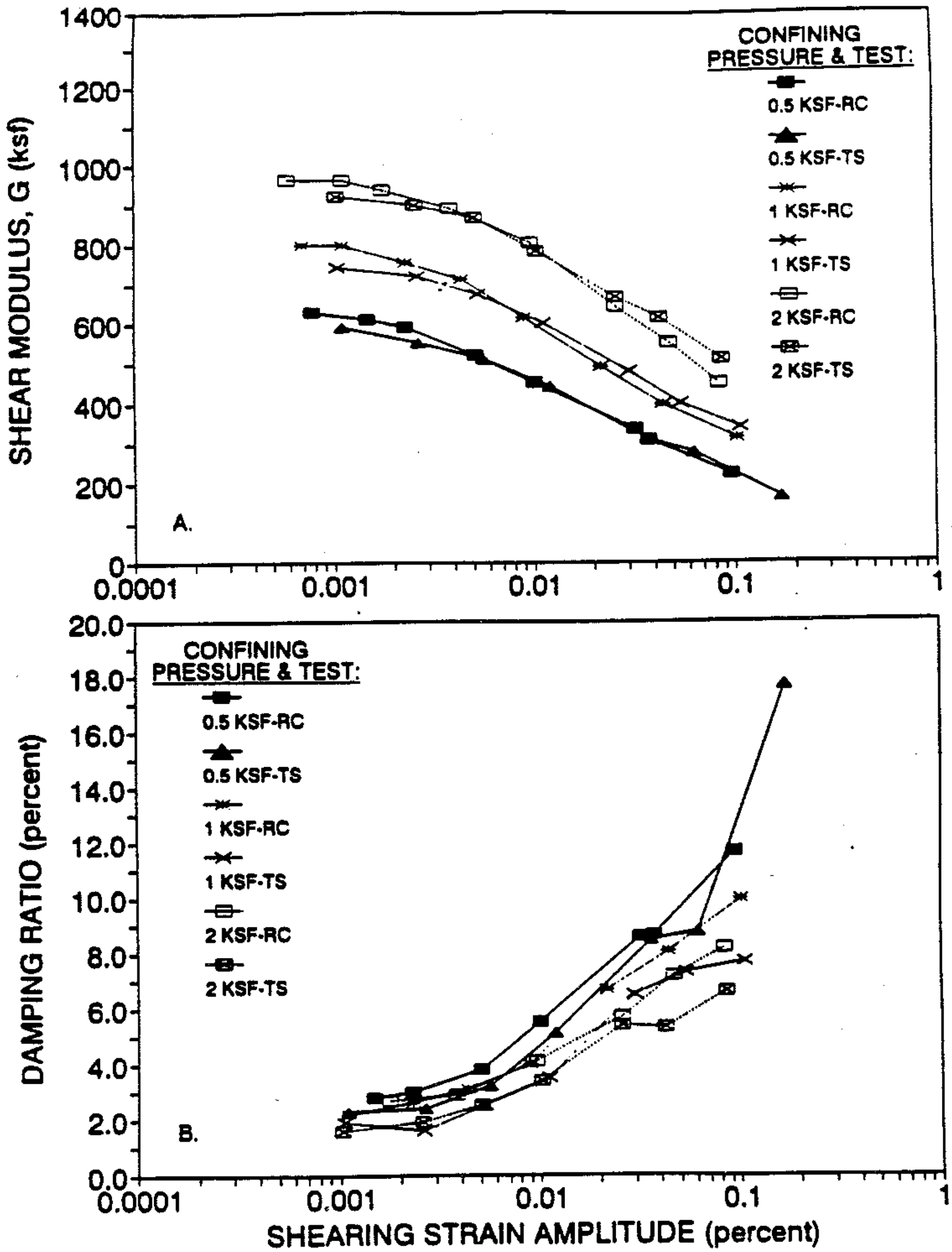


Figure A4.2.19 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimen TS-2

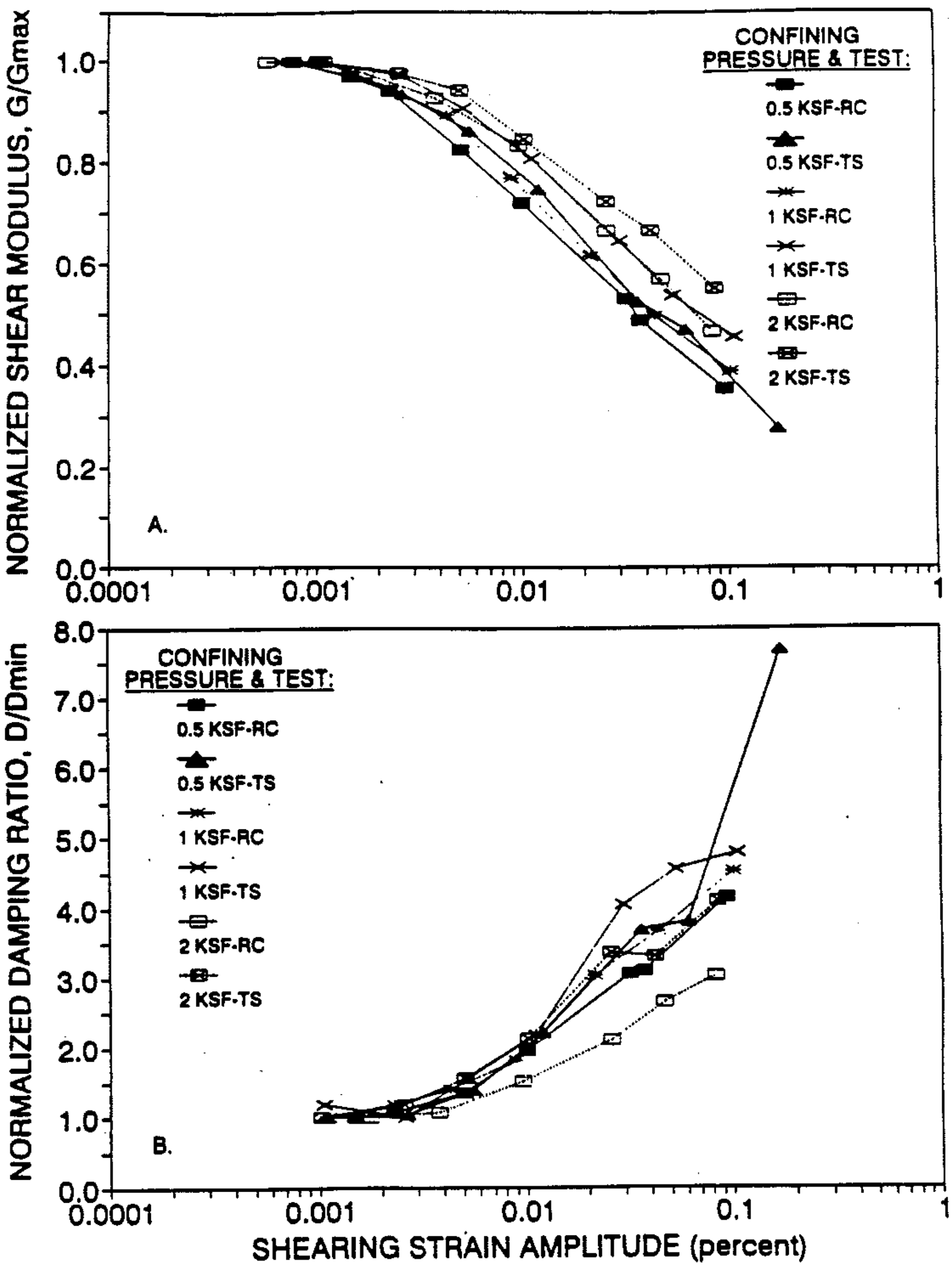


Figure A4.2.20 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimen TS-2

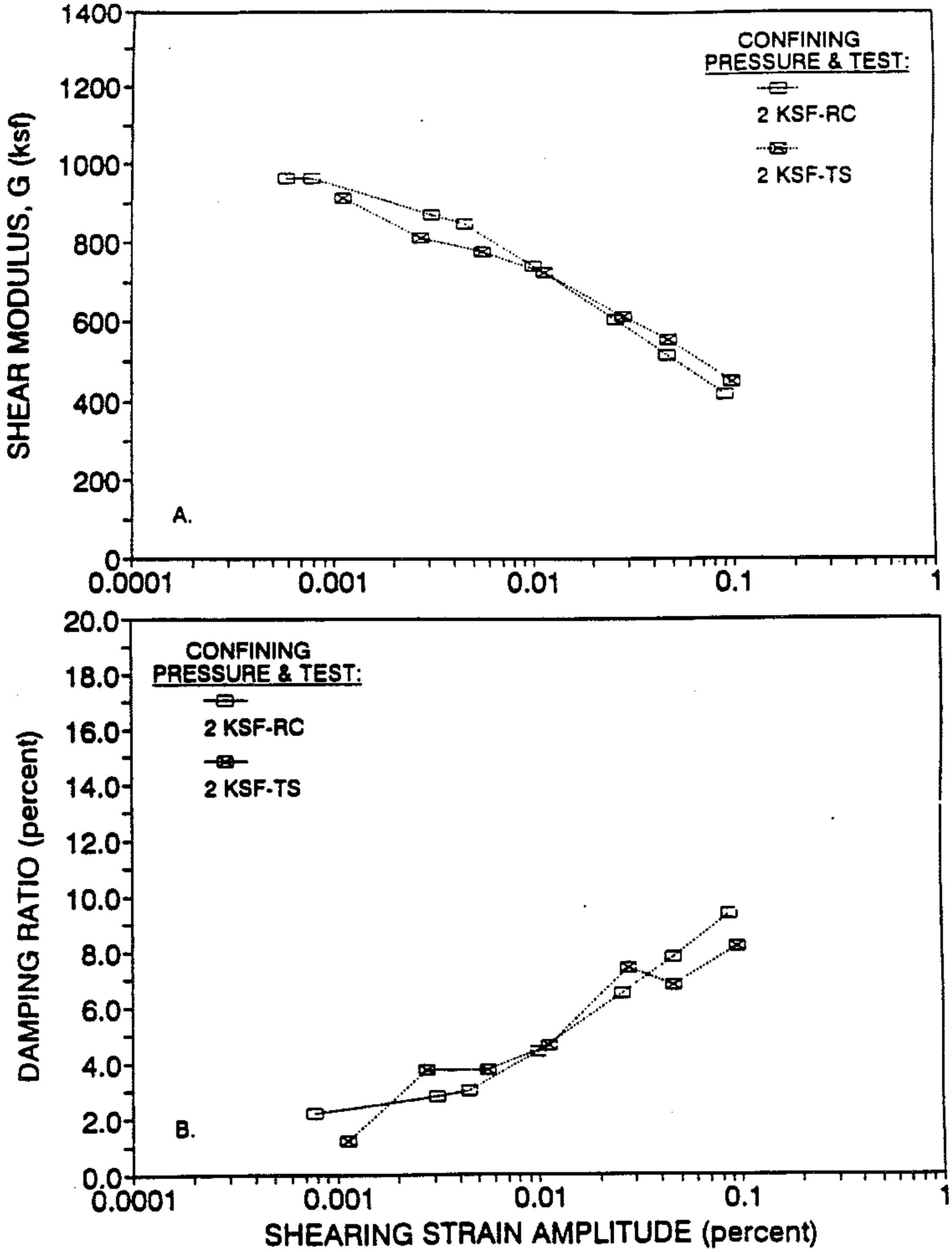


Figure A4.2.21 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimen TS-3

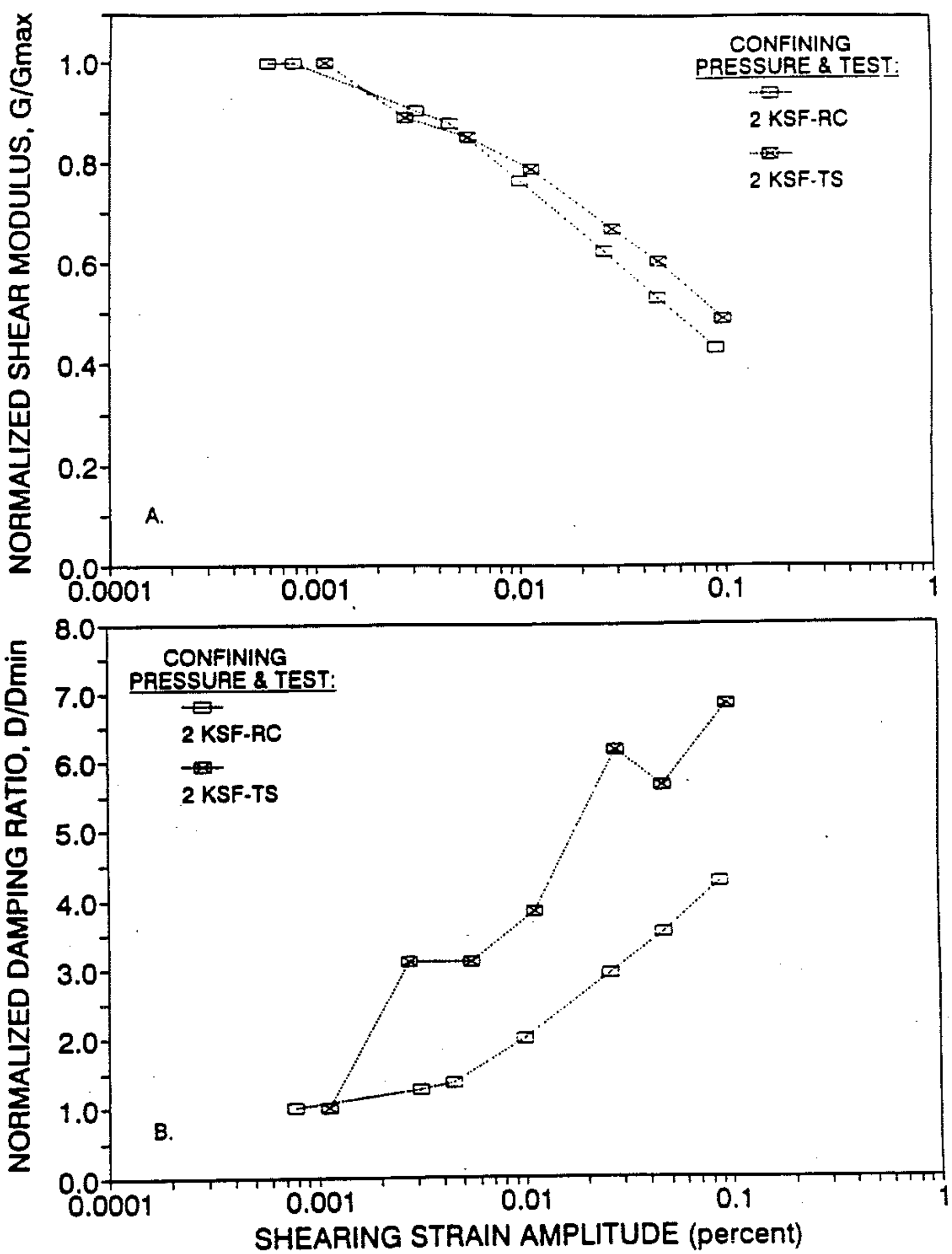


Figure A4.2.22 (A.) Normalized Shear Modulus and (B.) Normalized Damping Ratio as a function of Shearing Strain Amplitude for Specimen TS-3

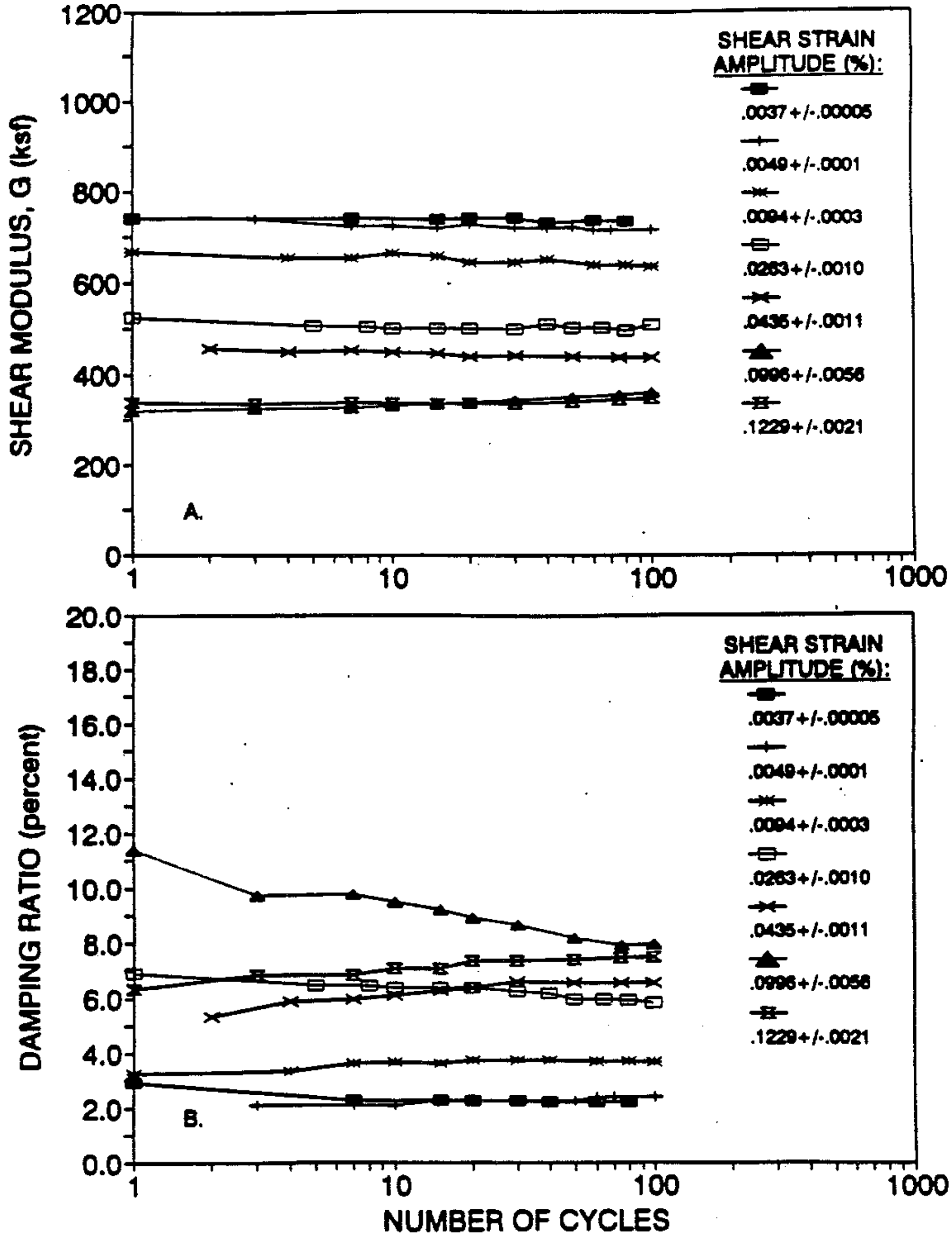


Figure A4.2.23 (A.) Shear Modulus and (B.) Damping Ratio as a function of Number of Loading Cycles for Specimen TS-1 for 0.5 ksf Confining Pressure

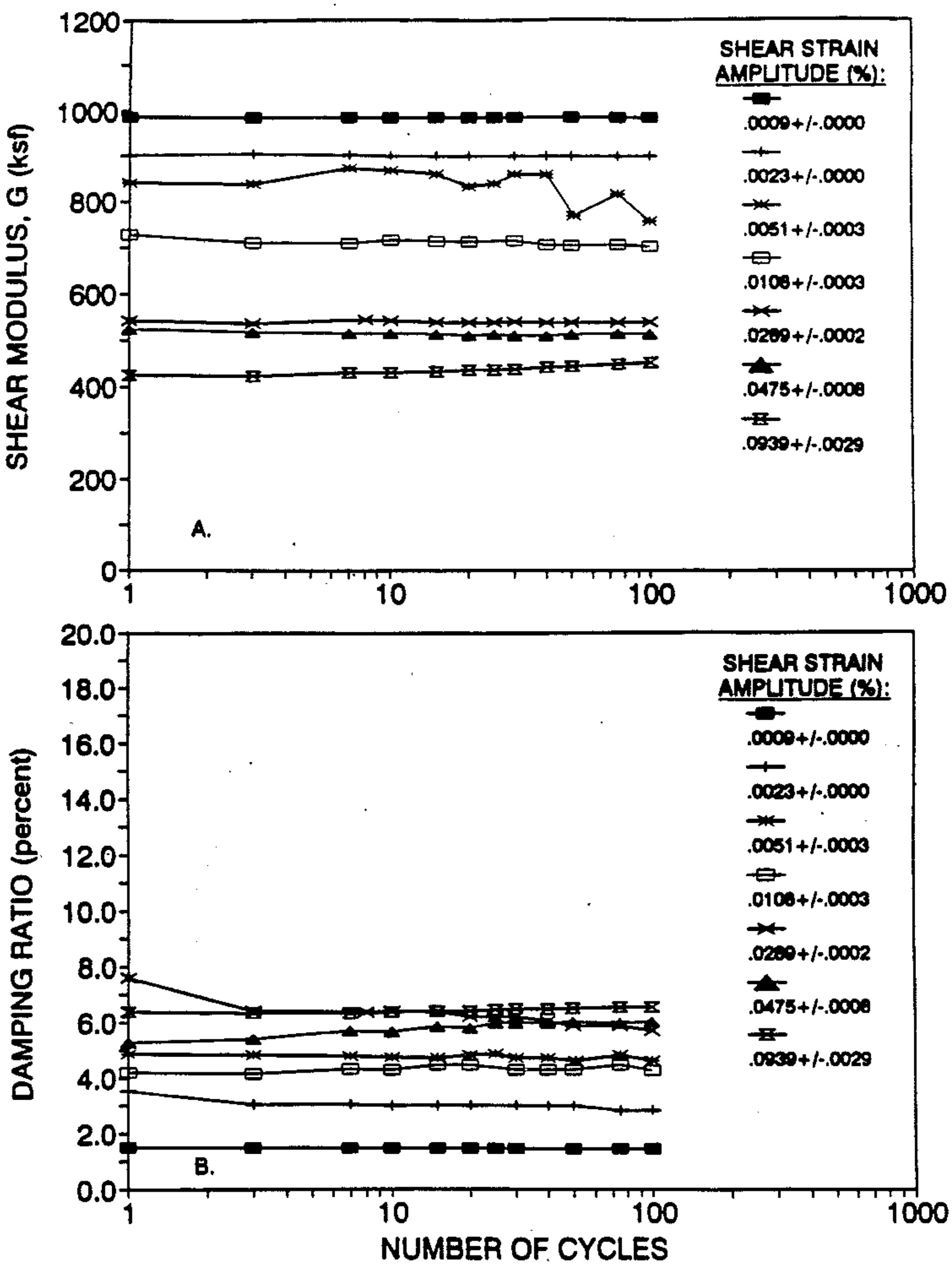


Figure A4.2.24 (A.) Shear Modulus and (B.) Damping Ratio as a function of Number of Loading Cycles for Specimen TS-1 for 1 ksf Confining Pressure

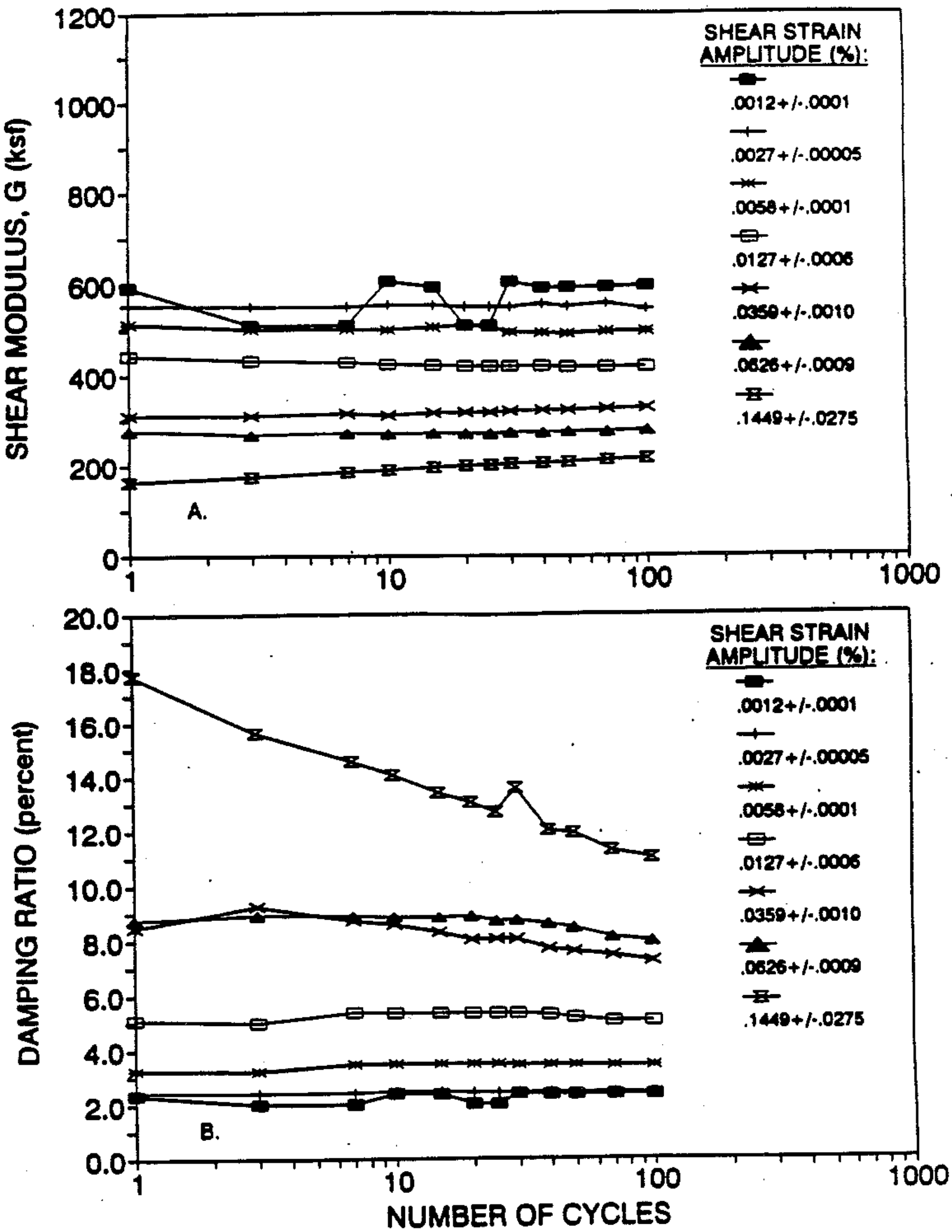


Figure A4.2.25 (A.) Shear Modulus and (B.) Damping Ratio as a function of Number of Loading Cycles for Specimen TS-2 for 0.5 ksf Confining Pressure

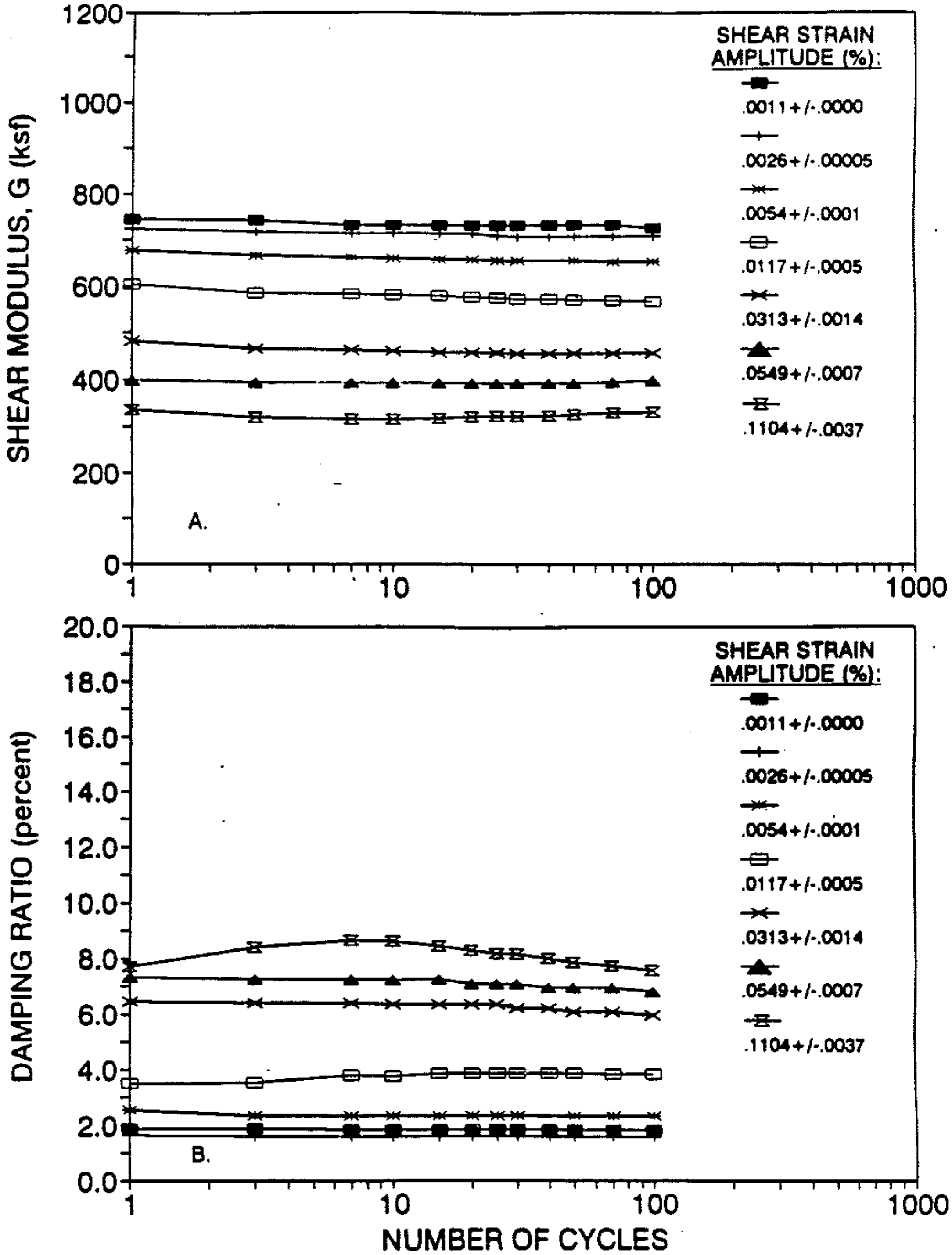


Figure A4.2.26 (A.) Shear Modulus and (B.) Damping Ratio as a function of Number of Loading Cycles for Specimen TS-2 for 1 ksf Confining Pressure

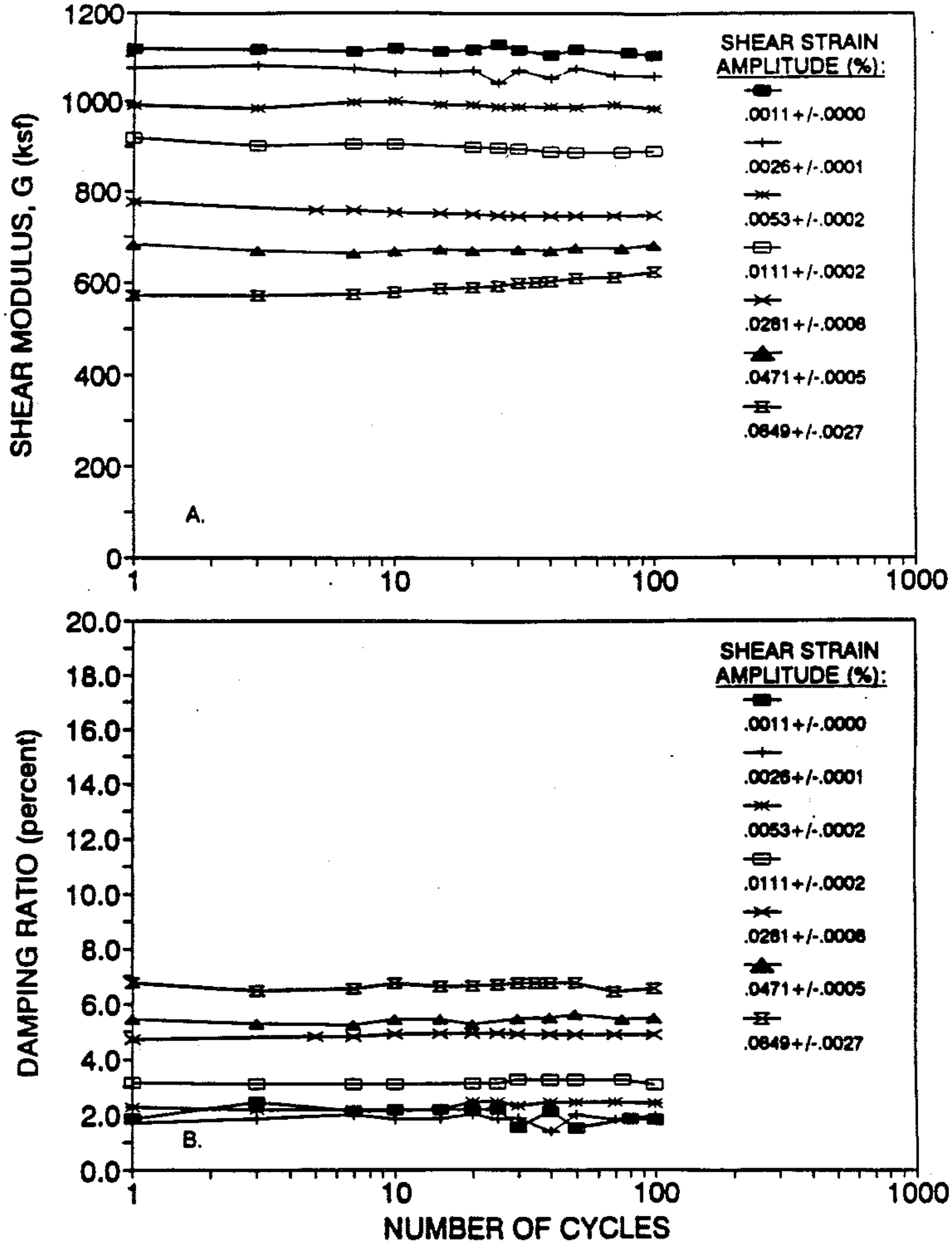


Figure A4.2.27 (A.) Shear Modulus and (B.) Damping Ratio as a function of Number of Loading Cycles for Specimen TS-1 for 2 ksf Confining Pressure

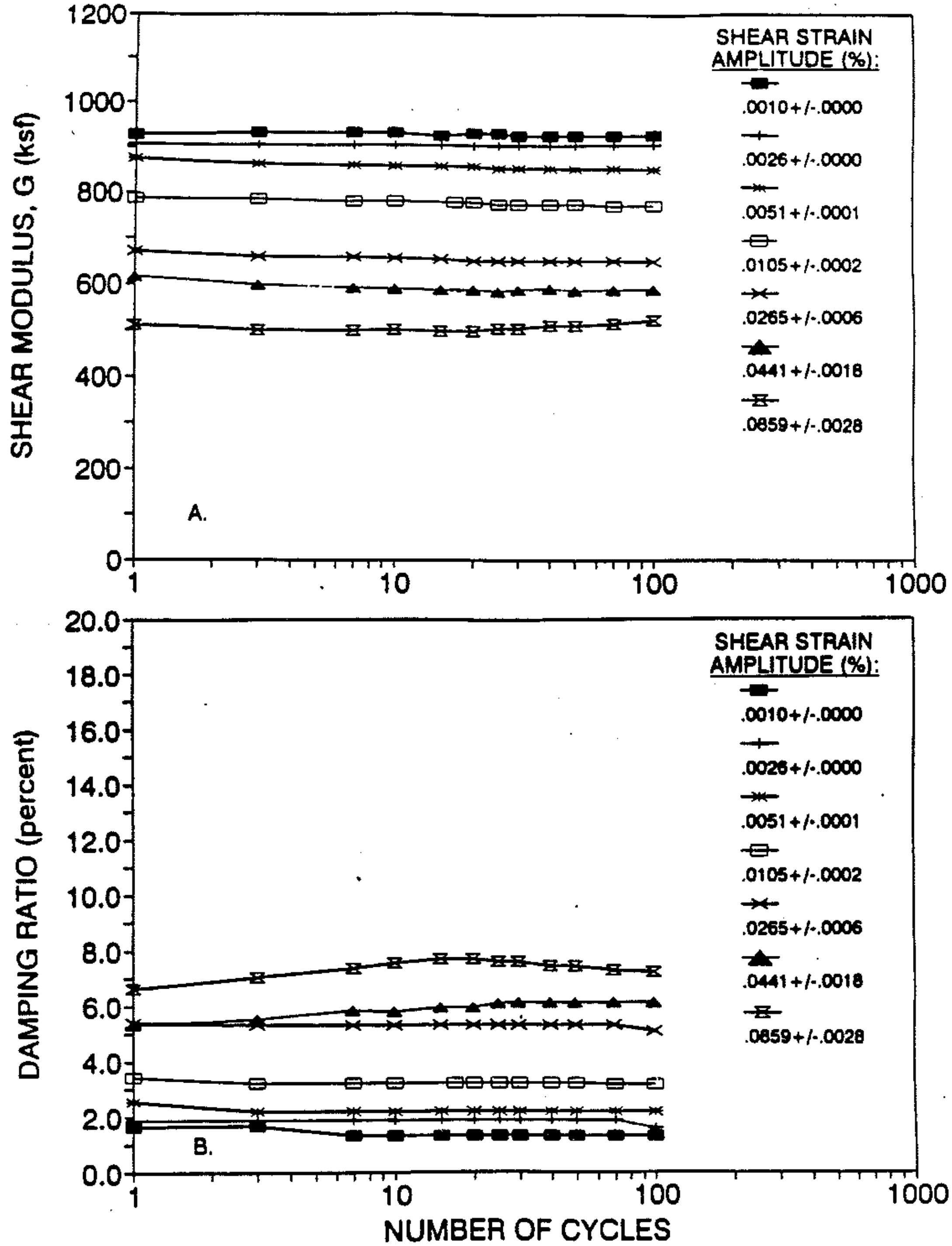


Figure A4.2.28 (A.) Shear Modulus and (B.) Damping Ratio as a function of Number of Loading Cycles for Specimen TS-2 for 2 ksf Confining Pressure

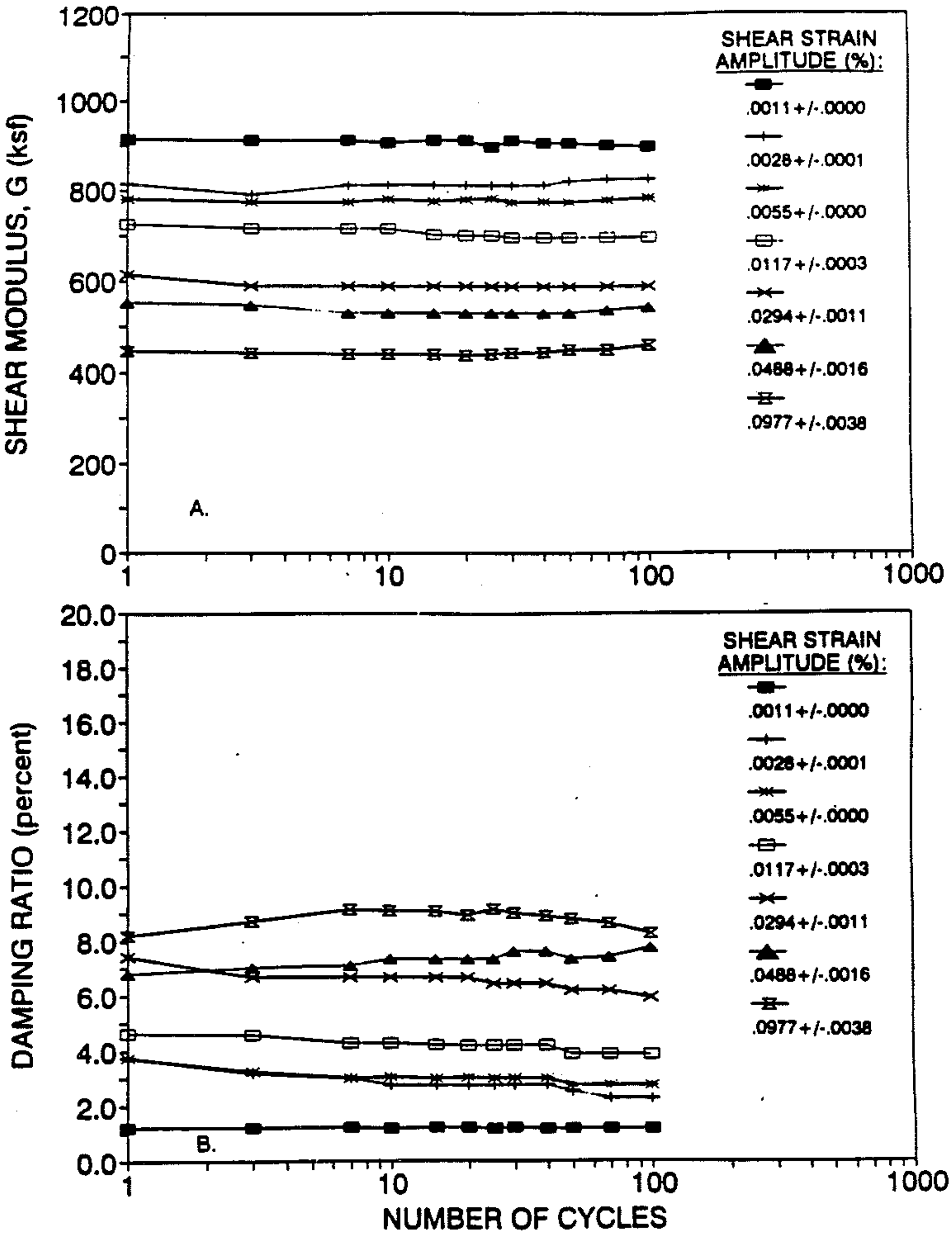


Figure A4.2.29 (A.) Shear Modulus and (B.) Damping Ratio as a function of Number of Loading Cycles for Specimen TS-3 for 2 ksf Confining Pressure

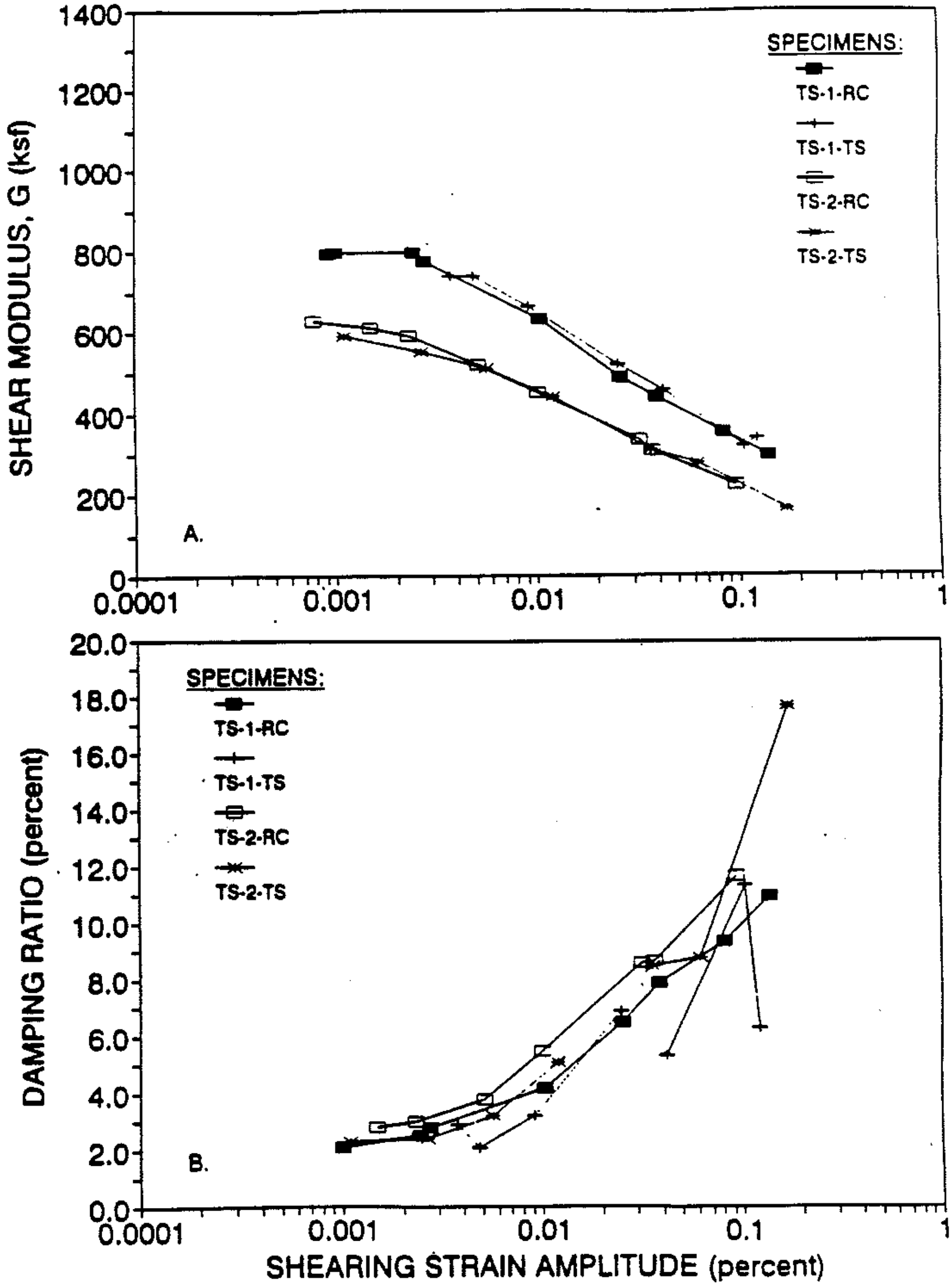


Figure A4.2.30 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens TS-1 and TS-2 at 0.5 ksf Confining Pressure

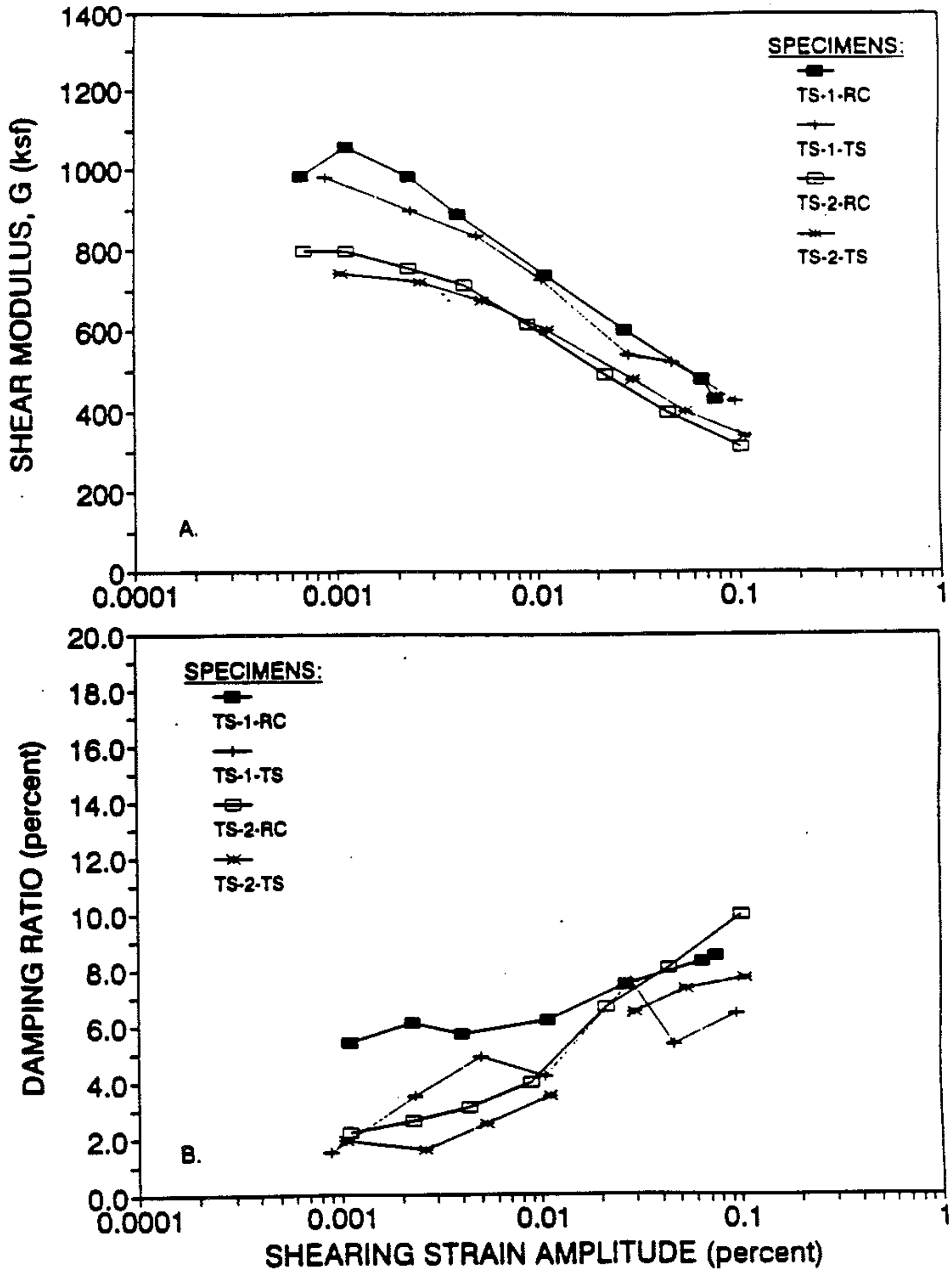


Figure A4.2.31 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens TS-1 and TS-2 at 1 ksf Confining Pressure

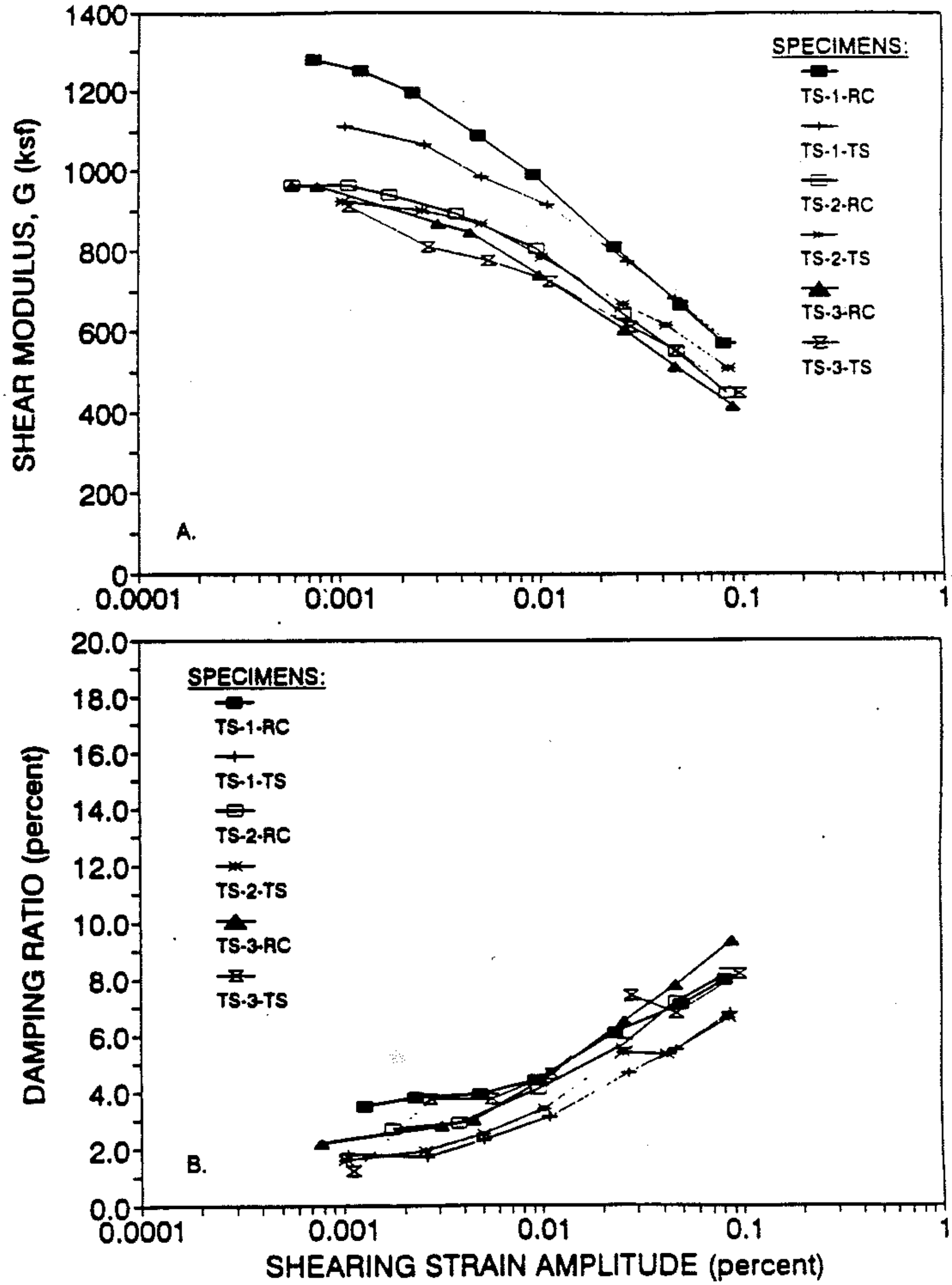


Figure A4.2.32 (A.) Shear Modulus and (B.) Damping Ratio as a function of Shearing Strain Amplitude for Specimens TS-1, TS-2, and TS-3 at 2 ksf Confining Pressure

APPENDIX 4.3

DATA SUMMARY OF PHASE II(a), II(b), & II(c) RESULTS

APPENDIX 4.3.1

DATA SUMMARY OF PHASE II(a) RESULTS

DATA SHEET # 1

SAMPLE # 1ST#4

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.877	5.908	2.783966	0.207	2.67	0.022226	125.2558	2.306517	103.7745	0.013844	0.605481	0.9128114	11130	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
11/25/92	25	72	80	12.5	10832	5.8931	2.869744	0.022058	2.783966	0.5933646	0.000619	0.289018	0.51304	481.15	908235.7	43.48632	0.000606
11/26/92	50	72	90	11.11111	9986	5.8508	2.849145	0.021587	2.783966	0.5592993	0.00061	0.284884	0.50968	540.95	1173112	56.1686	0.000479
12/21/92	100	86	112	8.928571	9844	5.8437	2.845688	0.021508	2.783966	0.5536295	0.000608	0.284193	0.50912	673.11	1822941	87.28243	0.000369

TORSIONAL SHEAR TEST FOR 1ST#4 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.001	2.67	4.775	0.4968	0.4889	40	2.863	5.893	0.0332	1.1672	4.4237E-05	8.5959E-04	3.1866E-02	3.1790E-04	9.5647	1.1127E+06
0.0025	2.98375	5.375	0.9957	0.991	40	2.863	5.893	0.0743	2.6633	9.9080E-05	1.9253E-03	7.2708E-02	3.1788E-04	21.8244	1.1336E+06
0.005	6.53125	5.125	0.9957	1.984	40	2.862	5.893	0.1626	5.0840	2.1688E-04	4.2143E-03	1.3879E-01	3.1787E-04	41.6618	9.8859E+05
0.01	4.0625	3.78	1.999	4.943	20	2.862	5.892	0.4060	9.3423	5.4167E-04	1.0525E-02	2.5504E-01	3.1782E-04	76.5659	7.2745E+05
0.025	6.90625	4.0625	4.9595	9.856	20	2.861	5.889	1.7126	20.0200	2.2846E-03	4.4392E-02	5.4655E-01	3.1712E-04	164.3511	3.7022E+05
0.05	5.796875	5.6975	10	9.856	20	2.857	5.882	2.8984	28.0773	3.8665E-03	7.5131E-02	7.6651E-01	3.1557E-04	231.3430	3.0792E+05

Confining Pressure = 50 kPa

Estimated Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.001	1.625	5.844	0.9957	0.4889	40	2.843	5.853	0.0405	1.4286	5.3961E-05	1.0485E-03	3.9000E-02	3.0933E-04	11.9484	1.1395E+06
0.0025	3.71875	6.857	0.9957	0.991	40	2.843	5.852	0.0926	3.3976	1.2349E-04	2.3995E-03	9.2756E-02	3.0927E-04	28.4218	1.1845E+06
0.005	4	6.52	1.999	1.984	40	2.843	5.852	0.1999	6.4678	2.6667E-04	5.1817E-03	1.7657E-01	3.0928E-04	54.1032	1.0441E+06
0.01	3.875	4.875	4.9595	4.943	40	2.843	5.852	0.4805	12.0486	6.4092E-04	1.2454E-02	3.2893E-01	3.0925E-04	100.7931	8.0933E+05
0.025	8.03125	5.125	4.9595	9.856	20	2.842	5.851	1.9915	25.2560	2.6567E-03	5.1624E-02	6.8949E-01	3.0900E-04	211.4068	4.0952E+05
0.05	7.59375	3.6875	10	19.71	20	2.841	5.849	3.7969	36.3403	5.0650E-03	9.8420E-02	9.9209E-01	3.0861E-04	304.4766	3.0936E+05

Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.001	1.625	4.5	0.9957	0.991	40	2.838	5.843	0.0405	2.2298	5.3961E-05	1.0485E-03	6.0872E-02	3.0732E-04	18.7409	1.7874E+06
0.0025	3.906	5.356	0.9957	1.984	40	2.838	5.843	0.0972	5.3132	1.2970E-04	2.5203E-03	1.4505E-01	3.0732E-04	44.6567	1.7719E+06
0.005	3.90625	4.0625	1.999	4.943	40	2.838	5.843	0.1952	10.0405	2.6042E-04	5.0602E-03	2.7410E-01	3.0729E-04	84.3941	1.6678E+06
0.01	4.33875	7.625	1.999	4.943	20	2.838	5.843	0.4337	18.8452	5.7850E-04	1.1241E-02	5.1447E-01	3.0723E-04	158.4248	1.4093E+06
0.025	5.218	8.09	10	19.71	20	2.838	5.841	2.6090	79.7270	3.4804E-03	6.7629E-02	2.1765E+00	3.0698E-04	670.6410	9.9165E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 1ST#4

DATE: 11/25/92

INITIAL LENGTH= 5.906 inch
INITIAL LVDT = 11130

STTLMT is in inches

e0 = 0.6055
V0 = 38.4065 inch^3
Vs = 23.9224 inch^3

25Kpa — SHEAR STRAIN AMPLITUDE (%)

	0.00086				0.00193				0.00421			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	10824	0.015300	-0.002590	-0.007769	10823	0.015350	-0.002598	-0.007795	10822	0.015400	-0.002607	-0.007820
10	10823	0.015350	-0.002598	-0.007795	10823	0.015350	-0.002598	-0.007795	10822	0.015400	-0.002607	-0.007820
15	10823	0.015350	-0.002598	-0.007795	10823	0.015350	-0.002598	-0.007795	10822	0.015400	-0.002607	-0.007820
20	10823	0.015350	-0.002598	-0.007795	10823	0.015350	-0.002598	-0.007795	10822	0.015400	-0.002607	-0.007820
30	10823	0.015350	-0.002598	-0.007795	10823	0.015350	-0.002598	-0.007795	10822	0.015400	-0.002607	-0.007820
50	10823	0.015350	-0.002598	-0.007795	10823	0.015350	-0.002598	-0.007795	10822	0.015400	-0.002607	-0.007820
100	10823	0.015350	-0.002598	-0.007795	10823	0.015350	-0.002598	-0.007795	10820	0.015500	-0.002624	-0.007871
200	10823	0.015350	-0.002598	-0.007795	10823	0.015350	-0.002598	-0.007795	10820	0.015500	-0.002624	-0.007871
400	10823	0.015350	-0.002598	-0.007795	10823	0.015350	-0.002598	-0.007795	10820	0.015500	-0.002624	-0.007871
600	10823	0.015350	-0.002598	-0.007795	10820	0.015500	-0.002624	-0.007871	10820	0.015500	-0.002624	-0.007871
800	10823	0.015350	-0.002598	-0.007795	10819	0.015550	-0.002632	-0.007896	10820	0.015500	-0.002624	-0.007871
1000	10823	0.015350	-0.002598	-0.007795	10819	0.015550	-0.002632	-0.007896	10820	0.015500	-0.002624	-0.007871

	0.01053				0.04430				0.07513			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	10821	0.015450	-0.002615	-0.007845	10812	0.015900	-0.002691	-0.008074	10680	0.022500	-0.003808	-0.011425
10	10821	0.015450	-0.002615	-0.007845	10806	0.016200	-0.002742	-0.008226	10673	0.022850	-0.003868	-0.011603
15	10820	0.015500	-0.002624	-0.007871	10803	0.016350	-0.002767	-0.008302	10669	0.023050	-0.003901	-0.011704
20	10819	0.015550	-0.002632	-0.007896	10800	0.016500	-0.002793	-0.008378	10664	0.023300	-0.003944	-0.011831
30	10818	0.015600	-0.002640	-0.007921	10783	0.017350	-0.002937	-0.008810	10660	0.023500	-0.003978	-0.011933
50	10817	0.015650	-0.002649	-0.007947	10767	0.018150	-0.003072	-0.009216	10637	0.024650	-0.004172	-0.012517
100	10816	0.015700	-0.002657	-0.007972	10750	0.019000	-0.003216	-0.009648	10614	0.025800	-0.004367	-0.013101
200	10813	0.015850	-0.002683	-0.008048	10720	0.020500	-0.003470	-0.010410	10572	0.027900	-0.004722	-0.014167
400	10813	0.015850	-0.002683	-0.008048	10703	0.021350	-0.003614	-0.010841	10548	0.029100	-0.004926	-0.014777
600	10813	0.015850	-0.002683	-0.008048	10694	0.021800	-0.003690	-0.011070	10530	0.030000	-0.005078	-0.015234
800	10813	0.015850	-0.002683	-0.008048	10689	0.022050	-0.003732	-0.011197	10522	0.030400	-0.005146	-0.015437
1000	10813	0.015850	-0.002683	-0.008048	10683	0.022350	-0.003783	-0.011349	10514	0.030800	-0.005213	-0.015640

50Kpa — SHEAR STRAIN AMPLITUDE (%)

	0.00149				0.0024				0.00518			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	10021	0.055450	-0.009386	-0.028157	10020	0.055500	-0.009394	-0.028182	10016	0.055600	-0.009411	-0.028233
10	10021	0.055450	-0.009386	-0.028157	10019	0.055550	-0.009403	-0.028208	10016	0.055600	-0.009411	-0.028233
15	10021	0.055450	-0.009386	-0.028157	10014	0.055800	-0.009445	-0.028334	10016	0.055600	-0.009411	-0.028233
20	10021	0.055450	-0.009386	-0.028157	10014	0.055800	-0.009445	-0.028334	10016	0.055600	-0.009411	-0.028233
30	10021	0.055450	-0.009386	-0.028157	10014	0.055800	-0.009445	-0.028334	10016	0.055600	-0.009411	-0.028233
50	10021	0.055450	-0.009386	-0.028157	10014	0.055800	-0.009445	-0.028334	10016	0.055600	-0.009411	-0.028233
100	10021	0.055450	-0.009386	-0.028157	10014	0.055800	-0.009445	-0.028334	10016	0.055600	-0.009411	-0.028233
200	10021	0.055450	-0.009386	-0.028157	10014	0.055800	-0.009445	-0.028334	10013	0.055850	-0.009453	-0.028360
400	10020	0.055500	-0.009394	-0.028182	10014	0.055800	-0.009445	-0.028334	10013	0.055850	-0.009453	-0.028360
600	10020	0.055500	-0.009394	-0.028182	10014	0.055800	-0.009445	-0.028334	10013	0.055850	-0.009453	-0.028360
800	10020	0.055500	-0.009394	-0.028182	10014	0.055800	-0.009445	-0.028334	10013	0.055850	-0.009453	-0.028360
1000	10020	0.055500	-0.009394	-0.028182	10014	0.055800	-0.009445	-0.028334	10013	0.055850	-0.009453	-0.028360

	0.01245				0.05162				0.09842			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	10014	0.055800	-0.009445	-0.028334	10012	0.055900	-0.009462	-0.028385	9968	0.058100	-0.009834	-0.029502
10	10014	0.055800	-0.009445	-0.028334	10005	0.056250	-0.009521	-0.028563	9965	0.058250	-0.009860	-0.029579
15	10014	0.055800	-0.009445	-0.028334	10004	0.056300	-0.009529	-0.028588	9964	0.058300	-0.009868	-0.029604
20	10014	0.055800	-0.009445	-0.028334	10002	0.056400	-0.009546	-0.028639	9963	0.058350	-0.009876	-0.029629
30	10013	0.055850	-0.009453	-0.028360	10002	0.056400	-0.009546	-0.028639	9963	0.058350	-0.009876	-0.029629
50	10013	0.055850	-0.009453	-0.028360	10002	0.056400	-0.009546	-0.028639	9962	0.058400	-0.009885	-0.029655
100	10013	0.055850	-0.009453	-0.028360	9990	0.057000	-0.009648	-0.028944	9958	0.058600	-0.009919	-0.029756
200	10013	0.055850	-0.009453	-0.028360	9982	0.057400	-0.009716	-0.029147	9954	0.058800	-0.009953	-0.029858
400	10013	0.055850	-0.009453	-0.028360	9974	0.057800	-0.009783	-0.029350	9944	0.059300	-0.010037	-0.030112
600	10012	0.055900	-0.009462	-0.028385	9970	0.058000	-0.009817	-0.029452	9938	0.059600	-0.010088	-0.030264
800	10012	0.055900	-0.009462	-0.028385	9968	0.058050	-0.009826	-0.029477	9931	0.059950	-0.010147	-0.030442
1000	10012	0.055900	-0.009462	-0.028385	9965	0.058250	-0.009860	-0.029579	9925	0.060250	-0.010198	-0.030594

100Kpa — SHEAR STRAIN AMPLITUDE (%)

	0.001049				0.00252				0.00506			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006
10	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006
15	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006
20	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006
30	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006
50	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006
100	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006
200	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9828	0.065100	-0.011019	-0.033057
400	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9824	0.065300	-0.011053	-0.033158
600	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9824	0.065300	-0.011053	-0.033158
800	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9824	0.065300	-0.011053	-0.033158
1000	9830	0.065000	-0.011002	-0.033006	9830	0.065000	-0.011002	-0.033006	9824	0.065300	-0.011053	-0.033158

	0.011241				0.06763			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	9824	0.065300	-0.011053	-0.033158	9814	0.065800	-0.011137	-0.033412
10	9824	0.065300	-0.011053	-0.033158	9813	0.065850	-0.011146	-0.033438
15	9824	0.065300	-0.011053	-0.033158	9813	0.065850	-0.011146	-0.033438
20	9823	0.065350	-0.011061	-0.033184	9813	0.065850	-0.011146	-0.033438
30	9823	0.065350	-0.011061	-0.033184	9813	0.065850	-0.011146	-0.033438
50	9823	0.065350	-0.011061	-0.033184	9812	0.065900	-0.011154	-0.033463
100	9823	0.065350	-0.011061	-0.033184	9809	0.066050	-0.011180	-0.033539
200	9823	0.065350	-0.011061	-0.033184	9804	0.066300	-0.011222	-0.033666
400	9823	0.065350	-0.011061	-0.033184	9785	0.067250	-0.011383	-0.034149
600	9821	0.065450	-0.011078	-0.033235	9773	0.067850	-0.011484	-0.034453
800	9819	0.065550	-0.011095	-0.033285	9770	0.068000	-0.011510	-0.034529
1000	9814	0.065800	-0.011137	-0.033412	9764	0.068300	-0.011561	-0.034682

DATA SHEET # 4

SAMPLE 1ST#4

INITIAL LENGTH = 5.908 inch

25 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00086	-0.002598	-0.007795	0.000000	0.000000
0.00193	-0.002632	-0.007896	-0.000034	-0.000102
0.00421	-0.002624	-0.007871	0.000008	0.000025
0.01053	-0.002683	-0.008048	-0.000059	-0.000178
0.04439	-0.003783	-0.011349	-0.001100	-0.003301
0.07513	-0.005213	-0.015640	-0.001430	-0.004291

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00149	-0.009394	-0.028182	0.000000	0.000000
0.0024	-0.009445	-0.028335	-0.000051	-0.000153
0.00518	-0.009453	-0.028359	-0.000008	-0.000024
0.01245	-0.009462	-0.028386	-0.000009	-0.000027
0.05162	-0.009860	-0.029580	-0.000398	-0.001194
0.09842	-0.010198	-0.030594	-0.000338	-0.001014

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00105	-0.011002	-0.033006	0.000000	0.000000
0.00252	-0.011002	-0.033006	0.000000	0.000000
0.00506	-0.011053	-0.033159	-0.000051	-0.000153
0.01124	-0.011137	-0.033411	-0.000084	-0.000252
0.06763	-0.011561	-0.034683	-0.000424	-0.001272

DATA SHEET # 1

SAMPLE # 2ST#1

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.86	5.87	2.103	0.335	2.785	0.021823	96.36589	1.5752809	72.18419	0.009065	1.4075079	0.6628559	11980	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
12/29/92	50	55	102	9.803922	11533	5.84765	2.849111	0.021575	2.103	1.3801128	0.000461	0.215195	0.4479	697.27	1473126	70.53328	0.000285

TORSIONAL SHEAR TEST FOR 2ST#1 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.0025	4.125	8.5	0.9957	0.991	40	2.849	5.848	0.1027	4.2118	1.3698E-04	2.6695E-03	1.1498E-01	3.1204E-04	3.4996E+01	1.3110E+06
0.005	4.0625	8	1.999	1.984	40	2.849	5.848	0.2030	7.9360	2.7083E-04	5.2782E-03	2.1665E-01	3.1204E-04	6.5942E+01	1.2493E+06
0.01	4.42	6.06	1.999	4.943	20	2.849	5.848	0.4418	14.9773	5.8933E-04	1.1485E-02	4.0888E-01	3.1203E-04	1.2445E+02	1.0836E+06
0.025	4.72	6.5	4.9595	9.856	20	2.849	5.847	1.1704	32.0320	1.5614E-03	3.0429E-02	8.7447E-01	3.1185E-04	2.6629E+02	8.7509E+05
0.05	4.25	4.84	10	19.71	20	2.848	5.845	2.1250	47.6982	2.8348E-03	5.5246E-02	1.3022E+00	3.1141E-04	3.9694E+02	7.1850E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 2ST#1

DATE: 12/29/92

INITIAL LENGTH= 5.87 Inch
INITIAL LVDT = 11980

STTLMT is in Inches

e0 = 1.4075
V0 = 37.7101 Inch^3

Vs = 15.6643 Inch^3

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00267				0.00528				0.01149				0.03043				0.05525			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11536	0.022200	-0.003782	-0.011346	11503	0.023850	-0.004063	-0.012189
10	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11532	0.022400	-0.003816	-0.011448	11500	0.024000	-0.004089	-0.012266
15	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11531	0.022450	-0.003825	-0.011474	11497	0.024150	-0.004114	-0.012342
20	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11530	0.022500	-0.003833	-0.011499	11493	0.024350	-0.004148	-0.012445
30	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11524	0.022800	-0.003884	-0.011652	11491	0.024450	-0.004165	-0.012496
50	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11524	0.022800	-0.003884	-0.011652	11485	0.024750	-0.004216	-0.012649
100	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11523	0.022850	-0.003893	-0.011678	11482	0.024900	-0.004242	-0.012726
200	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11520	0.023000	-0.003918	-0.011755	11473	0.025350	-0.004319	-0.012956
400	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11514	0.023300	-0.003969	-0.011908	11465	0.025750	-0.004387	-0.013160
600	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11536	0.022200	-0.003782	-0.011346	11512	0.023400	-0.003986	-0.011959	11462	0.025900	-0.004412	-0.013237
800	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11536	0.022200	-0.003782	-0.011346	11509	0.023550	-0.004012	-0.012036	11460	0.026000	-0.004429	-0.013288
1000	11540	0.022000	-0.003748	-0.011244	11540	0.022000	-0.003748	-0.011244	11536	0.022200	-0.003782	-0.011346	11506	0.023700	-0.004037	-0.012112	11453	0.026350	-0.004489	-0.013467

DATA SHEET # 4

SAMPLE 2ST#1

INITIAL LENGTH = 5.87 inch

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00267	-0.003748	-0.011244	0.000000	0.000000
0.00528	-0.003748	-0.011244	0.000000	0.000000
0.01149	-0.003782	-0.011346	-0.000034	-0.000102
0.03043	-0.004037	-0.012111	-0.000255	-0.000765
0.05525	-0.004489	-0.013467	-0.000452	-0.001356

DATA SHEET # 1

SAMPLE # 2ST#2

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.857	5.88	2.129	0.3312	2.855	0.021814	97.59601	1.599309	73.31431	0.008977	1.429976	0.661253	10024	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wa Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
12/31/92	100	80	88	11.36364	9283	5.84295	2.838998	0.021405	2.129	1.384331	0.000463	0.216312	0.44897	599.65	1111752	53.2307	0.000556

TORSIONAL SHEAR TEST FOR 2ST#2 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Confining Pressure = 100 kPa

Estimated Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	2.16	6.125	1.999	1.984	40	2.839	5.843	0.1079	6.0760	1.4400E-04	2.7987E-03	1.6587E-01	3.0756E-04	5.1037E+01	1.8236E+06
0.01	2.57	4.63	1.999	4.943	20	2.839	5.843	0.2569	11.4430	3.4267E-04	6.6599E-03	3.1240E-01	3.0755E-04	9.6124E+01	1.4433E+06
0.025	2.5	4.93	4.9595	9.856	20	2.839	5.842	0.6199	24.2950	8.2700E-04	1.6073E-02	6.6325E-01	3.0744E-04	2.0413E+02	1.2700E+06
0.05	2.03	7.38	10	9.856	20	2.838	5.842	1.0150	36.3686	1.3540E-03	2.6316E-02	9.9286E-01	3.0732E-04	3.0568E+02	1.1616E+06
0.075	1.43	4.88	20	19.71	20	2.838	5.841	1.4300	48.0924	1.9076E-03	3.7075E-02	1.3129E+00	3.0716E-04	4.0437E+02	1.0907E+06

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 2ST#2

DATE: 12/31/92

INITIAL LENGTH= 5.88 Inch
INITIAL LVDT = 10024

STTLMT is in Inches

e0 = 1.43
V0 = 37.6946 Inch^3
Vs = 15.5123 Inch^3

100Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00279				0.00666				0.01607				0.02632				0.03708			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	9283	0.037050	-0.006301	-0.018903	9283	0.037050	-0.006301	-0.018903	9274	0.037500	-0.006378	-0.019133	9263	0.038050	-0.006471	-0.019413	9250	0.038700	-0.006582	-0.019745
10	9283	0.037050	-0.006301	-0.018903	9283	0.037050	-0.006301	-0.018903	9273	0.037550	-0.006386	-0.019158	9263	0.038050	-0.006471	-0.019413	9250	0.038700	-0.006582	-0.019745
15	9283	0.037050	-0.006301	-0.018903	9283	0.037050	-0.006301	-0.018903	9273	0.037550	-0.006386	-0.019158	9263	0.038050	-0.006471	-0.019413	9250	0.038700	-0.006582	-0.019745
20	9283	0.037050	-0.006301	-0.018903	9283	0.037050	-0.006301	-0.018903	9273	0.037550	-0.006386	-0.019158	9263	0.038050	-0.006471	-0.019413	9251	0.038650	-0.006573	-0.019719
30	9283	0.037050	-0.006301	-0.018903	9283	0.037050	-0.006301	-0.018903	9273	0.037550	-0.006386	-0.019158	9263	0.038050	-0.006471	-0.019413	9251	0.038650	-0.006573	-0.019719
50	9283	0.037050	-0.006301	-0.018903	9283	0.037050	-0.006301	-0.018903	9273	0.037550	-0.006386	-0.019158	9263	0.038050	-0.006471	-0.019413	9250	0.038700	-0.006582	-0.019745
100	9283	0.037050	-0.006301	-0.018903	9283	0.037050	-0.006301	-0.018903	9273	0.037550	-0.006386	-0.019158	9262	0.038100	-0.006480	-0.019439	9250	0.038700	-0.006582	-0.019745
200	9283	0.037050	-0.006301	-0.018903	9283	0.037050	-0.006301	-0.018903	9273	0.037550	-0.006386	-0.019158	9261	0.038150	-0.006488	-0.019464	9250	0.038700	-0.006582	-0.019745
400	9283	0.037050	-0.006301	-0.018903	9283	0.037050	-0.006301	-0.018903	9273	0.037550	-0.006386	-0.019158	9258	0.038300	-0.006514	-0.019541	9243	0.039050	-0.006641	-0.019923
600	9283	0.037050	-0.006301	-0.018903	9278	0.037300	-0.006344	-0.019031	9270	0.037700	-0.006412	-0.019235	9254	0.038500	-0.006548	-0.019643	9234	0.039500	-0.006718	-0.020153
800	9283	0.037050	-0.006301	-0.018903	9276	0.037400	-0.006361	-0.019082	9266	0.037900	-0.006446	-0.019337	9250	0.038700	-0.006582	-0.019745	9230	0.039700	-0.006752	-0.020255
1000	9283	0.037050	-0.006301	-0.018903	9276	0.037400	-0.006361	-0.019082	9266	0.037900	-0.006446	-0.019337	9250	0.038700	-0.006582	-0.019745	9222	0.040100	-0.006820	-0.020459

DATA SHEET # 4

SAMPLE 2ST#2

INITIAL LENGTH = 5.88 inch

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00279	-0.006301	-0.018903	0.000000	0.000000
0.00666	-0.006361	-0.019083	-0.000060	-0.000180
0.01607	-0.006446	-0.019338	-0.000085	-0.000255
0.02632	-0.006582	-0.019746	-0.000136	-0.000408
0.03708	-0.006819	-0.020457	-0.000237	-0.000711

DATA SHEET # 1

SAMPLE # 2ST#3

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.881	5.786	2.001	0.3887	2.79	0.021828	91.67193	1.440916	66.01277	0.0082766	1.637308	0.6623512	8149	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
1/5/93	25	57	71	14.08451	7918	5.77445	2.875249	0.0216974	2.001	1.6215458	0.000446	0.208532	0.44137	486.37	678137.2	32.46921	0.000623
1/6/93	50	58	85	11.76471	7724	5.76475	2.870419	0.0215882	2.001	1.6083569	0.000445	0.207832	0.44068	582.20	976624.9	46.7608	0.000442
1/8/93	100	69	98	10.20408	7430	5.75005	2.8631	0.0214235	2.001	1.5884539	0.000443	0.206774	0.43963	671.13	1307745	62.61482	0.000396

TORSIONAL SHEAR TEST FOR 2ST#3 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.0025	2.13	4.1	0.9957	0.991	40	2.875	5.775	0.0530	2.0316	7.0730E-05	1.4087E-03	5.5461E-02	3.2362E-04	1.6426E+01	1.1660E+06
0.005	4.34	7.53	0.9957	0.991	40	2.875	5.775	0.1080	3.7311	1.4412E-04	2.8704E-03	1.0186E-01	3.2362E-04	3.0167E+01	1.0510E+06
0.01	4.79	7.25	1.999	1.984	40	2.875	5.775	0.2394	7.1920	3.1933E-04	6.3602E-03	1.9634E-01	3.2362E-04	5.8149E+01	9.1427E+05
0.025	2.53	6.09	4.9595	4.943	20	2.875	5.775	0.6274	15.0514	8.3692E-04	1.6669E-02	4.1090E-01	3.2355E-04	1.2171E+02	7.3019E+05
0.05	2.31	4.63	10	9.856	20	2.875	5.775	1.155	22.81664	1.5408E-03	3.0688E-02	6.2289E-01	3.2338E-04	1.8458E+02	6.0149E+05
0.1	4.875	7.69	10	9.856	20	2.875	5.775	2.4375	37.89632	3.2516E-03	6.4763E-02	1.0346E+00	3.2280E-04	3.0698E+02	4.7401E+05

Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	2.81	5.43	1.999	1.984	40	2.870	5.765	0.1404	5.3866	1.8733E-04	3.7311E-03	1.4705E-01	3.2141E-04	4.3777E+01	1.1733E+06
0.01	2.29	4.125	4.9595	4.943	40	2.870	5.765	0.2839	10.1949	3.7876E-04	7.5439E-03	2.7832E-01	3.2140E-04	8.2856E+01	1.0983E+06
0.025	2.85	8.75	4.9595	4.943	20	2.870	5.765	0.7067	21.6256	9.4278E-04	1.8777E-02	5.9038E-01	3.2133E-04	1.7578E+02	9.3615E+05
0.05	2.39	6.65	10	9.856	20	2.870	5.765	1.1950	32.7712	1.5941E-03	3.1750E-02	8.9465E-01	3.2116E-04	2.6649E+02	8.3932E+05
0.075	3.48	8.84	10	9.856	20	2.870	5.765	1.74	43.56352	2.3212E-03	4.6231E-02	1.1893E+00	3.2086E-04	3.5449E+02	7.6680E+05

Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	1.8	7.3	1.999	1.984	20	2.863	5.750	0.1799	7.2416	2.4000E-04	4.7801E-03	1.9770E-01	3.1818E-04	5.9300E+01	1.2406E+06
0.01	3.5	5.53	1.999	4.943	20	2.863	5.750	0.3498	13.6674	4.6667E-04	9.2946E-03	3.7312E-01	3.1818E-04	1.1192E+02	1.2041E+06
0.025	3.22	5.9	4.9595	9.856	20	2.863	5.750	0.7985	29.0752	1.0652E-03	2.1215E-02	7.9375E-01	3.1816E-04	2.3810E+02	1.1223E+06
0.05	5.19	8.9	4.9595	9.856	20	2.863	5.749	1.2870	43.8592	1.7168E-03	3.4194E-02	1.1974E+00	3.1799E-04	3.5931E+02	1.0508E+06

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 2ST#3

DATE: 01/05/93

INITIAL LENGTH= 5.786 inch
INITIAL LVDT = 8149

STTLMT is in inches

e0 = 1.6373
V0 = 37.7168 inch^3 Vs = 14.3019 inch^3

25Kpa	SHEAR STRAIN AMPLITUDE (%)																							
	0.00141				0.00287				0.00636				0.01667				0.03069				0.06476			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7910	0.011950	-0.002065	-0.006196	7888	0.013050	-0.002255	-0.006766
10	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7921	0.011400	-0.001970	-0.005911	7909	0.012000	-0.002074	-0.006222	7866	0.014150	-0.002446	-0.007337
15	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7920	0.011450	-0.001979	-0.005937	7909	0.012000	-0.002074	-0.006222	7862	0.014350	-0.002480	-0.007440
20	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7919	0.011500	-0.001988	-0.005963	7906	0.012150	-0.002100	-0.006300	7859	0.014500	-0.002506	-0.007518
30	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7918	0.011550	-0.001996	-0.005989	7905	0.012200	-0.002109	-0.006326	7855	0.014700	-0.002541	-0.007622
50	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7916	0.011650	-0.002013	-0.006040	7904	0.012250	-0.002117	-0.006352	7850	0.014950	-0.002584	-0.007751
100	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7916	0.011650	-0.002013	-0.006040	7902	0.012350	-0.002134	-0.006403	7845	0.015200	-0.002627	-0.007881
200	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7914	0.011750	-0.002031	-0.006092	7894	0.012750	-0.002204	-0.006611	7840	0.015450	-0.002670	-0.008011
400	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7913	0.011800	-0.002039	-0.006118	7892	0.012850	-0.002221	-0.006663	7835	0.015700	-0.002713	-0.008140
600	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7910	0.011950	-0.002065	-0.006196	7892	0.012850	-0.002221	-0.006663	7833	0.015800	-0.002731	-0.008192
800	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7910	0.011950	-0.002065	-0.006196	7890	0.012950	-0.002238	-0.006714	7830	0.015950	-0.002757	-0.008270
1000	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7922	0.011350	-0.001962	-0.005885	7910	0.011950	-0.002065	-0.006196	7888	0.013050	-0.002255	-0.006766	7825	0.016200	-0.002800	-0.008400

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00373				0.00754				0.01876				0.03175				0.04623			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	7724	0.021250	-0.003673	-0.011018	7724	0.021250	-0.003673	-0.011018	7721	0.021400	-0.003699	-0.011096	7709	0.022000	-0.003802	-0.011407	7683	0.023300	-0.004027	-0.012081
10	7724	0.021250	-0.003673	-0.011018	7724	0.021250	-0.003673	-0.011018	7721	0.021400	-0.003699	-0.011096	7709	0.022000	-0.003802	-0.011407	7683	0.023300	-0.004027	-0.012081
15	7724	0.021250	-0.003673	-0.011018	7724	0.021250	-0.003673	-0.011018	7720	0.021450	-0.003707	-0.011122	7709	0.022000	-0.003802	-0.011407	7683	0.023300	-0.004027	-0.012081
20	7724	0.021250	-0.003673	-0.011018	7724	0.021250	-0.003673	-0.011018	7720	0.021450	-0.003707	-0.011122	7709	0.022000	-0.003802	-0.011407	7683	0.023300	-0.004027	-0.012081
30	7724	0.021250	-0.003673	-0.011018	7724	0.021250	-0.003673	-0.011018	7720	0.021450	-0.003707	-0.011122	7709	0.022000	-0.003802	-0.011407	7682	0.023350	-0.004036	-0.012107
50	7724	0.021250	-0.003673	-0.011018	7723	0.021300	-0.003681	-0.011044	7719	0.021500	-0.003716	-0.011148	7706	0.022150	-0.003828	-0.011485	7682	0.023350	-0.004036	-0.012107
100	7724	0.021250	-0.003673	-0.011018	7723	0.021300	-0.003681	-0.011044	7716	0.021650	-0.003742	-0.011225	7702	0.022350	-0.003863	-0.011588	7675	0.023700	-0.004096	-0.012288
200	7724	0.021250	-0.003673	-0.011018	7723	0.021300	-0.003681	-0.011044	7715	0.021700	-0.003750	-0.011251	7702	0.022350	-0.003863	-0.011588	7672	0.023850	-0.004122	-0.012366
400	7724	0.021250	-0.003673	-0.011018	7723	0.021300	-0.003681	-0.011044	7714	0.021750	-0.003759	-0.011277	7696	0.022650	-0.003915	-0.011744	7670	0.023950	-0.004139	-0.012418
600	7724	0.021250	-0.003673	-0.011018	7723	0.021300	-0.003681	-0.011044	7713	0.021800	-0.003768	-0.011303	7693	0.022800	-0.003941	-0.011822	7665	0.024200	-0.004183	-0.012548
800	7724	0.021250	-0.003673	-0.011018	7722	0.021350	-0.003690	-0.011070	7713	0.021800	-0.003768	-0.011303	7691	0.022900	-0.003958	-0.011873	7662	0.024350	-0.004208	-0.012625
1000	7724	0.021250	-0.003673	-0.011018	7722	0.021350	-0.003690	-0.011070	7712	0.021850	-0.003776	-0.011329	7685	0.023200	-0.004010	-0.012029	7658	0.024550	-0.004243	-0.012729

100Kpa	SHEAR STRAIN AMPLITUDE (%)															
	0.00478				0.00929				0.02121				0.03419			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	7434	0.035750	[illegible]	-0.018536	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7424	0.036250	-0.006265	-0.018795
10	7434	0.035750	[illegible]	-0.018536	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7423	0.036300	-0.006274	-0.018821
15	7434	0.035750	-0.006179	-0.018536	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7422	0.036350	-0.006282	-0.018847
20	7434	0.035750	-0.006179	-0.018536	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7422	0.036350	-0.006282	-0.018847
30	7434	0.035750	-0.006179	-0.018536	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7422	0.036350	-0.006282	-0.018847
50	7434	0.035750	-0.006179	-0.018536	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7422	0.036350	-0.006282	-0.018847
100	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7420	0.036450	-0.006300	-0.018899
200	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7418	0.036550	-0.006317	-0.018951
400	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7432	0.035850	-0.006196	-0.018588	7414	0.036750	-0.006352	-0.019055
600	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7430	0.035950	-0.006213	-0.018640	7410	0.036950	-0.006386	-0.019158
800	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7428	0.036050	-0.006231	-0.018692	7405	0.037200	-0.006429	-0.019288
1000	7433	0.035800	-0.006187	-0.018562	7433	0.035800	-0.006187	-0.018562	7426	0.036150	-0.006248	-0.018744	7395	0.037700	-0.006516	-0.019547

DATA SHEET # 4

SAMPLE 2ST#3

INITIAL LENGTH = 5.786 inch

25 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00141	-0.001962	-0.005886	0.000000	0.000000
0.00287	-0.001962	-0.005886	0.000000	0.000000
0.00636	-0.001962	-0.005886	0.000000	0.000000
0.01667	-0.002065	-0.006195	-0.000103	-0.000309
0.03069	-0.002255	-0.006765	-0.000190	-0.000570
0.06476	-0.002799	-0.008397	-0.000544	-0.001632

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00373	-0.003673	-0.011019	0.000000	0.000000
0.00754	-0.003689	-0.011067	-0.000016	-0.000048
0.01878	-0.003776	-0.011329	-0.000087	-0.000262
0.03175	-0.004009	-0.012027	-0.000233	-0.000698
0.04623	-0.004243	-0.012729	-0.000234	-0.000702

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00478	-0.006187	-0.018561	0.000000	0.000000
0.00929	-0.006187	-0.018561	0.000000	0.000000
0.02121	-0.006248	-0.018744	-0.000061	-0.000183
0.03419	-0.006516	-0.019548	-0.000268	-0.000804

DATA SHEET # 1

SAMPLE # 2ST#5

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.852	5.706	2.1914	0.1476	2.6	0.021095	103.8831	1.90955	90.52208	0.01177.	0.79227	0.48438	7072	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wa' Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
5/27/93	50	37	122	8.196721	6674	5.6861	2.842053	0.020875	2.1914	0.773583	0.000478	0.223132	0.4555	797.41	2074981	99.35011	0.000138
5/31/93	100	38.9	138	7.246377	6412	5.673	2.835506	0.020731	2.1914	0.761353	0.000475	0.222105	0.45463	901.64	2671253	127.8996	0.000113

TORSIONAL SHEAR TEST FOR 2ST#5 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 5/28/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.0025	4.4667	6.1	0.9957	1.984	40	2.842	5.686	0.1112	6.0512	1.4832E-04	2.9654E-03	1.6520E-01	3.0882E-04	50.6742	1.7088E+06
0.005	4.81667	4.4	1.999	4.943	40	2.842	5.686	0.2407	10.8746	3.2111E-04	6.4200E-03	2.9688E-01	3.0878E-04	91.0739	1.4186E+06
0.01	2.95	6.1	4.9595	4.943	40	2.842	5.685	0.3658	15.0762	4.8793E-04	9.7551E-03	4.1158E-01	3.0874E-04	126.2750	1.2944E+06
0.025	4.6667	6.2	4.9595	9.856	20	2.841	5.683	1.1572	30.5536	1.5437E-03	3.0864E-02	8.3411E-01	3.0831E-04	256.1778	8.3002E+05
0.05	2.934	4.15	10	19.71	20	2.839	5.681	1.4670	40.8983	1.9570E-03	3.9126E-02	1.1165E+00	3.0778E-04	343.3573	8.7757E+05

Date : 5/31/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.3	4.45	1.999	4.943	40	2.835	5.672	0.1649	10.9982	2.2000E-04	4.3985E-03	3.0025E-01	3.0593E-04	92.7522	2.1087E+06
0.01	2.95	8.35	4.9595	4.943	40	2.835	5.672	0.3658	20.6370	4.8793E-04	9.7551E-03	5.6339E-01	3.0579E-04	174.1011	1.7847E+06
0.025	3.86417	8.9	4.9595	9.856	20	2.834	5.669	0.9582	43.8592	1.2783E-03	2.5556E-02	1.1974E+00	3.0529E-04	370.4622	1.4496E+06

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 2ST#5

DATE: 05/27/93

INITIAL LENGTH= 5.706 inch
INITIAL LVDT = 7072

STTLMT is in inches

e0= 0.79227
V0= 36.4519 Inch^3 Vs= 20.3384 Inch^3

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00297				0.00642				0.00976				0.03086				0.03913			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	6672	0.020232	-0.003546	-0.010637	6672	0.020232	-0.003546	-0.010637	6669	0.020384	-0.003572	-0.010717	6659	0.020889	-0.003661	-0.010983	6605	0.023621	-0.004140	-0.012419
10	6672	0.020232	-0.003546	-0.010637	6672	0.020232	-0.003546	-0.010637	6669	0.020384	-0.003572	-0.010717	6654	0.021142	-0.003705	-0.011116	6604	0.023671	-0.004149	-0.012446
15	6672	0.020232	-0.003546	-0.010637	6672	0.020232	-0.003546	-0.010637	6669	0.020384	-0.003572	-0.010717	6646	0.021547	-0.003776	-0.011329	6603	0.023722	-0.004157	-0.012472
20	6672	0.020232	-0.003546	-0.010637	6672	0.020232	-0.003546	-0.010637	6669	0.020384	-0.003572	-0.010717	6643	0.021699	-0.003803	-0.011408	6600	0.023874	-0.004184	-0.012552
30	6672	0.020232	-0.003546	-0.010637	6672	0.020232	-0.003546	-0.010637	6669	0.020384	-0.003572	-0.010717	6635	0.022103	-0.003874	-0.011621	6596	0.024076	-0.004219	-0.012658
50	6672	0.020232	-0.003546	-0.010637	6672	0.020232	-0.003546	-0.010637	6669	0.020384	-0.003572	-0.010717	6632	0.022255	-0.003900	-0.011701	6592	0.024278	-0.004255	-0.012765
100	6672	0.020232	-0.003546	-0.010637	6672	0.020232	-0.003546	-0.010637	6666	0.020535	-0.003589	-0.010797	6624	0.022660	-0.003971	-0.011914	6586	0.024582	-0.004308	-0.012924
200	6672	0.020232	-0.003546	-0.010637	6672	0.020232	-0.003546	-0.010637	6664	0.020637	-0.003617	-0.010850	6618	0.022963	-0.004024	-0.012073	6568	0.025492	-0.004468	-0.013403
400	6672	0.020232	-0.003546	-0.010637	6670	0.020333	-0.003563	-0.010690	6663	0.020687	-0.003626	-0.010877	6610	0.023368	-0.004095	-0.012286	6563	0.025745	-0.004512	-0.013536
600	6672	0.020232	-0.003546	-0.010637	6670	0.020333	-0.003563	-0.010690	6663	0.020687	-0.003626	-0.010877	6605	0.023621	-0.004140	-0.012419	6555	0.026150	-0.004583	-0.013749
800	6672	0.020232	-0.003546	-0.010637	6670	0.020333	-0.003563	-0.010690	6661	0.020788	-0.003643	-0.010930	6604	0.023671	-0.004149	-0.012446	6552	0.026302	-0.004609	-0.013828
1000	6672	0.020232	-0.003546	-0.010637	6666	0.020535	-0.003599	-0.010797	6661	0.020788	-0.003643	-0.010930	6593	0.024228	-0.004246	-0.012738	6550	0.026403	-0.004627	-0.013882

100Kpa	SHEAR STRAIN AMPLITUDE (%)											
	0.00439				0.00976				0.02556			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	6412	0.033383	-0.005850	-0.017551	6406	0.033686	-0.005904	-0.017711	6385	0.034748	-0.006090	-0.018269
10	6412	0.033383	-0.005850	-0.017551	6406	0.033686	-0.005904	-0.017711	6373	0.035355	-0.006196	-0.018589
15	6412	0.033383	-0.005850	-0.017551	6406	0.033686	-0.005904	-0.017711	6372	0.035406	-0.006205	-0.018615
20	6412	0.033383	-0.005850	-0.017551	6406	0.033686	-0.005904	-0.017711	6370	0.035507	-0.006223	-0.018668
30	6411	0.033433	-0.005859	-0.017578	6405	0.033737	-0.005913	-0.017738	6368	0.035608	-0.006240	-0.018721
50	6410	0.033484	-0.005868	-0.017605	6404	0.033787	-0.005921	-0.017764	6362	0.035912	-0.006294	-0.018881
100	6410	0.033484	-0.005868	-0.017605	6404	0.033787	-0.005921	-0.017764	6352	0.036418	-0.006382	-0.019147
200	6409	0.033534	-0.005877	-0.017631	6393	0.034344	-0.006019	-0.018057	6343	0.036873	-0.006462	-0.019386
400	6409	0.033534	-0.005877	-0.017631	6391	0.034445	-0.006037	-0.018110	6332	0.037429	-0.006560	-0.019679
600	6406	0.033686	-0.005904	-0.017711	6390	0.034495	-0.006045	-0.018136	6323	0.037884	-0.006639	-0.019918
800	6406	0.033686	-0.005904	-0.017711	6386	0.034698	-0.006081	-0.018243	6320	0.038036	-0.006666	-0.019998
1000	6405	0.033737	-0.005913	-0.017738	6385	0.034748	-0.006090	-0.018269	6315	0.038289	-0.006710	-0.020131

DATA SHEET # 4

SAMPLE 2ST#5

INITIAL LENGTH = 5.706 inch

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST..	Evol	VERT. ST.	Evol
0.00297	-0.003546	-0.010638	0.000000	0.000000
0.00642	-0.003599	-0.010797	-0.000053	-0.000159
0.00976	-0.003643	-0.010930	-0.000044	-0.000133
0.03086	-0.004246	-0.012738	-0.000603	-0.001808
0.03913	-0.004627	-0.013882	-0.000381	-0.001144

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00439	-0.005913	-0.017738	-0.000013	-0.000038
0.00976	-0.006090	-0.018269	-0.000177	-0.000532
0.02556	-0.006710	-0.020131	-0.000620	-0.001861

DATA SHEET # 1

SAMPLE # 2ST#7

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.8263	5.6665	2.0465	0.126	2.6	0.020573	99.47514	1.817496	88.34382	0.011203	0.8364612	0.3916499	5819	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
6/3/93	25	57	97	10.30928	5630	5.65705	2.821587	0.02047	2.0465	0.8272886	0.00044	0.205387	0.43825	655.60	1335717	63.95411	0.000334
6/4/93	50	57	110	9.090909	5371	5.6441	2.815127	0.02033	2.0465	0.8147683	0.000438	0.204448	0.43732	743.34	1729007	82.78484	0.00026
6/8/93	100	42	124	8.064516	5122	5.63165	2.808918	0.020196	2.0465	0.8027855	0.000436	0.203547	0.43642	837.82	2211073	105.8662	0.000151

TORSIONAL SHEAR TEST FOR 2ST#7 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 6/3/93
Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	5.4167	7.15	1.999	1.984	40	2.821	5.657	0.2707	7.0928	3.6111E-04	7.2045E-03	1.9363E-01	2.9998E-04	6.0704E+01	8.4258E+05
0.01	2.533	3.25	4.9595	4.943	40	2.821	5.656	0.3141	8.0324	4.1896E-04	8.3586E-03	2.1928E-01	2.9994E-04	6.8753E+01	8.2254E+05
0.025	4.883	4	10	9.856	40	2.821	5.655	1.2208	19.7120	1.6285E-03	3.2490E-02	5.3814E-01	2.9965E-04	1.6885E+02	5.1970E+05
0.05	3.27	4.9	10	9.856	20	2.820	5.653	1.6350	24.1472	2.1811E-03	4.3515E-02	6.5922E-01	2.9928E-04	2.0703E+02	4.7577E+05
0.1	3.75	4.1	1.999	19.71	2	2.818	5.650	3.748125	40.4055	5.0000E-03	9.9755E-02	1.1031E+00	2.9860E-04	3.4701E+02	3.4786E+05

Date : 6/4/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.4	8.25	1.999	1.984	40	2.815	5.644	0.2199	8.1840	2.9333E-04	5.8523E-03	2.2342E-01	2.9732E-04	7.0514E+01	1.2049E+06
0.01	3.3	5.25	4.9595	4.943	40	2.815	5.644	0.4092	12.9754	5.4582E-04	1.0890E-02	3.5423E-01	2.9727E-04	1.1181E+02	1.0267E+06
0.025	3.775	4.65	4.9595	9.856	20	2.815	5.643	0.9361	22.9152	1.2488E-03	2.4914E-02	6.2558E-01	2.9719E-04	1.9750E+02	7.9274E+05
0.05	2.79167	6.2	10	9.856	20	2.814	5.643	1.3958	30.5536	1.8620E-03	3.7150E-02	8.3411E-01	2.9706E-04	2.6342E+02	7.0908E+05
0.075	2.733	4.95	1.999	19.71	2	2.814	5.641	2.7316	48.7823	3.6440E-03	7.2701E-02	1.3318E+00	2.9676E-04	4.2090E+02	5.7894E+05

Date : 6/8/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.7667	3.84	1.999	4.943	40	2.809	5.632	0.1882	9.4906	2.5111E-04	5.0099E-03	2.5909E-01	2.9473E-04	8.2309E+01	1.6429E+06
0.01	2.9667	6.5	4.9595	4.943	40	2.809	5.631	0.3678	16.0648	4.9069E-04	9.7897E-03	4.3857E-01	2.9469E-04	1.3934E+02	1.4233E+06
0.025	3.9	6.625	4.9595	9.856	20	2.808	5.631	0.9671	32.6480	1.2901E-03	2.5739E-02	8.9129E-01	2.9451E-04	2.8330E+02	1.1007E+06
0.05	3.1833	4.75	10	19.71	20	2.808	5.629	1.5917	46.8113	2.1233E-03	4.2361E-02	1.2779E+00	2.9418E-04	4.0654E+02	9.5971E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 2ST#7

DATE: 06/01/93

INITIAL LENGTH= 5.6665 inch
INITIAL LVDT = 5819

STTLMT is in inches

e0= 0.836461
V0= 35.5501 inch^3
Vs= 19.35784 inch^3

25Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.0072				0.00836				0.03249				0.04352				0.09976			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	5624	0.009863	-0.001741	-0.005222	5621	0.010015	-0.001767	-0.005302	5620	0.010065	-0.001776	-0.005329	5564	0.012898	-0.002276	-0.006828	5549	0.013657	-0.002410	-0.007230
10	5624	0.009863	-0.001741	-0.005222	5621	0.010015	-0.001767	-0.005302					5564	0.012898	-0.002276	-0.006828	5513	0.015477	-0.002731	-0.008194
15	5624	0.009863	-0.001741	-0.005222	5621	0.010015	-0.001767	-0.005302					5564	0.012898	-0.002276	-0.006828	5503	0.015983	-0.002821	-0.008462
20	5624	0.009863	-0.001741	-0.005222	5621	0.010015	-0.001767	-0.005302					5563	0.012948	-0.002285	-0.006855	5501	0.016084	-0.002839	-0.008516
30	5624	0.009863	-0.001741	-0.005222	5621	0.010015	-0.001767	-0.005302	5592	0.011482	-0.002026	-0.006079	5563	0.012948	-0.002285	-0.006855	5492	0.016540	-0.002919	-0.008757
60	5624	0.009863	-0.001741	-0.005222	5621	0.010015	-0.001767	-0.005302	5584	0.011886	-0.002098	-0.006293	5563	0.012948	-0.002285	-0.006855	5472	0.017551	-0.003097	-0.009292
100	5623	0.009914	-0.001750	-0.005249	5621	0.010015	-0.001767	-0.005302	5580	0.012089	-0.002133	-0.006400	5562	0.012999	-0.002294	-0.006882	5466	0.017855	-0.003151	-0.009453
200	5624	0.009863	-0.001741	-0.005222	5621	0.010015	-0.001767	-0.005302	5573	0.012443	-0.002196	-0.006587	5559	0.013151	-0.002321	-0.006962	5456	0.018361	-0.003240	-0.009721
400	5622	0.009964	-0.001758	-0.005275	5620	0.010065	-0.001776	-0.005329	5570	0.012594	-0.002223	-0.006668	5554	0.013404	-0.002365	-0.007096	5450	0.018664	-0.003294	-0.009881
600	5622	0.009964	-0.001758	-0.005275	5620	0.010065	-0.001776	-0.005329	5565	0.012847	-0.002267	-0.006802	5553	0.013454	-0.002374	-0.007123	5448	0.018765	-0.003312	-0.009935
800	5621	0.010015	-0.001767	-0.005302	5616	0.010268	-0.001812	-0.005436	5563	0.012948	-0.002285	-0.006855	5550	0.013606	-0.002401	-0.007203	5443	0.019018	-0.003356	-0.010069
1000	5621	0.010015	-0.001767	-0.005302	5616	0.010268	-0.001812	-0.005436	5562	0.012999	-0.002294	-0.006882	5549	0.013657	-0.002410	-0.007230	5438	0.019271	-0.003401	-0.010203

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00585				0.01089				0.02491				0.03715				0.0727			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	5374	0.022508	-0.003972	-0.011916	5372	0.022609	-0.003990	-0.011970	5369	0.022761	-0.004017	-0.012050	5354	0.023520	-0.004151	-0.012452	5350	0.023722	-0.004186	-0.012559
30	5373	0.022559	-0.003981	-0.011943	5371	0.022660	-0.003999	-0.011997	5364	0.023014	-0.004061	-0.012184	5354	0.023520	-0.004151	-0.012452	5335	0.024481	-0.004320	-0.012961
60	5373	0.022559	-0.003981	-0.011943	5371	0.022660	-0.003999	-0.011997	5363	0.023064	-0.004070	-0.012211	5353	0.023570	-0.004160	-0.012479	5331	0.024683	-0.004356	-0.013068
100	5373	0.022559	-0.003981	-0.011943	5370	0.022710	-0.004008	-0.012023	5364	0.023014	-0.004061	-0.012184	5352	0.023621	-0.004169	-0.012506	5326	0.024936	-0.004401	-0.013202
200	5373	0.022559	-0.003981	-0.011943	5370	0.022710	-0.004008	-0.012023	5362	0.023115	-0.004079	-0.012238	5350	0.023722	-0.004186	-0.012559	5321	0.025189	-0.004445	-0.013336
400	5372	0.022609	-0.003990	-0.011970	5369	0.022761	-0.004017	-0.012050	5360	0.023216	-0.004097	-0.012291	5345	0.023975	-0.004231	-0.012693	5312	0.025644	-0.004526	-0.013577
600	5372	0.022609	-0.003990	-0.011970	5369	0.022761	-0.004017	-0.012050	5354	0.023520	-0.004151	-0.012452	5344	0.024025	-0.004240	-0.012720	5304	0.026049	-0.004597	-0.013791
800	5372	0.022609	-0.003990	-0.011970	5369	0.022761	-0.004017	-0.012050	5354	0.023520	-0.004151	-0.012452	5344	0.024025	-0.004240	-0.012720	5295	0.026504	-0.004677	-0.014032
1000	5372	0.022609	-0.003990	-0.011970	5366	0.022913	-0.004044	-0.012131	5353	0.023570	-0.004160	-0.012479	5344	0.024025	-0.004240	-0.012720	5292	0.026656	-0.004704	-0.014112

100Kpa	SHEAR STRAIN AMPLITUDE (%)															
	0.00501				0.00979				0.02574				0.04236			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	5130	0.034850	-0.006150	-0.018450	5129	0.034900	-0.006159	-0.018477	5124	0.035153	-0.006204	-0.018611	5103	0.036215	-0.006391	-0.019173
30	5129	0.034900	-0.006159	-0.018477	5129	0.034900	-0.006159	-0.018477	5121	0.035305	-0.006230	-0.018691	5095	0.036620	-0.006463	-0.019388
60	5129	0.034900	-0.006159	-0.018477	5129	0.034900	-0.006159	-0.018477	5116	0.035558	-0.006275	-0.018825	5092	0.036772	-0.006489	-0.019468
100	5129	0.034900	-0.006159	-0.018477	5129	0.034900	-0.006159	-0.018477	5113	0.035709	-0.006302	-0.018906	5090	0.036873	-0.006507	-0.019521
200	5129	0.034900	-0.006159	-0.018477	5129	0.034900	-0.006159	-0.018477	5112	0.035760	-0.006311	-0.018932	5083	0.037227	-0.006570	-0.019709
400	5129	0.034900	-0.006159	-0.018477	5126	0.035052	-0.006186	-0.018557	5106	0.036063	-0.006364	-0.019093	5070	0.037884	-0.006686	-0.020057
600	5129	0.034900	-0.006159	-0.018477	5125	0.035102	-0.006195	-0.018584	5104	0.036165	-0.006382	-0.019147	5062	0.038289	-0.006757	-0.020271
800	5129	0.034900	-0.006159	-0.018477	5124	0.035153	-0.006204	-0.018611	5095	0.036620	-0.006463	-0.019388	5056	0.038592	-0.006811	-0.020432
1000	5129	0.034900	-0.006159	-0.018477	5123	0.035204	-0.006213	-0.018638	5094	0.036670	-0.006471	-0.019414	5053	0.038744	-0.006837	-0.020512

DATA SHEET # 4

SAMPLE 2ST#7

INITIAL LENGTH = 5.667 inch

25 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.0072	-0.001767	-0.005301	0.000000	0.000000
0.00836	-0.001812	-0.005436	-0.000045	-0.000135
0.03249	-0.002294	-0.006882	-0.000482	-0.001446
0.04352	-0.002410	-0.007230	-0.000116	-0.000348
0.09976	-0.003401	-0.010203	-0.000991	-0.002972

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00585	-0.003990	-0.011970	0.000000	0.000000
0.01089	-0.004044	-0.012131	-0.000054	-0.000161
0.02491	-0.004160	-0.012479	-0.000116	-0.000348
0.03715	-0.004240	-0.012720	-0.000080	-0.000241
0.0727	-0.004704	-0.014112	-0.000464	-0.001392

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00501	-0.006159	-0.018477	0.000000	0.000000
0.00979	-0.006213	-0.018639	-0.000054	-0.000162
0.02574	-0.006471	-0.019413	-0.000258	-0.000774
0.04236	-0.006837	-0.020511	-0.000366	-0.001098

DATA SHEET # 1

SAMPLE # 2ST#8

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.83133	5.817	2.11883	0.1499	2.6	0.021195	99.97014	1.842621	86.93811	0.011357	0.866155	0.449966	8465	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wa' Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
6/10/93	100	36	118	8.474576	7713	5.7794	2.813029	0.020786	2.11883	0.830201	0.000452	0.211358	0.44416	803.94	2047931	98.05493	0.000139
6/11/93	50	36	109	9.174312	7762	5.78185	2.814221	0.020813	2.11883	0.83253	0.000453	0.211538	0.44433	742.65	1745371	83.56838	0.000163

TORSIONAL SHEAR TEST FOR 2ST#8 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 6/10/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.5	3.55	1.999	4.943	40	2.813	5.779	0.1749	8.7738	2.3333E-04	4.5428E-03	2.3953E-01	2.9631E-04	7.5789E+01	1.6683E+06
0.01	2.7333	6.1	4.9595	4.943	40	2.812	5.778	0.3389	15.0762	4.5209E-04	8.8018E-03	4.1158E-01	2.9622E-04	1.3026E+02	1.4799E+06
0.025	3.9	6.5	4.9595	9.856	20	2.812	5.777	0.9671	32.0320	1.2901E-03	2 5118E-02	8.7447E-01	2.9589E-04	2.7699E+02	1.1028E+06
0.04	3.24375	4.725	10	19.71	20	2.810	5.774	1.6219	46.5649	2.1636E-03	4.2124E-02	1.2712E+00	2.9528E-04	4.0328E+02	9.5737E+05

Date : 6/11/93
Confining Pressure = 50 kPa (after 100 kPa)

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.0875	8.15	1.999	1.984	40	2.812	5.776	0.2043	8.0848	2.7250E-04	5.3054E-03	2.2072E-01	2.9587E-04	6.9915E+01	1.3178E+06
0.01	3.2125	5.25	4.9595	4.943	40	2.812	5.776	0.3983	12.9754	5.3135E-04	1.0345E-02	3.5423E-01	2.9586E-04	1.1221E+02	1.0847E+06
0.025	4.34375	5.21	4.9595	9.856	20	2.812	5.777	1.0771	25.6749	1.4369E-03	2.7976E-02	7.0092E-01	2.9587E-04	2.2203E+02	7.9364E+05
0.05	4.075	8.1	0.9957	9.856	2	2.811	5.776	2.0287	39.9168	2.7063E-03	5.2691E-02	1.0897E+00	2.9581E-04	3.4523E+02	6.5521E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 2ST#8

DATE: 06/10/93

INITIAL LENGTH= 5.817 inch
INITIAL LVDT = 8465

STTLMT is in inches

e0= 0.866155
V0= 36.6236 inch^3
Vs= 19.625165 inch^3

100Kpa	SHEAR STRAIN AMPLITUDE (%)															
	0.00454				0.0088				0.02512				0.04212			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	7710	0.038188	-0.006565	-0.019695	7703	0.038542	-0.006626	-0.019877	7694	0.038997	-0.006704	-0.020112	7643	0.041577	-0.007147	-0.021442
30	7709	0.038238	-0.006574	-0.019721	7704	0.038491	-0.006617	-0.019851	7684	0.039503	-0.006791	-0.020373	7632	0.042133	-0.007243	-0.021729
60	7709	0.038238	-0.006574	-0.019721	7704	0.038491	-0.006617	-0.019851	7673	0.040059	-0.006887	-0.020660	7628	0.042335	-0.007278	-0.021834
100	7709	0.038238	-0.006574	-0.019721	7703	0.038542	-0.006626	-0.019877	7670	0.040211	-0.006913	-0.020738	7624	0.042538	-0.007313	-0.021938
200	7709	0.038238	-0.006574	-0.019721	7703	0.038542	-0.006626	-0.019877	7662	0.040616	-0.006982	-0.020947	7614	0.043043	-0.007400	-0.022199
400	7706	0.038390	-0.006600	-0.019799	7695	0.038947	-0.006695	-0.020086	7654	0.041020	-0.007052	-0.021155	7604	0.043549	-0.007487	-0.022460
600	7706	0.038390	-0.006600	-0.019799	7694	0.038997	-0.006704	-0.020112	7650	0.041223	-0.007087	-0.021260	7590	0.044257	-0.007608	-0.022825
800	7706	0.038390	-0.006600	-0.019799	7693	0.039048	-0.006713	-0.020138	7644	0.041526	-0.007139	-0.021416	7584	0.044561	-0.007660	-0.022981
1000	7703	0.038542	-0.006626	-0.019877	7693	0.039048	-0.006713	-0.020138	7638	0.041830	-0.007191	-0.021573	7572	0.045168	-0.007765	-0.023294

50Kpa	SHEAR STRAIN AMPLITUDE (%)															
	0.00531				0.01035				0.02798				0.05269			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	7665	0.040464	-0.006956	-0.020868	7663	0.040565	-0.006974	-0.020921	7666	0.040413	-0.006947	-0.020842	7664	0.040514	-0.006965	-0.020895
30	7664	0.040514	-0.006965	-0.020895	7668	0.040312	-0.006930	-0.020790	7669	0.040262	-0.006921	-0.020764	7665	0.040464	-0.006956	-0.020868
60	7664	0.040514	-0.006965	-0.020895	7668	0.040312	-0.006930	-0.020790	7670	0.040211	-0.006913	-0.020738	7665	0.040464	-0.006956	-0.020868
100	7664	0.040514	-0.006965	-0.020895	7668	0.040312	-0.006930	-0.020790	7670	0.040211	-0.006913	-0.020738	7665	0.040464	-0.006956	-0.020868
200	7663	0.040565	-0.006974	-0.020921	7668	0.040312	-0.006930	-0.020790	7670	0.040211	-0.006913	-0.020738	7665	0.040464	-0.006956	-0.020868
400	7663	0.040565	-0.006974	-0.020921	7665	0.040464	-0.006956	-0.020868	7665	0.040464	-0.006956	-0.020868	7663	0.040565	-0.006974	-0.020921
600	7663	0.040565	-0.006974	-0.020921	7665	0.040464	-0.006956	-0.020868	7665	0.040464	-0.006956	-0.020868	7660	0.040717	-0.007000	-0.020999
800	7663	0.040565	-0.006974	-0.020921	7663	0.040565	-0.006974	-0.020921	7664	0.040514	-0.006965	-0.020895	7655	0.040970	-0.007043	-0.021129
1000	7663	0.040565	-0.006974	-0.020921	7663	0.040565	-0.006974	-0.020921	7663	0.040565	-0.006974	-0.020921	7654	0.041020	-0.007052	-0.021155

DATA SHEET # 4

SAMPLE 2ST#8

INITIAL LENGTH = 5.706 inch

100 kPa @ 1000 CYCLES				
SHEAR ST. (%)	TOTAL		DYNAMIC	
	VERT. ST.	Evol	VERT. ST.	Evol
0.00454	-0.006626	-0.019878	0.000000	0.000000
0.0088	-0.006713	-0.020139	-0.000087	-0.000261
0.02512	-0.007191	-0.021573	-0.000478	-0.001434
0.04212	-0.007765	-0.023294	-0.000574	-0.001721

50 kPa (after 100 kPa) @ 1000 CYCLES				
SHEAR ST. (%)	TOTAL		DYNAMIC	
	VERT. ST.	Evol	VERT. ST.	Evol
0.00531	-0.006974	-0.020922	0.000000	0.000000
0.01035	-0.006974	-0.020922	0.000000	0.000000
0.02798	-0.006974	-0.020922	0.000000	0.000000
0.05269	-0.007052	-0.021155	-0.000078	-0.000233

DATA SHEET # 1

SAMPLE # 2ST#9

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.858	5.724	2.240079	0.262	2.69	0.021251	105.4128	1.775023	83.52841	0.0105747	1.0095678	0.6981007	7021	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
3/1/93	25	43	98	10.20408	6733	5.7096	2.85081	0.0210906	2.2400794	0.9944394	0.000491	0.229496	0.46149	634.85	1330637	63.71092	0.000247
3/2/93	50	44	107	9.345794	6518	5.69885	2.845443	0.0209717	2.2400794	0.9831952	0.000489	0.228633	0.46068	693.06	1594849	76.36136	0.000212
3/3/93	100	43	115	8.695652	6229	5.6844	2.838228	0.0208125	2.2400794	0.9681477	0.000487	0.227475	0.45959	744.75	1855700	88.85092	0.00018
3/4/93	25	43	99	10.10101	6409	5.6934	2.842721	0.0209115	2.2400794	0.9775109	0.000488	0.228196	0.46025	641.23	1369144	65.55459	0.000242

TORSIONAL SHEAR TEST FOR 2ST#9 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 3/1/93
Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.0025	3.9	7.875	0.9957	0.991	40	2.851	5.710	0.0971	3.9021	1.2951E-04	2.5865E-03	1.0653E-01	3.1271E-04	3.2371E+01	1.2515E+06
0.005	3.925	7.375	1.999	1.984	40	2.851	5.710	0.1962	7.3160	2.6167E-04	5.2260E-03	1.9973E-01	3.1271E-04	6.0693E+01	1.1614E+06
0.01	3.625	5.6	4.9595	4.943	40	2.851	5.710	0.4495	13.8404	5.9957E-04	1.1975E-02	3.7784E-01	3.1271E-04	1.1482E+02	9.5884E+05
0.025	5.233	5.48	10	9.856	40	2.851	5.710	1.3083	27.0054	1.7452E-03	3.4855E-02	7.3725E-01	3.1271E-04	2.2403E+02	6.4275E+05
0.05	3.45	6.65	10	9.856	20	2.851	5.710	1.725	32.7712	2.3012E-03	4.5959E-02	8.9465E-01	3.1271E-04	2.7187E+02	5.9154E+05
0.1	4.983	8.35	10	9.856	20	2.851	5.710	2.4915	41.1488	3.3237E-03	6.6380E-02	1.1234E+00	3.1271E-04	3.4136E+02	5.1426E+05

Date : 3/2/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.0025	3.117	7.85	0.9957	0.991	40	2.845	5.699	0.0776	3.8897	1.0350E-04	2.0672E-03	1.0619E-01	3.1037E-04	3.2451E+01	1.5698E+06
0.005	2.983	7.183	1.999	1.984	40	2.845	5.699	0.1491	7.1255	1.9887E-04	3.9718E-03	1.9453E-01	3.1037E-04	5.9448E+01	1.4968E+06
0.01	2.425	5.25	4.9595	4.943	40	2.845	5.699	0.3007	12.9754	4.0109E-04	8.0107E-03	3.5423E-01	3.1037E-04	1.0825E+02	1.3514E+06
0.025	1.783	5.65	10	9.856	20	2.845	5.699	0.8915	27.8432	1.1893E-03	2.3752E-02	7.6012E-01	3.1037E-04	2.3229E+02	9.7799E+05
0.05	3.017	8.033	10	9.856	20	2.845	5.699	1.5085	39.58662	2.0123E-03	4.0191E-02	1.0807E+00	3.1037E-04	3.3027E+02	8.2175E+05

Note : 1 psf = 47.88E-6 MPa

TORSIONAL SHEAR TEST FOR 2ST#9 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 3/3/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	1.5083	4.0917	4.9595	4.943	40	2.838	5.684	0.1870	10.1126	2.4947E-04	4.9825E-03	2.7607E-01	3.0723E-04	8.5014E+01	1.7063E+06
0.01	3.167	7.75	4.9595	4.943	40	2.838	5.684	0.3927	19.1541	5.2382E-04	1.0462E-02	5.2291E-01	3.0723E-04	1.6102E+02	1.5392E+06
0.025	3.883	7.6	4.9595	9.856	20	2.838	5.684	0.9629	37.4528	1.2845E-03	2.5654E-02	1.0225E+00	3.0723E-04	3.1485E+02	1.2273E+06
0.04	2.733	4.8917	10	19.71	20	2.838	5.684	1.3665	48.2077	1.8229E-03	3.6407E-02	1.3161E+00	3.0723E-04	4.0527E+02	1.1131E+06

Date : 3/3/93
Confining Pressure = 25 kPa (after 100 kPa)

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.0417	7.45	1.999	1.984	40	2.843	5.693	0.2020	7.3904	2.6945E-04	5.3814E-03	2.0176E-01	3.0918E-04	6.1835E+01	1.1490E+06
0.01	3.1417	5.05	4.9595	4.943	40	2.843	5.693	0.3895	12.4811	5.1964E-04	1.0378E-02	3.4073E-01	3.0918E-04	1.0443E+02	1.0062E+06
0.025	4.3083	5.05	10	9.856	40	2.843	5.693	1.0771	24.8864	1.4368E-03	2.8696E-02	6.7940E-01	3.0918E-04	2.0822E+02	7.2561E+05
0.05	3.3583	6.7083	10	9.856	20	2.843	5.693	1.6792	33.0585	2.2400E-03	4.4737E-02	9.0250E-01	3.0918E-04	2.7660E+02	6.1827E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 2ST#9

DATE: 03/05/93

INITIAL LENGTH= 5.724 inch
INITIAL LVDT = 7021

STTLMT is in inches

e0= 1.009568
V0= 36.72095 inch^3
Vs= 18.27306 inch^3

25Kpa — SHEAR STRAIN AMPLITUDE (%)

	0.00259				0.00523			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
10	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
15	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
20	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
30	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
50	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
100	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
200	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
400	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
600	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
800	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741
1000	6729	0.014769	-0.002580	-0.007741	6729	0.014769	-0.002580	-0.007741

	0.01197				0.03486				0.04596			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	6729	0.014769	-0.002580	-0.007741	6709	0.015781	-0.002757	-0.008271	6660	0.018259	-0.003190	-0.009570
10	6729	0.014769	-0.002580	-0.007741	6709	0.015781	-0.002757	-0.008271	6660	0.018259	-0.003190	-0.009570
15	6729	0.014769	-0.002580	-0.007741	6698	0.016337	-0.002854	-0.008563	6660	0.018259	-0.003190	-0.009570
20	6729	0.014769	-0.002580	-0.007741	6695	0.016489	-0.002881	-0.008642	6660	0.018259	-0.003190	-0.009570
30	6726	0.014921	-0.002607	-0.007820	6692	0.016641	-0.002907	-0.008722	6659	0.018310	-0.003199	-0.009596
50	6726	0.014921	-0.002607	-0.007820	6690	0.016742	-0.002925	-0.008775	6659	0.018310	-0.003199	-0.009596
100	6725	0.014972	-0.002616	-0.007847	6676	0.017450	-0.003049	-0.009146	6654	0.018563	-0.003243	-0.009729
200	6724	0.015022	-0.002624	-0.007873	6673	0.017602	-0.003075	-0.009225	6652	0.018664	-0.003261	-0.009782
400	6723	0.015073	-0.002633	-0.007900	6668	0.017855	-0.003119	-0.009358	6650	0.018765	-0.003278	-0.009835
600	6722	0.015123	-0.002642	-0.007926	6663	0.018108	-0.003163	-0.009490	6649	0.018816	-0.003287	-0.009861
800	6721	0.015174	-0.002651	-0.007953	6661	0.018209	-0.003181	-0.009543	6645	0.019018	-0.003323	-0.009968
1000	6720	0.015225	-0.002660	-0.007979	6660	0.018259	-0.003190	-0.009570	6643	0.019119	-0.003340	-0.010021

	0.06638			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol
1	6643	0.019119	-0.003340	-0.010021
10	6643	0.019119	-0.003340	-0.010021
15	6643	0.019119	-0.003340	-0.010021
20	6643	0.019119	-0.003340	-0.010021
30	6643	0.019119	-0.003340	-0.010021
50	6639	0.019322	-0.003376	-0.010127
100	6630	0.019777	-0.003455	-0.010365
200	6622	0.020161	-0.003526	-0.010577
400	6612	0.020687	-0.003614	-0.010842
600	6605	0.021041	-0.003676	-0.011028
800	6604	0.021092	-0.003685	-0.011054
1000	6593	0.021648	-0.003782	-0.011346

50Kpa — SHEAR STRAIN AMPLITUDE (%)

	0.00207				0.003972			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	6514	0.025644	-0.004480	-0.013440	6514	0.025644	-0.004480	-0.013440
10	6514	0.025644	-0.004480	-0.013440	6514	0.025644	-0.004480	-0.013440
15	6514	0.025644	-0.004480	-0.013440	6514	0.025644	-0.004480	-0.013440
20	6514	0.025644	-0.004480	-0.013440	6514	0.025644	-0.004480	-0.013440
30	6514	0.025644	-0.004480	-0.013440	6514	0.025644	-0.004480	-0.013440
50	6514	0.025644	-0.004480	-0.013440	6514	0.025644	-0.004480	-0.013440
100	6513	0.025695	-0.004489	-0.013467	6514	0.025644	-0.004480	-0.013440
200	6512	0.025745	-0.004498	-0.013493	6514	0.025644	-0.004480	-0.013440
400	6512	0.025745	-0.004498	-0.013493	6514	0.025644	-0.004480	-0.013440
600	6512	0.025745	-0.004498	-0.013493	6514	0.025644	-0.004480	-0.013440
800	6512	0.025745	-0.004498	-0.013493	6514	0.025644	-0.004480	-0.013440
1000	6512	0.025745	-0.004498	-0.013493	6514	0.025644	-0.004480	-0.013440

	0.00801				0.02375				0.04019			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	6514	0.025644	-0.004480	-0.013440	6512	0.025745	-0.004498	-0.013493	6483	0.027212	-0.004754	-0.014262
10	6514	0.025644	-0.004480	-0.013440	6510	0.025846	-0.004515	-0.013546	6482	0.027263	-0.004763	-0.014289
15	6514	0.025644	-0.004480	-0.013440	6508	0.025947	-0.004533	-0.013599	6482	0.027263	-0.004763	-0.014289
20	6514	0.025644	-0.004480	-0.013440	6506	0.026049	-0.004551	-0.013652	6482	0.027263	-0.004763	-0.014289
30	6514	0.025644	-0.004480	-0.013440	6504	0.026150	-0.004568	-0.013705	6475	0.027617	-0.004825	-0.014474
50	6514	0.025644	-0.004480	-0.013440	6504	0.026150	-0.004568	-0.013705	6470	0.027870	-0.004869	-0.014607
100	6514	0.025644	-0.004480	-0.013440	6499	0.026403	-0.004613	-0.013838	6468	0.027971	-0.004887	-0.014660
200	6514	0.025644	-0.004480	-0.013440	6494	0.026656	-0.004657	-0.013970	6465	0.028122	-0.004913	-0.014739
400	6513	0.025695	-0.004489	-0.013467	6490	0.026858	-0.004692	-0.014076	6462	0.028274	-0.004940	-0.014819
600	6512	0.025745	-0.004498	-0.013493	6490	0.026858	-0.004692	-0.014076	6455	0.028628	-0.005001	-0.015004
800	6512	0.025745	-0.004498	-0.013493	6485	0.027111	-0.004736	-0.014209	6455	0.028628	-0.005001	-0.015004
1000	6512	0.025745	-0.004498	-0.013493	6483	0.027212	-0.004754	-0.014262	6452	0.028780	-0.005028	-0.015084

DATA SHEET # 3

SAMPLE 2ST#9

DATE: 03/05/93

INITIAL LENGTH= 5.724 inch
INITIAL LVDT = 7021

STTLMT is in inches

e0= 1.009568
V0= 36.72095 inch^3
Vs= 18.273057 inch^3

100Kpa	SHEAR STRAIN AMPLITUDE (%)															
	0.00498				0.01046				0.02565				0.03641			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	6233	0.039857	-0.006963	-0.020889	6233	0.039857	-0.006963	-0.020889	6218	0.040616	-0.007096	-0.021287	6172	0.042942	-0.007502	-0.022506
10	6233	0.039857	-0.006963	-0.020889	6233	0.039857	-0.006963	-0.020889	6216	0.040717	-0.007113	-0.021340	6171	0.042993	-0.007511	-0.022533
15	6233	0.039857	-0.006963	-0.020889	6230	0.040009	-0.006990	-0.020969	6215	0.040767	-0.007122	-0.021367	6171	0.042993	-0.007511	-0.022533
20	6233	0.039857	-0.006963	-0.020889	6226	0.040211	-0.007025	-0.021075	6214	0.040818	-0.007131	-0.021393	6170	0.043043	-0.007520	-0.022559
30	6233	0.039857	-0.006963	-0.020889	6226	0.040211	-0.007025	-0.021075	6214	0.040818	-0.007131	-0.021393	6170	0.043043	-0.007520	-0.022559
50	6233	0.039857	-0.006963	-0.020889	6225	0.040262	-0.007034	-0.021101	6210	0.041020	-0.007166	-0.021499	6170	0.043043	-0.007520	-0.022559
100	6233	0.039857	-0.006963	-0.020889	6224	0.040312	-0.007043	-0.021128	6203	0.041374	-0.007228	-0.021685	6170	0.043043	-0.007520	-0.022559
200	6233	0.039857	-0.006963	-0.020889	6223	0.040363	-0.007051	-0.021154	6193	0.041880	-0.007317	-0.021950	6164	0.043347	-0.007573	-0.022719
400	6233	0.039857	-0.006963	-0.020889	6223	0.040363	-0.007051	-0.021154	6186	0.042234	-0.007378	-0.022135	6160	0.043549	0.007608	-0.022825
600	6233	0.039857	-0.006963	-0.020889	6223	0.04036[illegible]	[illegible]007051	-0.021154	6183	0.042386	-0.007405	-0.022215	6153	0.043903	-0.007670	-0.023010
800	6233	0.039857	-0.006963	-0.020889	6221	0.040464	-0.007069	-0.021208	6173	0.042892	-0.007493	-0.022480	6152	0.043954	-0.007679	-0.023037
1000	6233	0.039857	-0.006963	-0.020889	6220	0.040514	-0.007078	-0.021234	6172	0.042942	-0.007502	-0.022506	6143	0.044409	-0.007758	-0.023275

25Kpa	SHEAR STRAIN AMPLITUDE (%)															
	0.00538				0.01038				0.02869				0.04474			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	6408	0.031005	-0.005417	-0.016250	6408	0.031005	-0.005417	-0.016250	6403	0.031258	-0.005461	-0.016383	6385	0.032169	-0.005620	-0.016860
10	6408	0.031005	-0.005417	-0.016250	6408	0.031005	-0.005417	-0.016250	6402	0.031309	-0.005470	-0.016409	6385	0.032169	-0.005620	-0.016860
15	6408	0.031005	-0.005417	-0.016250	6408	0.031005	-0.005417	-0.016250	6398	0.031511	-0.005505	-0.016515	6385	0.032169	-0.005620	-0.016860
20	6408	0.031005	-0.005417	-0.016250	6408	0.031005	-0.005417	-0.016250	6394	0.031714	-0.005540	-0.016621	6384	0.032219	-0.005629	-0.016886
30	6408	0.031005	-0.005417	-0.016250	6408	0.031005	-0.005417	-0.016250	6392	0.031815	-0.005558	-0.016674	6384	0.032219	-0.005629	-0.016886
50	6408	0.031005	-0.005417	-0.016250	6405	0.031157	-0.005443	-0.016330	6391	0.031865	-0.005567	-0.016701	6384	0.032219	-0.005629	-0.016886
100	6408	0.031005	-0.005417	-0.016250	6405	0.031157	-0.005443	-0.016330	6390	0.031916	-0.005576	-0.016727	6383	0.032270	-0.005638	-0.016913
200	6408	0.031005	-0.005417	-0.016250	6404	0.031208	-0.005452	-0.016356	6390	0.031916	-0.005576	-0.016727	6383	0.032270	-0.005638	-0.016913
400	6408	0.031005	-0.005417	-0.016250	6404	0.031208	-0.005452	-0.016356	6388	0.032017	-0.005593	-0.016780	6383	0.032270	-0.005638	-0.016913
600	6408	0.031005	-0.005417	-0.016250	6404	0.031208	-0.005452	-0.016356	6388	0.032017	-0.005593	-0.016780	6383	0.032270	-0.005638	-0.016913
800	6408	0.031005	-0.005417	-0.016250	6403	0.031258	-0.005461	-0.016383	6384	0.032219	-0.005629	-0.016886	6375	0.032675	-0.005708	-0.017125
1000	6408	0.031005	-0.005417	-0.016250	6403	0.031258	-0.005461	-0.016383	6382	0.032321	-0.005646	-0.016939	6374	0.032725	-0.005717	-0.017152

DATA SHEET # 4

SAMPLE 2ST#9

INITIAL LENGTH = 5.724 inch

25 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00259	-0.002580	-0.007741	0.000000	0.000000
0.00523	-0.002580	-0.007741	0.000000	0.000000
0.01197	-0.002660	-0.007979	-0.000080	-0.000239
0.03486	-0.003190	-0.009570	-0.000530	-0.001591
0.04596	-0.003340	-0.010021	-0.000150	-0.000451
0.06638	-0.003782	-0.011346	-0.000442	-0.001325

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00207	-0.004498	-0.013494	0.000000	0.000000
0.00397	-0.004480	-0.013440	0.000018	0.000054
0.00801	-0.004498	-0.013494	-0.000018	-0.000054
0.02375	-0.004754	-0.014262	-0.000256	-0.000768
0.04019	-0.005028	-0.015084	-0.000274	-0.000822

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00498	-0.006963	-0.020889	0.000000	0.000000
0.01046	-0.007078	-0.021234	-0.000115	-0.000345
0.02565	-0.007502	-0.022506	-0.000424	-0.001272
0.03641	-0.007758	-0.023274	-0.000256	-0.000768

25 kPa (after 100 kPa) @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00538	-0.005417	-0.016250	0.000000	0.000000
0.01038	-0.005461	-0.016383	-0.000044	-0.000133
0.02869	-0.005646	-0.016939	-0.000186	-0.000557
0.04474	-0.005717	-0.017152	-0.000071	-0.000212

DATA SHEET # 1

SAMPLE # 2ST#10

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.859	5.817	2.272068	0.296	2.755	0.021611	105.1352	1.753139	81.12284	0.010198	1.119157	0.728656	8983	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wa Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
3/26/93	100	72	120	8.333333	8454	5.79055	2.846	0.021317	2.272068	1.09038	0.000497	0.231988	0.46379	784.4729	2038876	97.62136	0.000272

TORSIONAL SHEAR TEST FOR 2ST#10 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 3/26/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.0025	4.05	5.95	0.9957	1.984	40	2.846	5.791	0.1008	5.9024	1.3449E-04	2.6440E-03	1.6114E-01	3.1061E-04	4.9214E+01	1.8614E+06
0.005	1.62	4.43	4.9595	4.943	40	2.846	5.791	0.2009	10.9487	2.6795E-04	5.2677E-03	2.9890E-01	3.1061E-04	9.1291E+01	1.7330E+06
0.01	4.58	5.25	4.9595	9.856	40	2.846	5.791	0.5679	25.8720	7.5753E-04	1.4893E-02	7.0631E-01	3.1061E-04	2.1572E+02	1.4485E+06
0.025	1.9	7.58	10	9.856	20	2.846	5.791	0.9500	37.3542	1.2673E-03	2.4915E-02	1.0198E+00	3.1061E-04	3.1146E+02	1.2501E+06

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 2ST#10

DATE: 03/05/93

INITIAL LENGTH= 5.817 inch
INITIAL LVDT = 8983

STTLMT is in inches

e0= 1.1192
V0= 36.7218 inch^3
Vs= 18.2731 inch^3

100Kpa	SHEAR STRAIN AMPLITUDE (%)															
	0.00264				0.00527				0.01489				0.02492			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8433	0.027500	-0.004728	-0.014183
10	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8432	0.027550	-0.004736	-0.014208
15	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8453	0.026500	-0.004556	-0.013667	8432	0.027550	-0.004736	-0.014208
20	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8452	0.026550	-0.004564	-0.013693	8432	0.027550	-0.004736	-0.014208
30	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8452	0.026550	-0.004564	-0.013693	8432	0.027550	-0.004736	-0.014208
50	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8450	0.026650	-0.004581	-0.013744	8432	0.027550	-0.004736	-0.014208
100	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8449	0.026700	-0.004590	-0.013770	8432	0.027550	-0.004736	-0.014208
200	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8445	0.026900	-0.004624	-0.013873	8432	0.027550	-0.004736	-0.014208
400	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8444	0.026950	-0.004633	-0.013899	8429	0.027700	-0.004762	-0.014286
600	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8442	0.027050	-0.004650	-0.013950	8423	0.028000	-0.004813	-0.014440
800	8454	0.026450	-0.004547	-0.013641	8454	0.026450	-0.004547	-0.013641	8434	0.027450	-0.004719	-0.014157	8421	0.028100	-0.004831	-0.014492
1000	8453	0.026500	-0.004556	-0.013667	8454	0.026450	-0.004547	-0.013641	8433	0.027500	-0.004728	-0.014183	8419	0.028200	-0.004848	-0.014544

DATA SHEET # 4

SAMPLE 2ST#10

INITIAL LENGTH = 5.817 inch

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00264	-0.004556	-0.013668	0.000000	0.000000
0.00527	-0.004547	-0.013641	0.000009	0.000027
0.01489	-0.004728	-0.014184	-0.000181	-0.000543
0.02492	-0.004848	-0.014544	-0.000120	-0.000360

DATA SHEET # 1

SAMPLE # 2ST#11

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.864	5.819	2.226323	0.296	2.71	0.021694	102.6238	1.7178416	79.18501	0.010158	1.135556	0.706403	9653	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
3/31/93	50	51	101	9.90099	9304	5.80155	2.855411	0.021499	2.226323	1.116401	0.00049	0.228824	0.46085	665.74	1426652	68.30809	0.000272

TORSIONAL SHEAR TEST FOR 2ST#11 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 3/31/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.0025	4.175	8.375	0.9957	0.991	40	2.855	5.802	0.1039	4.1498	1.3864E-04	2.7294E-03	1.1329E-01	3.1474E-04	3.4260E+01	1.2552E+06
0.005	8.47	7.592	0.9957	1.984	40	2.855	5.802	0.2108	7.5313	2.8126E-04	5.5372E-03	2.0560E-01	3.1474E-04	6.2177E+01	1.1229E+06
0.01	8.883	5.5	1.999	4.943	40	2.855	5.802	0.4439	13.5933	5.9220E-04	1.1659E-02	3.7110E-01	3.1474E-04	1.1222E+02	9.6257E+05
0.025	4.933	5.483	4.9595	9.856	20	2.855	5.802	1.2233	27.0202	1.6318E-03	3.2126E-02	7.3765E-01	3.1474E-04	2.2307E+02	6.9437E+05
0.05	4.15	7.75	10	9.856	20	2.85541	5.80155	2.075	38.192	2.7681E-03	5.4495E-02	1.0426E+00	3.1474E-04	3.1531E+02	5.7860E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 2ST#11

DATE: 03/31/93

INITIAL LENGTH= 5.819 inch
INITIAL LVDT = 9644

STTLMT is in inches

e0= 1.1356
V0= 37.4872 inch^3

Vs= 17.553 inch^3

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00273				0.00554				0.01166				0.03213				0.05449			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	9304	0.017000	-0.002921	-0.008764	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9292	0.017600	-0.003025	-0.009074	9259	0.019250	-0.003308	-0.009924
10	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9290	0.017700	-0.003042	-0.009125	9256	0.019400	-0.003334	-0.010002
15	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9289	0.017750	-0.003050	-0.009151	9255	0.019450	-0.003342	-0.010027
20	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9289	0.017750	-0.003050	-0.009151	9253	0.019550	-0.003360	-0.010079
30	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9284	0.018000	-0.003093	-0.009280	9253	0.019550	-0.003360	-0.010079
50	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9299	0.017250	-0.002964	-0.008893	9283	0.018050	-0.003102	-0.009306	9251	0.019650	-0.003377	-0.010131
100	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9298	0.017300	-0.002973	-0.008919	9274	0.018500	-0.003179	-0.009538	9244	0.020000	-0.003437	-0.010311
200	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9295	0.017450	-0.002999	-0.008996	9271	0.018650	-0.003205	-0.009615	9239	0.020250	-0.003480	-0.010440
400	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9293	0.017550	-0.003016	-0.009048	9266	0.018900	-0.003248	-0.009744	9234	0.020500	-0.003523	-0.010569
600	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9293	0.017550	-0.003016	-0.009048	9263	0.019050	-0.003274	-0.009821	9231	0.020650	-0.003549	-0.010646
800	9303	0.017050	-0.002930	-0.008790	9303	0.017050	-0.002930	-0.008790	9293	0.017550	-0.003016	-0.009048	9260	0.019200	-0.003300	-0.009899	9230	0.020700	-0.003557	-0.010672
1000	9303	0.017050	-0.002930	-0.008790	9304	0.017000	-0.002921	-0.008764	9292	0.017600	-0.003025	-0.009074	9259	0.019250	-0.003308	-0.009924	9224	0.021000	-0.003609	-0.010827
2000																	9211	0.021650	-0.003721	-0.011162
54300																	9196	0.022400	-0.003849	-0.011548
75600																	9184	0.023000	-0.003953	-0.011858
149880																	9183	0.023050	-0.003961	-0.011883
172980																	9183	0.023050	-0.003961	-0.011883
411600																	9175	0.023450	-0.004030	-0.012090

DATA SHEET # 4

SAMPLE 2ST#11

INITIAL LENGTH = 5.819 inch

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00273	-0.002930	-0.008790	0.000000	0.000000
0.00554	-0.002922	-0.008765	0.000009	0.000026
0.01166	-0.003025	-0.009074	-0.000103	-0.000309
0.03213	-0.003308	-0.009924	-0.000283	-0.000850
0.05449	-0.003609	-0.010827	-0.000301	-0.000902

DATA SHEET # 1

SAMPLE # 3ST#2

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.85367	5.89617	1.998	0.2391	2.75	0.021823	91.55292	1.612461	73.88663	0.009397	1.322477	0.497192	9912	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
6/22/93	25	34	70	14.28571	9662	5.88367	2.84762	0.021685	1.998	1.307737	0.000437	0.204237	0.43711	493.35	697098.2	33.37706	0.000372
6/23/93	50	28	79	12.65823	9426	5.87187	2.841909	0.021555	1.998	1.29388	0.000435	0.203419	0.4363	556.69	892966.1	42.75522	0.00024
6/24/93	100	30	91	10.98901	9110	5.85607	2.834262	0.021381	1.998	1.275413	0.000433	0.202326	0.4352	641.15	1194061	57.17163	0.000194

TORSIONAL SHEAR TEST FOR 3ST#2 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 6/22/93
Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.35	3.6	1.999	1.984	40	2.848	5.883	0.2174	3.5712	2.9000E-04	5.6142E-03	9.7494E-02	3.1127E-04	2.9729E+01	5.2953E+05
0.01	3.8125	6.695	4.9595	1.984	40	2.847	5.883	0.4727	6.6414	6.3058E-04	1.2208E-02	1.8131E-01	3.1122E-04	5.5294E+01	4.5294E+05
0.025	4.475	4.85	4.9595	4.943	20	2.847	5.882	1.1097	11.9868	1.4803E-03	2.8658E-02	3.2724E-01	3.1098E-04	9.9857E+01	3.4844E+05
0.05	3.344	6.7	10	4.943	20	2.847	5.882	1.6720	16.5591	2.2304E-03	4.3180E-02	4.5206E-01	3.1089E-04	1.3798E+02	3.1954E+05
0.1	2.934	4.93	1.999	9.856	2	2.846	5.880	2.9325	24.2950	3.9120E-03	7.5734E-02	6.6325E-01	3.1061E-04	2.0257E+02	2.6748E+05

Date : 6/23/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.9917	4.35	1.999	1.984	40	2.842	5.872	0.1995	4.3152	2.6611E-04	5.1518E-03	1.1780E-01	3.0875E-04	3.6142E+01	7.0155E+05
0.01	2.9383	7.35	4.9595	1.984	40	2.842	5.871	0.3643	7.2912	4.8599E-04	9.4086E-03	1.9905E-01	3.0874E-04	6.1070E+01	6.4909E+05
0.025	3.57083	5.85	10	4.943	40	2.842	5.871	0.8927	14.4583	1.1909E-03	2.3055E-02	3.9471E-01	3.0866E-04	1.2112E+02	5.2537E+05
0.05	3.62	4.9267	10	9.856	20	2.841	5.870	1.8100	24.2788	2.4145E-03	4.6744E-02	6.6281E-01	3.0836E-04	2.0354E+02	4.3544E+05
0.1	2.15	7.45	1.999	9.856	2	2.840	5.868	2.1489	36.7136	2.8667E-03	5.5497E-02	1.0023E+00	3.0795E-04	3.0809E+02	5.5515E+05

Date : 6/24/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.05	6.075	1.999	1.984	40	2.834	5.856	0.2024	6.0264	2.7000E-04	5.2271E-03	1.6452E-01	3.0544E-04	5.0884E+01	9.7348E+05
0.01	2.8675	4	4.9595	4.943	40	2.834	5.856	0.3555	9.8860	4.7428E-04	9.1819E-03	2.6989E-01	3.0542E-04	8.3477E+01	9.0915E+05
0.025	3.864167	8.9	10	4.943	40	2.834	5.855	0.9660	21.9964	1.2887E-03	2.4949E-02	6.0050E-01	3.0528E-04	1.8580E+02	7.4474E+05
0.05	3.259167	6.73	10	9.856	20	2.833	5.853	1.6296	33.1654	2.1739E-03	4.2085E-02	9.0542E-01	3.0493E-04	2.8038E+02	6.6623E+05
0.06	2.396667	4.58	20	19.71	20	2.832	5.851	2.3967	45.1359	3.1972E-03	6.1895E-02	1.2322E+00	3.0450E-04	3.8199E+02	6.1716E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 3ST#2

DATE: 06/22/93

INITIAL LENGTH= 5.89617 Inch
INITIAL LVDT = 9912

STTLMT is in inches

e0= 1.322477
V0= 37.71094 Inch^3
Vs= 16.23738 Inch^3

25Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00561				0.01221				0.02866				0.04318				0.07573			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	9662	0.012645	-0.002145	-0.006434	9659	0.012797	-0.002170	-0.006511	9635	0.014011	-0.002376	-0.007129	9631	0.014213	-0.002411	-0.007232	9618	0.014870	-0.002522	-0.007566
30	9661	0.012696	-0.002153	-0.006460	9656	0.012948	-0.002196	-0.006588	9634	0.014061	-0.002385	-0.007154	9630	0.014264	-0.002419	-0.007257	9609	0.015326	-0.002599	-0.007798
60	9661	0.012696	-0.002153	-0.006460	9655	0.012999	-0.002205	-0.006614	9634	0.014061	-0.002385	-0.007154	9629	0.014314	-0.002428	-0.007283	9604	0.015579	-0.002642	-0.007926
100	9661	0.012696	-0.002153	-0.006460	9655	0.012999	-0.002205	-0.006614	9634	0.014061	-0.002385	-0.007154	9626	0.014466	-0.002453	-0.007360	9602	0.015680	-0.002659	-0.007978
200	9661	0.012696	-0.002153	-0.006460	9655	0.012999	-0.002205	-0.006614	9634	0.014061	-0.002385	-0.007154	9623	0.014618	-0.002479	-0.007436	9596	0.015983	-0.002711	-0.008132
400	9659	0.012797	-0.002170	-0.006511	9654	0.013050	-0.002213	-0.006640	9633	0.014112	-0.002393	-0.007180	9623	0.014618	-0.002479	-0.007436	9589	0.016337	-0.002771	-0.008313
600	9659	0.012797	-0.002170	-0.006511	9654	0.013050	-0.002213	-0.006640	9633	0.014112	-0.002393	-0.007180	9622	0.014668	-0.002488	-0.007463	9586	0.016489	-0.002797	-0.008390
800	9659	0.012797	-0.002170	-0.006511	9653	0.013100	-0.002222	-0.006665	9632	0.014162	-0.002402	-0.007206	9620	0.014769	-0.002505	-0.007515	9585	0.016540	-0.002805	-0.008415
1000	9659	0.012797	-0.002170	-0.006511	9653	0.013100	-0.002222	-0.006665	9631	0.014213	-0.002411	-0.007232	9618	0.014870	-0.002522	-0.007566	9580	0.016793	-0.002848	-0.008544

* Note: Test stopped after 20cycles @ shear strain = 0.026%.
Settlement caused by these 20 cycles from 9652 to 9635.

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00515				0.00941				0.02306				0.04674				0.05549			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	9426	0.024582	-0.004169	-0.012507	9423	0.024734	-0.004195	-0.012585	9423	0.024734	-0.004195	-0.012585	9409	0.025442	-0.004315	-0.012945	9373	0.027263	-0.004624	-0.013871
15	9426	0.024582	-0.004169	-0.012507	9424	0.024683	-0.004186	-0.012559	9421	0.024835	-0.004212	-0.012636	9403	0.025745	-0.004366	-0.013099	9369	0.027465	-0.004658	-0.013974
30	9426	0.024582	-0.004169	-0.012507	9424	0.024683	-0.004186	-0.012559	9419	0.024936	-0.004229	-0.012688	9402	0.025796	-0.004375	-0.013125	9365	0.027667	-0.004692	-0.014077
45	9426	0.024582	-0.004169	-0.012507	9424	0.024683	-0.004186	-0.012559	9417	0.025037	-0.004246	-0.012739	9397	0.026049	-0.004418	-0.013254	9362	0.027819	-0.004718	-0.014154
60	9426	0.024582	-0.004169	-0.012507	9424	0.024683	-0.004186	-0.012559	9416	0.025088	-0.004255	-0.012765	9391	0.026352	-0.004469	-0.013408	9360	0.027920	-0.004735	-0.014206
100	9426	0.024582	-0.004169	-0.012507	9424	0.024683	-0.004186	-0.012559	9415	0.025138	-0.004263	-0.012790	9391	0.026352	-0.004469	-0.013408	9358	0.028021	-0.004752	-0.014257
200	9425	0.024632	-0.004178	-0.012533	9423	0.024734	-0.004195	-0.012585	9414	0.025189	-0.004272	-0.012816	9384	0.026706	-0.004529	-0.013588	9350	0.028426	-0.004821	-0.014463
400	9425	0.024632	-0.004178	-0.012533	9423	0.024734	-0.004195	-0.012585	9412	0.025290	-0.004289	-0.012868	9376	0.027111	-0.004598	-0.013794	9340	0.028932	-0.004907	-0.014721
600	9423	0.024734	-0.004195	-0.012585	9423	0 024734	-0.004195	-0.012585	9411	0.025341	-0.004298	-0.012893	9372	0.027313	-0.004632	-0.013897	9334	0.029235	-0.004958	-0.014875
800	9423	0.024734	-0.004195	-0.012585	9423	0.024734	-0.004195	-0.012585	9410	0.025391	-0.004306	-0.012919	9371	0.027364	-0.004641	-0.013923	9332	0.029336	-0.004975	-0.014926
1000	9423	0.024734	-0.004195	-0.012585	9423	0.024734	-0.004195	-0.012585	9409	0.025442	-0.004315	-0.012945	9366	0.027617	-0.004684	-0.014051	9326	0.029640	-0.005027	-0.015081

100Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00523				0.00918				0.02495				0.04208				0.06189			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	9112	0.040464	-0.006863	-0.020588	9112	0.040464	-0.006863	-0.020588	9109	0.040616	-0.006888	-0.020665	9083	0.041931	-0.007112	-0.021335	9043	0.043954	-0.007455	-0.022364
15	9112	0.040464	-0.006863	-0.020588	9112	0.040464	-0.006863	-0.020588	9104	0.040869	-0.006931	-0.020794	9074	0.042386	-0.007189	-0.021566	9043	0.043954	-0.007455	-0.022364
30	9112	0.040464	-0.006863	-0.020588	9112	0.040464	-0.006863	-0.020588	9104	0.040869	-0.006931	-0.020794	9074	0.042386	-0.007189	-0.021566	9043	0.043954	-0.007455	-0.022364
45	9112	0.040464	-0.006863	-0.020588	9112	0.040464	-0.006863	-0.020588	9104	0.040869	-0.006931	-0.020794	9073	0.042437	-0.007197	-0.021592	9037	0.044257	-0.007506	-0.022518
60	9112	0.040464	-0.006863	-0.020588	9112	0.040464	-0.006863	-0.020588	9104	0.040869	-0.006931	-0.020794	9072	0.042487	-0.007206	-0.021618	9035	0.044359	-0.007523	-0.022570
100	9112	0.040464	-0.006863	-0.020588	9112	0.040464	-0.006863	-0.020588	9096	0.041273	-0.007000	-0.021000	9070	0.042588	-0.007223	-0.021669	9033	0.044460	-0.007540	-0.022621
200	9112	0.040464	-0.006863	-0.020588	9110	0.040565	-0.006880	-0.020640	9094	0.041374	-0.007017	-0.021051	9064	0.042892	-0.007275	-0.021824	9030	0.044611	-0.007566	-0.022699
400	9112	0.040464	-0.006863	-0.020588	9110	0.040565	-0.006880	-0.020640	9092	0.041476	-0.007034	-0.021103	9056	0.043296	-0.007343	-0.022029	9021	0.045067	-0.007643	-0.022930
600	9112	0.040464	-0.006863	-0.020588	9109	0.040616	-0.006888	-0.020665	9090	0.041577	-0.007051	-0.021154	9053	0.043448	-0.007369	-0.022107	9014	0.045421	-0.007703	-0.023110
800	9112	0.040464	-0.006863	-0.020588	9109	0.040616	-0.006888	-0.020665	9085	0.041830	-0.007094	-0.021283	9049	0.043650	-0.007403	-0.022210	9010	0.045623	-0.007738	-0.023213
1000	9112	0.040464	-0.006863	-0.020588	9109	0.040616	-0.006888	-0.020665	9084	0.041880	-0.007103	-0.021309	9045	0.043853	-0.007438	-0.022313	9003	0.045977	-0.007798	-0.023393

DATA SHEET # 4

SAMPLE 3ST#2

INITIAL LENGTH = 5.896 inch

25 kPa @ 1000 CYCLES				
SHEAR ST. (%)	TOTAL		DYNAMIC	
	VERT. ST.	Evol	VERT. ST.	Evol
0.00561	-0.002170	-0.006511	0.000000	0.000000
0.01221	-0.002222	-0.006666	-0.000052	-0.000155
0.02866	-0.002411	-0.007233	-0.000189	-0.000567
0.04318	-0.002522	-0.007566	-0.000111	-0.000333
0.07573	-0.002848	-0.008544	-0.000326	-0.000978

50 kPa @ 1000 CYCLES				
SHEAR ST. (%)	TOTAL		DYNAMIC	
	VERT. ST.	Evol	VERT. ST.	Evol
0.00515	-0.004195	-0.012585	0.000000	0.000000
0.00941	-0.004195	-0.012585	0.000000	0.000000
0.02306	-0.004315	-0.012945	-0.000120	-0.000360
0.04674	-0.004684	-0.014052	-0.000369	-0.001107
0.05549	-0.005027	-0.015081	-0.000343	-0.001029

100 kPa @ 1000 CYCLES				
SHEAR ST. (%)	TOTAL		DYNAMIC	
	VERT. ST.	Evol	VERT. ST.	Evol
0.00523	-0.006863	-0.020589	0.000000	0.000000
0.00918	-0.006888	-0.020664	-0.000025	-0.000075
0.02495	-0.007103	-0.021309	-0.000215	-0.000645
0.04208	-0.007438	-0.022314	-0.000335	-0.001005
0.06189	-0.007798	-0.023394	-0.000360	-0.001080

DATA SHEET # 1

SAMPLE # 3ST#2L

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.8507	5.58	1.9372	0.229	2.75	0.02061	93.99212	1.576241	76.47854	0.009186	1.243767	0.506325	3054	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wa' Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
6/28/93	25	30	73	13.69863	2715	5.56305	2.842041	0.020423	1.9372	1.185029	0.000422	0.197247	0.43004	494.45	720866	34.51506	0.000318

TORSIONAL SHEAR TEST FOR 3ST#2L (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 6/28/93
Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.08	3	5.13	20	9.856	20	2.840	5.559	3.0000	25.2806	4.0020E-03	8.1781E-02	6.9016E-01	3.0792E-04	2.1217E+02	2.5943E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3 & 4

SAMPLE 3ST#2L

DATE: 06/28/93

INITIAL LENGTH = 5.58 inch e0= 1.2437 Vs= 16.94651 inch^3
INITIAL LVDT = 3054 V0= 37.3681 inch^3 STTLMT is in inches

25Kpa	SHEAR STRAIN AMPLITUDE (%) = 0.08178					
	TOTAL				DYNAMIC	
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	VERT. ST.	Evol
1	2722	0.016793	-0.003009	-0.009028	0.000000	0.000000
15	2685	0.018664	-0.003345	-0.010034	-0.000335	-0.001006
30	2676	0.019119	-0.003426	-0.010279	-0.000417	-0.001251
45	2670	0.019423	-0.003481	-0.010442	-0.000471	-0.001414
60	2663	0.019777	-0.003544	-0.010633	-0.000535	-0.001604
100	2663	0.019777	-0.003544	-0.010633	-0.000535	-0.001604
200	2658	0.020030	-0.003590	-0.010769	-0.000580	-0.001740
400	2654	0.020232	-0.003626	-0.010877	-0.000616	-0.001849
600	2652	0.020333	-0.003644	-0.010932	-0.000635	-0.001904
870	2650	0.020434	-0.003662	-0.010986	-0.000653	-0.001958
1025	2648	0.020535	-0.003680	-0.011041	-0.000671	-0.002012
2000	2642	0.020839	-0.003735	-0.011204	-0.000725	-0.002175
4000	2635	0.021193	-0.003798	-0.011394	-0.000789	-0.002366
8000	2632	0.021345	-0.003825	-0.011476	-0.000816	-0.002447
16000	2625	0.021699	-0.003889	-0.011666	-0.000879	-0.002638
32000	2620	0.021952	-0.003934	-0.011802	-0.000925	-0.002774
45900	2615	0.022205	-0.003979	-0.011938	-0.000970	-0.002910
78400	2610	0.022457	-0.004025	-0.012074	-0.001015	-0.003046
85600	2608	0.022559	-0.004043	-0.012128	-0.001033	-0.003100
92800	2606	0.022660	-0.004061	-0.012183	-0.001051	-0.003154
100000	2605	0.022710	-0.004070	-0.012210	-0.001061	-0.003182
107200	2605	0.022710	-0.004070	-0.012210	-0.001061	-0.003182
114400	2605	0.022710	-0.004070	-0.012210	-0.001061	-0.003182
121600	2605	0.022710	-0.004070	-0.012210	-0.001061	-0.003182
128000	2604	0.022761	-0.004079	-0.012237	-0.001070	-0.003209
172000	2594	0.023267	-0.004170	-0.012509	-0.001160	-0.003481
179200	2594	0.023267	-0.004170	-0.012509	-0.001160	-0.003481

DATA SHEET # 1

SAMPLE # 3ST#3

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.86833	5.783	2.13915	0.2682	2.67	0.021625	98.91998	1.686761	78.0003	0.010124	1.1359917	0.630369	7964	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
6/16/93	50	31	83	12.04819	7473	5.75845	2.856153	0.021351	2.13915	1.1089039	0.000471	0.219978	0.4525	553.05	952582.2	45.60964	0.000247
6/17/93	100	36	96	10.41667	7152	5.7424	2.848193	0.021173	2.13915	1.0913191	0.000468	0.218754	0.45132	639.56	1284603	61.50679	0.000214

TORSIONAL SHEAR TEST FOR 3ST#3 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 6/16/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.9813	5.05	1.999	1.984	40	2.843	5.733	0.1990	5.0096	2.6542E-04	5.2659E-03	1.3676E-01	3.0952E-04	4.1881E+01	7.9532E+05
0.01	2.7625	7.92	4.9595	1.984	40	2.843	5.733	0.3425	7.8566	4.5692E-04	9.0651E-03	2.1449E-01	3.0947E-04	6.5689E+01	7.2464E+05
0.025	4.0375	6.88	4.9595	4.943	20	2.843	5.732	1.0012	17.0039	1.3356E-03	2.6498E-02	4.6421E-01	3.0925E-04	1.4224E+02	5.3681E+05
0.05	3.025	4.65	10	9.856	20	2.842	5.730	1.5125	22.9152	2.0177E-03	4.0030E-02	6.2558E-01	3.0886E-04	1.9188E+02	4.7934E+05
0.1	3.5313	4.275	1.999	19.71	2	2.840	5.725	3.5295	42.1301	4.7084E-03	9.3413E-02	1.1502E+00	3.0786E-04	3.5363E+02	3.7857E+05

Date : 6/17/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.85	6.725	1.999	1.984	40	2.827	5.700	0.1924	6.6712	2.5667E-04	5.0922E-03	1.8212E-01	3.0245E-04	5.6746E+01	1.1144E+06
0.01	2.85	4.575	4.9595	4.943	40	2.827	5.700	0.3534	11.3071	4.7139E-04	9.3522E-03	3.0868E-01	3.0240E-04	9.6192E+01	1.0285E+06
0.025	3.7	4.85	4.9595	9.856	20	2.826	5.698	0.9175	23.9008	1.2240E-03	2.4283E-02	6.5249E-01	3.0213E-04	2.0347E+02	8.3789E+05
0.05	3.025	7.08	10	9.856	20	2.825	5.696	1.5125	34.8902	2.0177E-03	4.0030E-02	9.5250E-01	3.0169E-04	2.9734E+02	7.4280E+05
0.06	2.21	4.75	1.999	19.71	2	2.824	5.693	2.2089	46.8113	2.9467E-03	5.8461E-02	1.2779E+00	3.0103E-04	3.9959E+02	6.8352E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 3ST#3

DATE: 06/16/93

INITIAL LENGTH= 5.783 Inch
INITIAL LVDT = 7964

STTLMT is in Inches

e0= 1.1360
V0= 37.3681 Inch^3
Vs= 17.49449 Inch^3

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00527				0.00907				0.02649				0.04003				0.09341			
CYCLES	LVDT	STTLMT	VERT. ST	Evol	LVDT	STTLMT	VERT. ST	Evol	LVDT	STTLMT	VERT. ST	Evol	LVDT	STTLMT	VERT. ST	Evol	LVDT	STTLMT	VERT. ST	Evol
1	7474	0.024784	-0.008641	-0.025922	7472	0.024885	-0.008676	-0.026028	7470	0.024986	-0.008711	-0.026133	7452	0.025897	-0.009029	-0.027086	7433	0.026858	-0.009364	-0.028091
30	7474	0.024784	-0.008641	-0.025922	7472	0.024885	-0.008676	-0.026028	7463	0.025341	-0.008835	-0.026504	7452	0.025897	-0.009029	-0.027086	7414	0.027819	-0.009699	-0.029096
60	7474	0.024784	-0.008641	-0.025922	7472	0.024885	-0.008676	-0.026028	7463	0.025341	-0.008835	-0.026504	7450	0.025998	-0.009064	-0.027192	7407	0.028173	-0.009822	-0.029466
100	7473	0.024835	-0.008658	-0.025975	7471	0.024936	-0.008694	-0.026081	7462	0.025391	-0.008852	-0.026557	7449	0.026049	-0.009081	-0.027244	7394	0.028831	-0.010051	-0.030154
200	7473	0.024835	-0.008658	-0.025975	7470	0.024986	-0.008711	-0.026133	7460	0.025492	-0.008887	-0.026662	7446	0.026200	-0.009134	-0.027403	7390	0.029033	-0.010122	-0.030366
400	7473	0.024835	-0.008658	-0.025975	7470	0.024986	-0.008711	-0.026133	7456	0.025695	-0.008958	-0.026874	7443	0.026352	-0.009187	-0.027562	7375	0.029792	-0.010386	-0.031159
600	7473	0.024835	-0.008658	-0.025975	7470	0.024986	-0.008711	-0.026133	7454	0.025796	-0.008993	-0.026980	7442	0.026403	-0.009205	-0.027615	7371	0.029994	-0.010457	-0.031371
800	7473	0.024835	-0.008658	-0.025975	7470	0.024986	-0.008711	-0.026133	7454	0.025796	-0.008993	-0.026980	7438	0.026605	-0.009275	-0.027826	7366	0.030247	-0.010545	-0.031635
1000	7472	0.024885	-0.008676	-0.026028	7470	0.024986	-0.008711	-0.026133	7452	0.025897	-0.009029	-0.027086	7434	0.026807	-0.009346	-0.028038	7362	0.030449	-0.010616	-0.031847

100Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00509				0.00935				0.02428				0.04003				0.05846			
CYCLES	LVDT	STTLMT	VERT. ST	Evol	LVDT	STTLMT	VERT. ST	Evol	LVDT	STTLMT	VERT. ST	Evol	LVDT	STTLMT	VERT. ST	Evol	LVDT	STTLMT	VERT. ST	Evol
1	7150	0.041172	-0.014354	-0.043062	7149	0.041223	-0.014372	-0.043115	7144	0.041476	-0.014460	-0.043379	7125	0.042437	-0.014795	-0.044385	7104	0.043499	-0.015165	-0.045496
30	7150	0.041172	-0.014354	-0.043062	7150	0.041172	-0.014354	-0.043062	7142	0.041577	-0.014495	-0.043485	7124	0.042487	-0.014812	-0.044437	7102	0.043600	-0.015200	-0.045601
60	7149	0.041223	-0.014372	-0.043115	7150	0.041172	-0.014354	-0.043062	7134	0.041981	-0.014636	-0.043908	7122	0.042588	-0.014848	-0.044543	7095	0.043954	-0.015324	-0.045972
100	7149	0.041223	-0.014372	-0.043115	7146	0.041374	-0.014425	-0.043274	7133	0.042032	-0.014654	-0.043961	7121	0.042639	-0.014865	-0.044596	7094	0.044005	-0.015342	-0.046025
200	7149	0.041223	-0.014372	-0.043115	7146	0.041374	-0.014425	-0.043274	7132	0.042082	-0.014671	-0.044014	7116	0.042892	-0.014954	-0.044861	7090	0.044207	-0.015412	-0.046236
400	7149	0.041223	-0.014372	-0.043115	7146	0.041374	-0.014425	-0.043274	7130	0.042184	-0.014707	-0.044120	7112	0.043094	-0.015024	-0.045072	7084	0.044510	-0.015518	-0.046554
600	7149	0.041223	-0.014372	-0.043115	7145	0.041425	-0.014442	-0.043327	7129	0.042234	-0.014724	-0.044173	7110	0.043195	-0.015059	-0.045178	7072	0.045117	-0.015729	-0.047188
800	7149	0.041223	-0.014372	-0.043115	7145	0.041425	-0.014442	-0.043327	7126	0.042386	-0.014777	-0.044332	7105	0.043448	-0.015148	-0.045443	7070	0.045218	-0.015765	-0.047294
1000	7149	0.041223	-0.014372	-0.043115	7145	0.041425	-0.014442	-0.043327	7125	0.042437	-0.014795	-0.044385	7103	0.043549	-0.015183	-0.045548	7063	0.045572	-0.015888	-0.047664

DATA SHEET # 4

SAMPLE 3ST#3

INITIAL LENGTH = 5.783 inch

50 kPa @ 1000 CYCLES				
SHEAR ST. (%)	TOTAL		DYNAMIC	
	VERT. ST.	Evol	VERT. ST.	Evol
0.00527	-0.008676	-0.026028	0.000000	0.000000
0.00907	-0.008711	-0.026133	-0.000035	-0.000105
0.02649	-0.009029	-0.027087	-0.000318	-0.000954
0.04003	-0.009346	-0.028038	-0.000317	-0.000951
0.09341	-0.010616	-0.031848	-0.001270	-0.003810

100 kPa @ 1000 CYCLES				
SHEAR ST. (%)	TOTAL		DYNAMIC	
	VERT. ST.	Evol	VERT. ST.	Evol
0.00509	-0.014372	-0.043115	0.000000	0.000000
0.00935	-0.014442	-0.043326	-0.000070	-0.000211
0.02428	-0.014795	-0.044385	-0.000353	-0.001059
0.04003	-0.015183	-0.045549	-0.000388	-0.001164
0.05846	-0.015888	-0.047664	-0.000705	-0.002115

DATA SHEET # 1

SAMPLE # 3ST#4

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.86267	5.72483	2.01526	0.2355	2.657	0.021323	94.51052	1.631129	76.49576	0.009838	1.167398	0.535998	6210	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wa' Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
7/7/93	25	43	67	14.92537	5809	5.70478	2.852644	0.0211	2.01526	1.144706	0.000443	0.206729	0.43959	455.26	615358.9	29.46338	0.00053
7/8/93	50	48	77	12.98701	5465	5.68758	2.844043	0.02091	2.01526	1.125365	0.00044	0.205484	0.43835	523.11	819832.8	39.25359	0.000448
7/10/93	100	48	87	11.49425	4984	5.66353	2.832017	0.020645	2.01526	1.098517	0.000436	0.20375	0.43662	590.88	1059394	50.72377	0.000351

TORSIONAL SHEAR TEST FOR 3ST#4 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 7/7/93
Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.457	3.59	1.999	1.984	40	2.852	5.704	0.2227	3.5613	2.9713E-04	5.9432E-03	9.7223E-02	3.1344E-04	2.9493E+01	4.9624E+05
0.01	3.314286	5.78	4.9595	1.984	40	2.852	5.704	0.4109	5.7338	5.4818E-04	1.0965E-02	1.5653E-01	3.1332E-04	4.7497E+01	4.3319E+05
0.025	4.683333	4.85	10	4.943	40	2.852	5.703	1.1708	11.9868	1.5619E-03	3.1241E-02	3.2724E-01	3.1309E-04	9.9351E+01	3.1802E+05
0.05	3.558333	6.4	10	4.943	20	2.851	5.702	1.7792	15.8176	2.3734E-03	4.7472E-02	4.3182E-01	3.1284E-04	1.3118E+02	2.7633E+05
0.1	3.418	5.08	1.999	9.856	2	2.850	5.700	3.4163	25.0342	4.5573E-03	9.1155E-02	6.8343E-01	3.1248E-04	2.0780E+02	2.2796E+05

Date : 7/9/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.838333	4.35	1.999	1.984	40	2.844	5.687	0.1918	4.3152	2.5589E-04	5.1182E-03	1.1780E-01	3.0961E-04	3.6067E+01	7.0469E+05
0.01	3.033333	3.03	4.9595	4.943	40	2.844	5.687	0.3761	7.4886	5.0171E-04	1.0035E-02	2.0444E-01	3.0956E-04	6.2599E+01	6.2379E+05
0.025	4.141667	6.28	10	4.943	40	2.843	5.686	1.0354	15.5210	1.3812E-03	2.7627E-02	4.2372E-01	3.0943E-04	1.2978E+02	4.6977E+05
0.05	3.455	4.5	10	9.856	20	2.843	5.685	1.7275	22.1760	2.3045E-03	4.6094E-02	6.0540E-01	3.0920E-04	1.8554E+02	4.0252E+05
0.1	3.135	6.88	1.999	9.856	2	2.842	5.683	3.1334	33.9046	4.1800E-03	8.3607E-02	9.2560E-01	3.0877E-04	2.8396E+02	3.3963E+05

Date : 7/11/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.5	5.53	1.999	1.984	40	2.831	5.662	0.1749	5.4858	2.3333E-04	4.6671E-03	1.4976E-01	3.0423E-04	4.6457E+01	9.9542E+05
0.01	3.193333	4.35	4.9595	4.943	40	2.831	5.662	0.3959	10.7510	5.2818E-04	1.0564E-02	2.9350E-01	3.0421E-04	9.1053E+01	8.6188E+05
0.025	3.641667	4.12	10	9.856	40	2.831	5.661	0.9104	20.3034	1.2145E-03	2.4292E-02	5.5428E-01	3.0411E-04	1.7200E+02	7.0803E+05
0.05	3.016667	6	10	9.856	20	2.831	5.661	1.5083	29.5680	2.0121E-03	4.0246E-02	8.0721E-01	3.0391E-04	2.5060E+02	6.2268E+05
0.075	2.641667	4.58	2	19.71	2	2.830	5.659	2.6417	45.1359	3.5240E-03	7.0486E-02	1.2322E+00	3.0350E-04	3.8294E+02	5.4329E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 3ST#4

DATE: 07/07/93

INITIAL LENGTH= 5.72483 inch
INITIAL LVDT = 6210

STTLMT is in inches

e0= 1.167398
V0= 36.8464 inch^3

Vs= 17.00029 inch^3

25Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00594				0.01097				0.03124				0.04747				0.09116			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	5810	0.020232	-0.003534	-0.010602	5803	0.020586	-0.003596	-0.010788	5789	0.021294	-0.003720	-0.011159	5761	0.022710	-0.003967	-0.011901	5745	0.023520	-0.004108	-0.012325
30	5805	0.020485	-0.003578	-0.010735	5804	0.020535	-0.003587	-0.010761	5774	0.022053	-0.003852	-0.011556	5756	0.022963	-0.004011	-0.012034	5734	0.024076	-0.004206	-0.012617
60	5805	0.020485	-0.003578	-0.010735	5803	0.020586	-0.003596	-0.010788	5771	0.022205	-0.003879	-0.011636	5755	0.023014	-0.004020	-0.012060	5724	0.024582	-0.004294	-0.012882
100	5805	0.020485	-0.003578	-0.010735	5803	0.020586	-0.003596	-0.010788	5769	0.022306	-0.003896	-0.011689	5752	0.023166	-0.004047	-0.012140	5721	0.024734	-0.004320	-0.012961
200	5805	0.020485	-0.003578	-0.010735	5791	0.021193	-0.003702	-0.011106	5768	0.022356	-0.003905	-0.011715	5752	0.023166	-0.004047	-0.012140	5716	0.024986	-0.004365	-0.013094
400	5805	0.020485	-0.003578	-0.010735	5791	0.021193	-0.003702	-0.011106	5764	0.022559	-0.003940	-0.011821	5751	0.023216	-0.004055	-0.012166	5710	0.025290	-0.004418	-0.013253
600	5804	0.020535	-0.003587	-0.010761	5789	0.021294	-0.003720	-0.011159	5762	0.022660	-0.003958	-0.011874	5746	0.023469	-0.004100	-0.012299	5704	0.025593	-0.004471	-0.013412
800	5804	0.020535	-0.003587	-0.010761	5789	0.021294	-0.003720	-0.011159	5761	0.022710	-0.003967	-0.011901	5743	0.023621	-0.004126	-0.012378	5699	0.025846	-0.004515	-0.013544
1000	5803	0.020586	-0.003596	-0.010788	5789	0.021294	-0.003720	-0.011159	5761	0.022710	-0.003967	-0.011901	5743	0.023621	-0.004126	-0.012378	5694	0.026099	-0.004559	-0.013677

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00512				0.01003				0.02763				0.04609				0.08361			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	5461	0.037884	-0.006618	-0.019853	5459	0.037986	-0.006635	-0.019906	5454	0.038238	-0.006679	-0.020038	5433	0.039301	-0.006865	-0.020595	5414	0.040262	-0.007033	-0.021098
30	5459	0.037986	-0.006635	-0.019906	5458	0.038036	-0.006644	-0.019932	5451	0.038390	-0.006706	-0.020118	5432	0.039351	-0.006874	-0.020621	5403	0.040818	-0.007130	-0.021390
60	5459	0.037986	-0.006635	-0.019906	5456	0.038137	-0.006662	-0.019985	5450	0.038441	-0.006715	-0.020144	5431	0.039402	-0.006883	-0.020648	5390	0.041476	-0.007245	-0.021735
100	5459	0.037986	-0.006635	-0.019906	5456	0.038137	-0.006662	-0.019985	5446	0.038643	-0.006750	-0.020250	5430	0.039452	-0.006891	-0.020674	5386	0.041678	-0.007280	-0.021841
200	5459	0.037986	-0.006635	-0.019906	5456	0.038137	-0.006662	-0.019985	5444	0.038744	-0.006768	-0.020303	5423	0.039806	-0.006953	-0.020860	5374	0.042285	-0.007386	-0.022159
400	5459	0.037986	-0.006635	-0.019906	5456	0.038137	-0.006662	-0.019985	5442	0.038845	-0.006785	-0.020356	5422	0.039857	-0.006962	-0.020886	5366	0.042689	-0.007457	-0.022371
600	5459	0.037986	-0.006635	-0.019906	5453	0.038289	-0.006688	-0.020065	5436	0.039149	-0.006838	-0.020515	5416	0.040160	-0.007015	-0.021045	5362	0.042892	-0.007492	-0.022477
800	5459	0.037986	-0.006635	-0.019906	5453	0.038289	-0.006688	-0.020065	5435	0.039199	-0.006847	-0.020542	5414	0.040262	-0.007033	-0.021098	5359	0.043043	-0.007519	-0.022556
1000	5459	0.037986	-0.006635	-0.019906	5453	0.038289	-0.006688	-0.020065	5434	0.039250	-0.006856	-0.020568	5413	0.040312	-0.007042	-0.021125	5354	0.043296	-0.007563	-0.022689

100Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00467				0.01056				0.02429				0.04025				0.07049			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	4969	0.062770	-0.010964	-0.032893	4969	0.062770	-0.010964	-0.032893	4964	0.063023	-0.011009	-0.033026	4952	0.063630	-0.011115	-0.033344	4930	0.064742	-0.011309	-0.033927
30	4969	0.062770	-0.010964	-0.032893	4970	0.062719	-0.010956	-0.032867	4962	0.063124	-0.011026	-0.033079	4949	0.063781	-0.011141	-0.033423	4919	0.065299	-0.011406	-0.034219
60	4969	0.062770	-0.010964	-0.032893	4970	0.062719	-0.010956	-0.032867	4962	0.063124	-0.011026	-0.033079	4946	0.063933	-0.011168	-0.033503	4913	0.065602	-0.011459	-0.034378
100	4969	0.062770	-0.010964	-0.032893	4970	0.062719	-0.010956	-0.032867	4961	0.063174	-0.011035	-0.033105	4945	0.063984	-0.011177	-0.033530	4910	0.065754	-0.011486	-0.034457
200	4969	0.062770	-0.010964	-0.032893	4966	0.062921	-0.010991	-0.032973	4956	0.063427	-0.011079	-0.033238	4942	0.064135	-0.011203	-0.033609	4904	0.066057	-0.011539	-0.034616
400	4969	0.062770	-0.010964	-0.032893	4966	0.062921	-0.010991	-0.032973	4954	0.063528	-0.011097	-0.033291	4935	0.064489	-0.011265	-0.033795	4992	0.061606	-0.010761	-0.032284
600	4969	0.062770	-0.010964	-0.032893	4966	0.062921	-0.010991	-0.032973	4953	0.063579	-0.011106	-0.033317	4932	0.064641	-0.011291	-0.033874	4885	0.067018	-0.011707	-0.035120
800	4969	0.062770	-0.010964	-0.032893	4965	0.062972	-0.011000	-0.032999	4952	0.063630	-0.011115	-0.033344	4929	0.064793	-0.011318	-0.033954	4874	0.067575	-0.011804	-0.035411
1000	4969	0.062770	-0.010964	-0.032893	4964	0.063023	-0.011009	-0.033026	4951	0.063680	-0.011123	-0.033370	4926	0.064945	-0.011344	-0.034033	4872	0.067676	-0.011821	-0.035464

DATA SHEET # 4

SAMPLE 3ST#4

INITIAL LENGTH = 5.725 inch

25 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00594	-0.003596	-0.010788	0.000000	0.000000
0.01097	-0.003720	-0.011159	-0.000124	-0.000371
0.03124	-0.003967	-0.011901	-0.000247	-0.000742
0.04747	-0.004126	-0.012378	-0.000159	-0.000477
0.09116	-0.004559	-0.013677	-0.000433	-0.001299

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00512	-0.006635	-0.019905	0.000000	0.000000
0.01003	-0.006688	-0.020064	-0.000053	-0.000159
0.02763	-0.006856	-0.020568	-0.000168	-0.000504
0.04609	-0.007042	-0.021125	-0.000186	-0.000557
0.08361	-0.007563	-0.022689	-0.000521	-0.001564

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00467	-0.010964	-0.032892	0.000000	0.000000
0.01056	-0.011009	-0.033027	-0.000045	-0.000135
0.02429	-0.011123	-0.033369	-0.000114	-0.000342
0.04025	-0.011344	-0.034033	-0.000221	-0.000664
0.07049	-0.011821	-0.035463	-0.000477	-0.001430

DATA SHEET # 1

SAMPLE # 3ST#5L

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.8743	5.7243	1.97888	0.1842	2.694	0.021495	92.0634	1.671069	77.74312	0.009941	1.1623213	0.4269343	6303	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
7/26/93	25	31	74	13.51351	5962	5.707052	2.86564	0.021301	1.9788796	1.1428344	0.000438	0.204851	0.43771	505.19	737018.3	35.28844	0.000315

TORSIONAL SHEAR TEST FOR 3ST#5L (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 7/26/93
Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.08	6.95	5.5	10	9.856	20	2.874	5.724	3.4750	27.1040	4.6357E-03	9.3107E-02	7.3994E-01	3.2315E-04	2.1938E+02	2.3564E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3 & 4

SAMPLE 3ST#5L

DATE: 7/26/93

INITIAL LENGTH = 5.724 inch   e0= 1.1623   Vs= 17.17752 inch^3
INITIAL LVDT = 6303   V0= 37.14296 inch^3   STTLMT is in inches

25Kpa	SHEAR STRAIN AMPLITUDE (%) = 0.09311					
	TOTAL				DYNAMIC	
CYCLES	LVDT	STTLMT	VERT. ST	Evol	VERT. ST	Evol
1	5969	0.016894	-0.002951	-0.008854	0.000000	0.000000
15	5936	0.018563	-0.003243	-0.009728	-0.000292	-0.000875
30	5920	0.019372	-0.003384	-0.010153	-0.000433	-0.001299
45	5916	0.019574	-0.003420	-0.010259	-0.000468	-0.001405
60	5915	0.019625	-0.003428	-0.010285	-0.000477	-0.001431
100	5914	0.019676	-0.003437	-0.010312	-0.000486	-0.001458
200	5912	0.019777	-0.003455	-0.010365	-0.000504	-0.001511
400	5907	0.020030	-0.003499	-0.010497	-0.000548	-0.001643
600	5903	0.020232	-0.003534	-0.010603	-0.000583	-0.001750
800	5900	0.020384	-0.003561	-0.010683	-0.000610	-0.001829
1000	5895	0.020637	-0.003605	-0.010815	-0.000654	-0.001962
2000	5890	0.020889	-0.003649	-0.010948	-0.000698	-0.002094
4000	5881	0.021345	-0.003729	-0.011186	-0.000778	-0.002333
8000	5872	0.021800	-0.003808	-0.011425	-0.000857	-0.002571
16000	5865	0.022154	-0.003870	-0.011611	-0.000919	-0.002757
32000	5857	0.022559	-0.003941	-0.011823	-0.000990	-0.002969
42800	5855	0.022660	-0.003959	-0.011876	-0.001007	-0.003022
75200	5846	0.023115	-0.004038	-0.012114	-0.001087	-0.003260
83100	5846	0.023115	-0.004038	-0.012114	-0.001087	-0.003260
93900	5846	0.023115	-0.004038	-0.012114	-0.001087	-0.003260
124500	5842	0.023317	-0.004073	-0.012220	-0.001122	-0.003367
168600	5839	0.023469	-0.004100	-0.012300	-0.001149	-0.003446
179400	5839	0.023469	-0.004100	-0.012300	-0.001149	-0.003446

DATA SHEET # 1

SAMPLE # 3ST#6

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.91533	5.83967	2.3925	0.195	2.746	0.022558	106.0578	2.002092	88.75126	0.011684	0.930681	0.575353	8450	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wa Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
7/20/93	50	29	85	11.76471	7338	5.783425	2.887251	0.021913	2.3925	0.875431	0.000538	0.251418	0.48135	534.74	970473.2	46.46626	0.000222
7/21/93	100	28	96	10.41667	6658	5.749031	2.87008	0.021524	2.3925	0.84217	0.000532	0.248436	0.47871	603.66	1259087	60.28507	0.000168

TORSIONAL SHEAR TEST FOR 3ST#6 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 7/20/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	5.416667	5.8	1.999	1.984	40	2.915	5.840	0.2707	5.7536	3.6111E-04	7.2111E-03	1.5707E-01	3.4200E-04	4.4632E+01	6.1893E+05
0.01	4.05	3.9	4.9595	4.943	40	2.915	5.840	0.5021	9.6389	6.6987E-04	1.3377E-02	2.6314E-01	3.4200E-04	7.4770E+01	5.5896E+05
0.025	4.87	3.6	10	9.856	40	2.915	5.840	1.2175	17.7408	1.6241E-03	3.2433E-02	4.8432E-01	3.4200E-04	1.3762E+02	4.2432E+05
0.05	3.82	4.9	10	9.856	20	2.915	5.840	1.9100	24.1472	2.5479E-03	5.0880E-02	6.5922E-01	3.4200E-04	1.8731E+02	3.6815E+05
0.1	3.65	3.75	1.999	19.71	2	2.915	5.840	3.6482	36.9563	4.8667E-03	9.7183E-02	1.0089E+00	3.4200E-04	2.8668E+02	2.9499E+05

Date : 7/21/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.253333	6.95	1.999	1.984	40	2.915	5.840	0.2126	6.8944	2.8356E-04	5.6624E-03	1.8822E-01	3.4200E-04	5.3481E+01	9.4450E+05
0.01	3.081667	4.55	4.9595	4.943	40	2.915	5.840	0.3821	11.2453	5.0971E-04	1.0178E-02	3.0700E-01	3.4200E-04	8.7232E+01	8.5703E+05
0.025	3.786667	4.48	10	9.856	40	2.915	5.840	0.9467	22.0774	1.2629E-03	2.5218E-02	6.0271E-01	3.4200E-04	1.7126E+02	6.7911E+05
0.05	3.088333	6.38	10	9.856	20	2.915	5.840	1.5442	31.4406	2.0599E-03	4.1135E-02	8.5833E-01	3.4200E-04	2.4389E+02	5.9291E+05
0.075	2.501667	4.57	20	19.71	20	2.915	5.840	2.5017	45.0374	3.3372E-03	6.6641E-02	1.2295E+00	3.4200E-04	3.4936E+02	5.2424E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 3ST#6

DATE: 05/27/93

INITIAL LENGTH= 5.83967 Inch STTLMT is in inches e0= 0.93068
INITIAL LVDT = 8450 V0= 36.4519 inch^3 Vs= 20.3384 inch^3

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00721				0.01338				0.03243				0.05088				0.09718			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	7423	0.051946	-0.008895	-0.026686	7422	0.051996	-0.008904	-0.026712	7413	0.052451	-0.008982	-0.026946	7384	0.053918	-0.009233	-0.027699	7360	0.055132	-0.009441	-0.028323
30	7424	0.051895	-0.008887	-0.026660	7421	0.052047	-0.008913	-0.026738	7408	0.052704	-0.009025	-0.027076	8383	0.003389	-0.000580	-0.001741	7335	0.056397	-0.009657	-0.028972
60	7424	0.051895	-0.008887	-0.026660	7421	0.052047	-0.008913	-0.026738	7405	0.052856	-0.009051	-0.027154	7374	0.054424	-0.009320	-0.027959	7331	0.056599	-0.009692	-0.029076
100	7424	0.051895	-0.008887	-0.026660	7419	0.052148	-0.008930	-0.026790	7404	0.052907	-0.009060	-0.027180	7373	0.054475	-0.009328	-0.027985	7326	0.056852	-0.009735	-0.029206
200	7422	0.051996	-0.008904	-0.026712	7420	0.052097	-0.008921	-0.026764	7393	0.053463	-0.009155	-0.027465	7371	0.054576	-0.009346	-0.028037	7319	0.057206	-0.009796	-0.029388
400	7422	0.051996	-0.008904	-0.026712	7416	0.052300	-0.008956	-0.026868	7391	0.053564	-0.009172	-0.027517	7365	0.054879	-0.009398	-0.028193	7312	0.057560	-0.009857	-0.029570
600	7422	0.051996	-0.008904	-0.026712	7416	0.052300	-0.008956	-0.026868	7388	0.053716	-0.009198	-0.027595	7362	0.055031	-0.009424	-0.028271	7306	0.057863	-0.009909	-0.029726
800	7422	0.051996	-0.008904	-0.026712	7413	0.052451	-0.008982	-0.026946	7385	0.053868	-0.009224	-0.027673	7361	0.055082	-0.009432	-0.028297	7298	0.058268	-0.009978	-0.029934
1000	7422	0.051996	-0.008904	-0.026712	7413	0.052451	-0.008982	-0.026946	7384	0.053918	-0.009233	-0.027699	7357	0.055284	-0.009467	-0.028401	7292	0.058572	-0.010030	-0.030090

100Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00566				0.01018				0.02522				0.04114				0.06664			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	6732	0.086896	-0.014880	-0.044641	6729	0.087048	-0.014906	-0.044719	6722	0.087402	-0.014967	-0.044901	6692	0.088919	-0.015227	-0.045680	6654	0.090841	-0.015556	-0.046668
15	6732	0.086896	-0.014880	-0.044641	6730	0.086997	-0.014898	-0.044693	6714	0.087807	-0.015036	-0.045109					6652	0.090943	-0.015573	-0.046720
30	6732	0.086896	-0.014880	-0.044641	6726	0.087200	-0.014932	-0.044797	6714	0.087807	-0.015036	-0.045109	6686	0.089223	-0.015279	-0.045836	6649	0.091094	-0.015599	-0.046798
45	6732	0.086896	-0.014880	-0.044641	6726	0.087200	-0.014932	-0.044797	6713	0.087857	-0.015045	-0.045135					6645	0.091297	-0.015634	-0.046902
60	6732	0.086896	-0.014880	-0.044641	6726	0.087200	-0.014932	-0.044797	6712	0.087908	-0.015054	-0.045161	6685	0.089274	-0.015287	-0.045862	6644	0.091347	-0.015643	-0.046928
100	6732	0.086896	-0.014880	-0.044641	6726	0.087200	-0.014932	-0.044797	6711	0.087958	-0.015062	-0.045187	6683	0.089375	-0.015305	-0.045914	6635	0.091803	-0.015720	-0.047161
200	6732	0.086896	-0.014880	-0.044641	6725	0.087250	-0.014941	-0.044823	6706	0.088211	-0.015106	-0.045317	6673	0.089880	-0.015391	-0.046174	6629	0.092106	-0.015772	-0.047317
400	6731	0.086947	-0.014889	-0.044667	6724	0.087301	-0.014950	-0.044849	6703	0.088363	-0.015132	-0.045395	6666	0.090235	-0.015452	-0.046356	6620	0.092561	-0.015850	-0.047551
600	6730	0.086997	-0.014898	-0.044693	6724	0.087301	-0.014950	-0.044849	6695	0.088768	-0.015201	-0.045602	6663	0.090386	-0.015478	-0.046434	6614	0.092865	-0.015902	-0.047707
800	6730	0.086997	-0.014898	-0.044693	6723	0.087351	-0.014958	-0.044875	6694	0.088818	-0.015209	-0.045628	6660	0.090538	-0.015504	-0.046512	6608	0.093168	-0.015954	-0.047863
1000	6729	0.087048	-0.014906	-0.044719	6722	0.087402	-0.014967	-0.044901	6692	0.088919	-0.015227	-0.045680	6654	0.090841	-0.015556	-0.046668	6603	0.093421	-0.015998	-0.047993

DATA SHEET # 4

SAMPLE 3ST#6

INITIAL LENGTH = 5.839 inch

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00721	-0.008904	-0.026712	0.000000	0.000000
0.01338	-0.008982	-0.026946	-0.000078	-0.000234
0.03243	-0.009233	-0.027699	-0.000251	-0.000753
0.05088	-0.009467	-0.028401	-0.000234	-0.000702
0.09718	-0.010030	-0.030090	-0.000563	-0.001689

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00566	-0.014906	-0.044718	0.000000	0.000000
0.01018	-0.014967	-0.044901	-0.000061	-0.000183
0.02522	-0.015227	-0.045681	-0.000260	-0.000780
0.04114	-0.015556	-0.046668	-0.000329	-0.000987
0.06664	-0.015998	-0.047994	-0.000442	-0.001326

DATA SHEET # 1

SAMPLE # 3ST#8

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.8687	5.5722	1.9427	0.2279	2.72	0.020642	93.21011	1.5821321	75.91018	0.009322	1:2359057	0.5015658	8450	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
8/12/93	25	33	69	14.49275	8053	5.55235	2.858481	0.02062	1.9427	1.2120957	0.000428	0.200102	0.43294	463.34	628715.9	30.10292	0.000395
8/13/93	50	33	79	12.65823	7735	5.53645	2.850295	0.020444	1.9427	1.193146	0.000426	0.198958	0.43179	530.38	830933.3	39.78509	0.000301
8/16/93	100	34	92	10.86957	7319	5.51565	2.839587	0.020214	1.9427	1.1685204	0.000423	0.197465	0.43027	617.51	1139162	54.54306	0.000229

TORSIONAL SHEAR TEST FOR 3ST#8 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 8/12/93
Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.267	3.43	1.999	1.984	40	2.869	5.572	0.2132	3.4026	2.8444E-04	5.8575E-03	9.2890E-02	3.2064E-04	2.7702E+01	4.7293E+05
0.01	2.883	5.2	4.9595	1.984	40	2.869	5.572	0.3575	5.1584	4.7690E-04	9.8208E-03	1.4082E-01	3.2064E-04	4.1998E+01	4.2764E+05
0.025	3.617	4.03	10	4.943	40	2.869	5.572	0.9043	9.9601	1.2063E-03	2.4842E-02	2.7191E-01	3.2064E-04	8.1092E+01	3.2644E+05
0.05	2.942	5.65	10	4.943	20	2.869	5.572	1.4708	13.9640	1.9621E-03	4.0405E-02	3.8122E-01	3.2064E-04	1.1369E+02	2.8137E+05
0.1	4.630	6.13	1.999	9.856	2	2.869	5.572	4.6277	30.2086	6.1733E-03	1.2713E-01	8.2470E-01	3.2064E-04	2.4595E+02	1.9347E+05

Date : 8/13/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.258	3.85	1.999	1.984	40	2.869	5.572	0.1628	3.8192	2.1722E-04	4.4732E-03	1.0426E-01	3.2064E-04	3.1094E+01	6.9512E+05
0.01	2.860	7.42	4.9595	1.984	40	2.869	5.572	0.3546	7.3606	4.7304E-04	9.7413E-03	2.0095E-01	3.2064E-04	5.9928E+01	6.1519E+05
0.025	4.008	6.22	10	4.943	40	2.869	5.572	1.0021	15.3727	1.3368E-03	2.7528E-02	4.1968E-01	3.2064E-04	1.2516E+02	4.5466E+05
0.05	3.332	4.47	10	9.856	20	2.869	5.572	1.6658	22.0282	2.2222E-03	4.5762E-02	6.0137E-01	3.2064E-04	1.7935E+02	3.9191E+05
0.1	3.290	7.3	1.999	9.856	2	2.869	5.572	3.2884	35.9744	4.3867E-03	9.0334E-02	9.8210E-01	3.2064E-04	2.9289E+02	3.2423E+05

Date : 8/16/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.785	6.15	1.999	1.984	40	2.869	5.572	0.1892	6.1008	2.5233E-04	5.1963E-03	1.6655E-01	3.2064E-04	4.9670E+01	9.5588E+05
0.01	2.693	4.13	4.9595	4.943	40	2.869	5.572	0.3339	10.2073	4.4548E-04	9.1737E-03	2.7866E-01	3.2064E-04	8.3104E+01	9.0590E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 3ST#8

DATE: 08/16/93

INITIAL LENGTH= 5.5722 Inch
INITIAL LVDT = 8450

STTLMT is in Inches

e0= 1.2359
V0= 36.01528 Inch^3 Vs= 16.10773 Inch^3

25Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00586				0.00982				0.0248				0.0404				0.1271			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT.	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	8054	0.020030	-0.003595	-0.010784	8052	0.020131	-0.003613	-0.010838	8049	0.020283	-0.003640	-0.010920	8030	0.021244	-0.003812	-0.011437	8014	0.022053	-0.003958	-0.011873
15	8052	0.020131	-0.003613	-0.010838	8052	0.020131	-0.003613	-0.010838	8043	0.020586	-0.003694	-0.011083	8029	0.021294	-0.003821	-0.011464				
30	8052	0.020131	-0.003613	-0.010838	8051	0.020181	-0.003622	-0.010865	8043	0.020586	-0.003694	-0.011083	8029	0.021294	-0.003821	-0.011464	7930	0.026302	-0.004720	-0.014160
45	8052	0.020131	-0.003613	-0.010838	8051	0.020181	-0.003622	-0.010865	8042	0.020637	-0.003703	-0.011110	8026	0.021446	-0.003849	-0.011546				
60	8052	0.020131	-0.003613	-0.010838	8051	0.020181	-0.003622	-0.010865	8042	0.020637	-0.003703	-0.011110	8026	0.021446	-0.003849	-0.011546	7922	0.026706	-0.004793	-0.014378
100	8052	0.020131	-0.003613	-0.010838	8051	0.020181	-0.003622	-0.010865	8036	0.020940	-0.003758	-0.011274	8025	0.021496	-0.003858	-0.011573	7919	0.026858	-0.004820	-0.014460
200	8052	0.020131	-0.003613	-0.010838	8051	0.020181	-0.003622	-0.010865	8034	0.021041	-0.003776	-0.011328	8023	0.021598	-0.003876	-0.011628	7913	0.027161	-0.004874	-0.014623
400	8052	0.020131	-0.003613	-0.010838	8049	0.020283	-0.003640	-0.010920	8033	0.021092	-0.003785	-0.011356	8021	0.021699	-0.003894	-0.011682	7910	0.027313	-0.004902	-0.014705
600	8052	0.020131	-0.003613	-0.010838	8049	0.020283	-0.003640	-0.010920	8032	0.021142	-0.003794	-0.011383	8016	0.021952	-0.003939	-0.011818	7905	0.027566	-0.004947	-0.014841
800	8052	0.020131	-0.003613	-0.010838	8049	0.020283	-0.003640	-0.010920	8032	0.021142	-0.003794	-0.011383	8014	0.022053	-0.003958	-0.011873	7903	0.027667	-0.004965	-0.014896
1000	8052	0.020131	-0.003613	-0.010838	8049	0.020283	-0.003640	-0.010920	8030	0.021244	-0.003812	-0.011437	8014	0.022053	-0.003958	-0.011873	7898	0.027920	-0.005011	-0.015032

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00447				0.00974				0.0275				0.0458				0.0903			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	7735	0.036165	-0.006490	-0.019471	7733	0.036266	-0.006508	-0.019525	7731	0.036367	-0.006526	-0.019579	7713	0.037277	-0.006690	-0.020070	7694	0.038238	-0.006862	-0.020587
15	7735	0.036165	-0.006490	-0.019471	7733	0.036266	-0.006508	-0.019525	7726	0.036620	-0.006572	-0.019716	7712	0.037328	-0.006699	-0.020097	7685	0.038694	-0.006944	-0.020832
30	7735	0.036165	-0.006490	-0.019471	7733	0.036266	-0.006508	-0.019525	7724	0.036721	-0.006590	-0.019770	7712	0.037328	-0.006699	-0.020097	7673	0.039301	-0.007053	-0.021159
45	7734	0.036215	-0.006499	-0.019498	7733	0.036266	-0.006508	-0.019525	7724	0.036721	-0.006590	-0.019770	7711	0.037379	-0.006708	-0.020124	7670	0.039452	-0.007080	-0.021241
60	7734	0.036215	-0.006499	-0.019498	7732	0.036316	-0.006517	-0.019552	7724	0.036721	-0.006590	-0.019770	7711	0.037379	-0.006708	-0.020124	7669	0.039503	-0.007089	-0.021268
100	7733	0.036266	-0.006508	-0.019525	7732	0.036316	-0.006517	-0.019552	7724	0.036721	-0.006590	-0.019770	7710	0.037429	-0.006717	-0.020151	7664	0.039756	-0.007135	-0.021404
200	7733	0.036266	-0.006508	-0.019525	7732	0.036316	-0.006517	-0.019552	7722	0.036822	-0.006608	-0.019825	7704	0.037733	-0.006772	-0.020315	7659	0.040009	-0.007180	-0.021540
400	7733	0.036266	-0.006508	-0.019525	7732	0.036316	-0.006517	-0.019552	7719	0.036974	-0.006635	-0.019906	7703	0.037783	-0.006781	-0.020342	7651	0.040413	-0.007253	-0.021758
600	7733	0.036266	-0.006508	-0.019525	7732	0.036316	-0.006517	-0.019552	7714	0.037227	-0.006681	-0.020042	7694	0.038238	-0.006862	-0.020587	7644	0.040767	-0.007316	-0.021949
800	7733	0.036266	-0.006508	-0.019525	7731	0.036367	-0.006526	-0.019579	7714	0.037227	-0.006681	-0.020042	7693	0.038289	-0.006871	-0.020614	7641	0.040919	-0.007343	-0.022030
1000	7734	0.036215	-0.006499	-0.019498	7731	0.036367	-0.006526	-0.019579	7713	0.037277	-0.006690	-0.020070	7692	0.038340	-0.006881	-0.020642	7634	0.041273	-0.007407	-0.022221

100Kpa	SHEAR STRAIN AMPLITUDE (%)							
	0.0052				0.00917			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	7325	0.056902	-0.010212	-0.030636	7325	0.056902	-0.010212	-0.030636
15	7325	0.056902	-0.010212	-0.030636	7324	0.056953	-0.010221	-0.030663
30	7325	0.056902	-0.010212	-0.030636	7324	0.056953	-0.010221	-0.030663
45	7325	0.056902	-0.010212	-0.030636	7324	0.056953	-0.010221	-0.030663
60	7325	0.056902	-0.010212	-0.030636	7324	0.056953	-0.010221	-0.030663
100	7325	0.056902	-0.010212	-0.030636	7324	0.056953	-0.010221	-0.030663
200	7325	0.056902	-0.010212	-0.030636	7323	0.057004	-0.010230	-0.030690
400	7325	0.056902	-0.010212	-0.030636	7323	0.057004	-0.010230	-0.030690
600	7325	0.056902	-0.010212	-0.030636	7323	0.057004	-0.010230	-0.030690
800	7325	0.056902	-0.010212	-0.030636	7324	0.056953	-0.010221	-0.030663
1000	7325	0.056902	-0.010212	-0.030636	7324	0.056953	-0.010221	-0.030663

DATA SHEET # 4

SAMPLE 3ST#8

INITIAL LENGTH = 5.572 inch

25 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00586	-0.003613	-0.010839	0.000000	0.000000
0.00982	-0.003640	-0.010920	-0.000027	-0.000081
0.0248	-0.003812	-0.011436	-0.000172	-0.000516
0.0404	-0.003958	-0.011874	-0.000146	-0.000438
0.1271	-0.005011	-0.015033	-0.001053	-0.003159

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.00447	-0.006499	-0.019497	0.000000	0.000000
0.00974	-0.006526	-0.019578	-0.000027	-0.000081
0.0275	-0.006690	-0.020070	-0.000164	-0.000492
0.0458	-0.006881	-0.020643	-0.000191	-0.000573
0.0903	-0.007407	-0.022221	-0.000526	-0.001578

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.0052	-0.010212	-0.030636	0.000000	0.000000
0.00917	-0.010221	-0.030663	-0.000009	-0.000027

DATA SHEET # 1

SAMPLE # 3ST#9

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.853	5.836	2.2871	0.1531	2.738	0.021591	105.9304	1.983436	91.86574	0.011609	0.859792	0.487545	10760	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wa Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
10/20/93	50	42	93	10.75269	10334	5.8147	2.842587	0.021355	2.2871	0.839503	0.000499	0.232964	0.4647	609.31	1235962	59.17786	0.000263
10/22/93	100	57	103	9.708738	10064	5.8012	2.835988	0.021207	2.2871	0.826721	0.000496	0.231883	0.4637	674.71	1526140	73.07157	0.000291

TORSIONAL SHEAR TEST FOR 3ST#9 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 10/20/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.867	6.01	1.999	1.984	40	2.853	5.836	0.1933	5.9619	2.5780E-04	5.0411E-03	1.6276E-01	3.1368E-04	4.9345E+01	9.7885E+05
0.01	3.217	4.22	4.9595	4.943	40	2.853	5.836	0.3989	10.4297	5.3209E-04	1.0405E-02	2.8473E-01	3.1368E-04	8.6325E+01	8.2967E+05
0.025	4.823	4.45	10	9.856	40	2.853	5.836	1.2058	21.9296	1.6085E-03	3.1453E-02	5.9868E-01	3.1368E-04	1.8151E+02	5.7708E+05
0.05	3.212	5.35	10	9.856	20	2.853	5.836	1.6060	26.3648	2.1424E-03	4.1894E-02	7.1976E-01	3.1368E-04	2.1822E+02	5.2088E+05
0.1	3.704	4.61	1.999	19.71	2	2.853	5.836	3.7021	45.4316	4.9387E-03	9.6573E-02	1.2403E+00	3.1368E-04	3.7603E+02	3.8937E+05

Date : 10/22/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.175	8.04	1.999	1.984	40	2.853	5.836	0.2086	7.9757	2.7833E-04	5.4427E-03	2.1774E-01	3.1368E-04	6.6013E+01	1.2129E+06
0.01	3.033333	5.21	4.9595	4.943	40	2.853	5.836	0.3761	12.8765	5.0171E-04	9.8107E-03	3.5153E-01	3.1368E-04	1.0658E+02	1.0863E+06
0.025	3.705	5.05	10	9.856	40	2.853	5.836	0.9263	24.8864	1.2356E-03	2.4162E-02	6.7940E-01	3.1368E-04	2.0598E+02	8.5250E+05
0.05	3.11	7.28	10	9.856	20	2.853	5.836	1.5550	35.8758	2.0744E-03	4.0563E-02	9.7941E-01	3.1368E-04	2.9694E+02	7.3203E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 3ST#9

DATE: 10/04/93

INITIAL LENGTH= 5.836 Inch STTLMT is in inches e0= 0.8598
INITIAL LVDT = 10760 V0= 37.309 Inch^3 Vs= 23.4574 Inch^3

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00504				0.0104				0.03145				0.04189				0.09657			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	10332	0.021648	-0.003709	-0.011128	10332	0.021648	-0.003709	-0.011128	10319	0.022306	-0.003822	-0.011466	10302	0.023166	-0.003969	-0.011908	10294	0.023570	-0.004039	-0.012116
15	10332	0.021648	-0.003709	-0.011128	10332	0.021648	-0.003709	-0.011128	10314	0.022559	-0.003865	-0.011596	10302	0.023166	-0.003969	-0.011908	10253	0.025644	-0.004394	-0.013182
30	10332	0.021648	-0.003709	-0.011128	10332	0.021648	-0.003709	-0.011128	10312	0.022660	-0.003883	-0.011648	10302	0.023166	-0.003969	-0.011908	10253	0.025644	-0.004394	-0.013182
45	10332	0.021648	-0.003709	-0.011128	10332	0.021648	-0.003709	-0.011128	10310	0.022761	-0.003900	-0.011700	10302	0.023166	-0.003969	-0.011908	10253	0.025644	-0.004394	-0.013182
60	10332	0.021648	-0.003709	-0.011128	10332	0.021648	-0.003709	-0.011128	10310	0.022761	-0.003900	-0.011700	10296	0.023469	-0.004021	-0.012064	10251	0.025745	-0.004411	-0.013234
100	10332	0.021648	-0.003709	-0.011128	10321	0.022205	-0.003805	-0.011414	10306	0.022963	-0.003935	-0.011804	10294	0.023570	-0.004039	-0.012116	10246	0.025998	-0.004455	-0.013364
200	10332	0.021648	-0.003709	-0.011128	10321	0.022205	-0.003805	-0.011414	10305	0.023014	-0.003943	-0.011830	10294	0.023570	-0.004039	-0.012116	10244	0.026099	-0.004472	-0.013416
400	10332	0.021648	-0.003709	-0.011128	10320	0.022255	-0.003813	-0.011440	10303	0.023115	-0.003961	-0.011882	10293	0.023621	-0.004047	-0.012142	10234	0.026605	-0.004559	-0.013676
600	10332	0.021648	-0.003709	-0.011128	10320	0.022255	-0.003813	-0.011440	10302	0.023166	-0.003969	-0.011908	10292	0.023671	-0.004056	-0.012168	10231	0.026757	-0.004585	-0.013754
800	10332	0.021648	-0.003709	-0.011128	10319	0.022306	-0.003822	-0.011466	10295	0.023520	-0.004030	-0.012090	10292	0.023671	-0.004056	-0.012168	10227	0.026959	-0.004619	-0.013858
1000	10332	0.021648	-0.003709	-0.011128	10319	0.022306	-0.003822	-0.011466	10294	0.023570	-0.004039	-0.012116	10291	0.023722	-0.004065	-0.012194	10226	0.027010	-0.004628	-0.013884

100Kpa	SHEAR STRAIN AMPLITUDE (%)															
	0.00544				0.00981				0.02416				0.04056			
CYCLES	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol	LVDT	STTLMT	VERT. ST.	Evol
1	10035	0.036670	-0.006283	-0.018850	10032	0.036822	-0.006309	-0.018928	10029	0.036974	-0.006335	-0.019006	10012	0.037834	-0.006483	-0.019448
15	10035	0.036670	-0.006283	-0.018850	10032	0.036822	-0.006309	-0.018928	10024	0.037227	-0.006379	-0.019136	10010	0.037935	-0.006500	-0.019500
30	10035	0.036670	-0.006283	-0.018850	10032	0.036822	-0.006309	-0.018928	10024	0.037227	-0.006379	-0.019136	10006	0.038137	-0.006535	-0.019604
45	10035	0.036670	-0.006283	-0.018850	10032	0.036822	-0.006309	-0.018928	10024	0.037227	-0.006379	-0.019136	10004	0.038238	-0.006552	-0.019656
60	10035	0.036670	-0.006283	-0.018850	10032	0.036822	-0.006309	-0.018928	10022	0.037328	-0.006396	-0.019188	10003	0.038289	-0.006561	-0.019682
100	10034	0.036721	-0.006292	-0.018876	10032	0.036822	-0.006309	-0.018928	10021	0.037379	-0.006405	-0.019214	10003	0.038289	-0.006561	-0.019682
200	10033	0.036772	-0.006301	-0.018902	10032	0.036822	-0.006309	-0.018928	10017	0.037581	-0.006439	-0.019318	9990	0.038947	-0.006673	-0.020020
400	10033	0.036772	-0.006301	-0.018902	10031	0.036873	-0.006318	-0.018954	10015	0.037682	-0.006457	-0.019370	9986	0.039149	-0.006708	-0.020124
600	10034	0.036721	-0.006292	-0.018876	10030	0.036923	-0.006327	-0.018980	10013	0.037783	-0.006474	-0.019422	9983	0.039301	-0.006734	-0.020202
800	10034	0.036721	-0.006292	-0.018876	10029	0.036974	-0.006335	-0.019006	10011	0.037884	-0.006491	-0.019474	9974	0.039756	-0.006812	-0.020436
1000	10033	0.036772	-0.006301	-0.018902	10029	0.036974	-0.006335	-0.019006	10011	0.037884	-0.006491	-0.019474	9974	0.039756	-0.006812	-0.020436

DATA SHEET # 4

SAMPLE 3ST#9

INITIAL LENGTH = 5.836 inch

50 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
			(Ev)	
0.00504	-0.003709	-0.011128	0.000000	0.000000
0.01041	-0.003822	-0.011466	-0.000113	-0.000338
0.03145	-0.004039	-0.012116	-0.000217	-0.000650
0.04189	-0.004065	-0.012194	-0.000026	-0.000078
0.09657	-0.004628	-0.013884	-0.000563	-0.001690

100 kPa @ 1000 CYCLES				
SHEAR ST.	TOTAL		DYNAMIC	
(%)	VERT. ST.	Evol	VERT. ST.	Evol
0.0054	-0.006301	-0.018902	0.000000	0.000000
0.0098	-0.006335	-0.019006	-0.000035	-0.000104
0.0242	-0.006491	-0.019474	-0.000156	-0.000468
0.0406	-0.006812	-0.020436	-0.000321	-0.000962

APPENDIX 4.3.2

DATA SUMMARY OF PHASE II(b) RESULTS

DATA SHEET # 1

SAMPLE # 3ST#10L

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.854	5.86267	2.0789	0.3478	2.76	0.021704	95.78212	1.5424395	71.06553	0.008956	1.4234535	0.6743656	8490	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
11/12/93	25	57	73	13.69863	8245	5.8502779	2.847967	0.021567	2.0789	1.4081184	0.000455	0.212559	0.44533	502.13	755477.5	36.17226	0.000576

TORSIONAL SHEAR TEST FOR 3ST#10L (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 11/12/93
Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.1	5.031429	4.1	2	19.71	2	2.854	5.863	5.0314	40.4055	6.7119E-03	1.3070E-01	1.1031E+00	3.1412E-04	3.3408E+02	2.5561E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3 & 4

SAMPLE 3ST#10L

DATE: 11/1/93

INITIAL LENGTH=	5.8627 inch	e0=	1.4234	Vs=	16.49847 inch^3
INITIAL LVDT =	8490	V0=	37.143 inch^3	STTLMT is in inches	

25Kpa	SHEAR STRAIN AMPLITUDE (%) = 0.1307						
	TOTAL					DYNAMIC	
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	VERT. ST.	Evol
1	8235	0.012898	-0.002200	-0.001591	-0.005382	0.000000	0.000000
15	8135	0.017956	-0.003063		-0.009188	-0.000863	-0.002588
45	8125	0.018462	-0.003149		-0.009447	-0.000949	-0.002847
60	8123	0.018563	-0.003166		-0.009499	-0.000966	-0.002899
100	8120	0.018715	-0.003192		-0.009576	-0.000992	-0.002976
200	8114	0.019018	-0.003244		-0.009732	-0.001044	-0.003132
400	8109	0.019271	-0.003287		-0.009861	-0.001087	-0.003261
600	8104	0.019524	-0.003330		-0.009991	-0.001130	-0.003391
800	8101	0.019676	-0.003356		-0.010068	-0.001156	-0.003468
1050	8096	0.019928	-0.003399	-0.001789	-0.006977	-0.001199	-0.003598

DATA SHEET # 1

SAMPLE # 3ST#12

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.8503	5.8657	2.052	0.3562	2.723	0.021659	94.73939	1.513051	69.8565	0.008905	1.432346	0.677164	9250	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wa Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
11/1/93	25	56	72	13.88889	9002	5.8533	2.844275	0.021522	2.052	1.416953	0.000448	0.209264	0.44209	499.14	738377.4	35.35351	0.000581
11/2/93	50	60	79	12.65823	8853	5.84585	2.840654	0.02144	2.052	1.407736	0.000447	0.208732	0.44157	547.61	892160.5	42.71664	0.000517
11/3/93	100	62	87	11.49425	8565	5.83145	2.833657	0.021282	2.052	1.389987	0.000445	0.207705	0.44056	602.96	1089651	52.17249	0.000441
11/4/93	50	62	80	12.5	8642	5.8353	2.835528	0.021324	2.052	1.394724	0.000445	0.207979	0.44083	554.47	919623.5	44.03158	0.000521

TORSIONAL SHEAR TEST FOR 3ST#12 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 11/1/93
Confining Pressure = 25 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.927143	4.12	1.999	1.984	40	2.8503	5.8657	0.1963	4.0870	2.6181E-04	5.0888E-03	1.1158E-01	3.1249E-04	3.3924E+01	6.6663E+05
0.01	2.915714	6.91	4.9595	1.984	40	2.8503	5.8657	0.3615	6.8547	4.8226E-04	9.3737E-03	1.8713E-01	3.1249E-04	5.6896E+01	6.0698E+05
0.025	4.415	6.3	10	4.943	40	2.8503	5.8657	1.1038	15.5705	1.4724E-03	2.8619E-02	4.2507E-01	3.1249E-04	1.2924E+02	4.5158E+05
0.05	4.021667	4.7	10	9.853	20	2.8503	5.8657	2.0108	23.1546	2.6825E-03	5.2139E-02	6.3212E-01	3.1249E-04	1.9219E+02	3.6861E+05
0.1	3.371667	6.6	1.999	9.856	2	2.8503	5.8657	3.3700	32.5248	4.4956E-03	8.7380E-02	8.8793E-01	3.1249E-04	2.6997E+02	3.0896E+05

Date : 11/2/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.091667	5.2	1.999	1.984	40	2.8503	5.8657	0.2045	5.1584	2.7278E-04	5.3020E-03	1.4082E-01	3.1249E-04	4.2816E+01	8.0755E+05
0.01	3.068333	3.6	4.9595	4.943	40	2.8503	5.8657	0.3804	8.8974	5.0750E-04	9.8643E-03	2.4290E-01	3.1249E-04	7.3851E+01	7.4867E+05
0.025	4.692857	4.1	10	9.856	40	2.8503	5.8657	1.1732	20.2048	1.5651E-03	3.0420E-02	5.5159E-01	3.1249E-04	1.6771E+02	5.5130E+05
0.05	3.926667	5.8	10	9.856	20	2.8503	5.8657	1.9633	28.5824	2.6191E-03	5.0907E-02	7.8030E-01	3.1249E-04	2.3724E+02	4.6603E+05
0.1	3.605	4.3	1.999	19.71	2	2.8503	5.8657	3.6032	42.3765	4.8067E-03	9.3427E-02	1.1569E+00	3.1249E-04	3.5174E+02	3.7648E+05

Note : 1 psf = 47.88E-6 MPa

TORSIONAL SHEAR TEST FOR 3ST#12 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 11/3/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.883333	6.15	1.999	1.984	40	2.8503	5.8657	0.1941	6.1008	2.5889E-04	5.0320E-03	1.6655E-01	3.1249E-04	5.0639E+01	1.0063E+06
0.01	3.186667	4.9	4.9595	4.943	40	2.8503	5.8657	0.3951	12.1104	5.2707E-04	1.0245E-02	3.3061E-01	3.1249E-04	1.0052E+02	9.8118E+05
0.025	4.038333	4.85	10	9.856	40	2.8503	5.8657	1.0096	23.9008	1.3468E-03	2.6178E-02	6.5249E-01	3.1249E-04	1.9838E+02	7.5784E+05
0.05	3.56	7.16	10	9.856	20	2.8503	5.8657	1.7800	35.2845	2.3745E-03	4.6154E-02	9.6327E-01	3.1249E-04	2.9287E+02	6.3456E+05
0.065	2.565	4.56	20	19.71	20	2.8503	5.8657	2.5650	44.9388	3.4217E-03	6.6508E-02	1.2268E+00	3.1249E-04	3.7301E+02	5.6084E+05

Date : 11/4/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.05	3.698571	5.8	10	9.856	20	2.8503	5.8657	1.8493	28.5824	2.4669E-03	4.7950E-02	7.8030E-01	3.1249E-04	2.3724E+02	4.9477E+05
0.1	3.594	4.5	20	19.71	20	2.8503	5.8657	3.5940	44.3475	4.7944E-03	9.3189E-02	1.2107E+00	3.1249E-04	3.6810E+02	3.9500E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 3ST#12

DATE: 11/4/93

INITIAL LENGTH=	5.8657 Inch	STTLMT is in Inches		e0=	1.4323		
INITIAL DIAMETER =	2.8503 Inch	INITIAL LVDT =	9241	V0=	37.4984 Inch^3	Vs=	21.08547 Inch^3

25Kpa — SHEAR STRAIN AMPLITUDE (%)

25Kpa	0.005069					0.00937				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8992	0.012594	-0.002147	-0.002446	-0.007038	8992	0.012594	-0.002147	-0.002469	-0.007065
30	8992	0.012594	-0.002147		-0.006441	8992	0.012594	-0.002147		-0.006441
60	8992	0.012594	-0.002147		-0.006441	8992	0.012594	-0.002147		-0.006441
100	8992	0.012594	-0.002147		-0.006441	8992	0.012594	-0.002147		-0.006441
200	8992	0.012594	-0.002147		-0.006441	8991	0.012645	-0.002156		-0.006467
400	8992	0.012594	-0.002147		-0.006441	8991	0.012645	-0.002156		-0.006467
600	8992	0.012594	-0.002147		-0.006441	8991	0.012645	-0.002156		-0.006467
800	8992	0.012594	-0.002147		-0.006441	8991	0.012645	-0.002156		-0.006467
1000	8992	0.012594	-0.002147	-0.002469	-0.007065	8991	0.012645	-0.002156	-0.002511	-0.007177

25Kpa	0.02862					0.05214					0.08738				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8991	0.012645	-0.002156	-0.002511	-0.007177	8974	0.013505	-0.002302	-0.002536	-0.007383	8971	0.013657	-0.002328	-0.002626	-0.007633
30	8985	0.012948	-0.002207		-0.006622	8973	0.013555	-0.002311		-0.006933	8964	0.014011	-0.002389		-0.007166
60	8983	0.013050	-0.002225		-0.006674	8972	0.013606	-0.002320		-0.006959	8963	0.014061	-0.002397		-0.007192
100	8983	0.013050	-0.002225		-0.006674	8972	0.013606	-0.002320		-0.006959	8962	0.014112	-0.002406		-0.007217
200	8982	0.013100	-0.002233		-0.006700	8970	0.013707	-0.002337		-0.007010	8962	0.014112	-0.002406		-0.007217
400	8982	0.013100	-0.002233		-0.006700	8969	0.013758	-0.002345		-0.007036	8960	0.014213	-0.002423		-0.007269
600	8976	0.013404	-0.002285		-0.006855	8969	0.013758	-0.002345		-0.007036	8956	0.014415	-0.002458		-0.007373
800	8973	0.013555	-0.002311		-0.006933	8966	0.013909	-0.002371		-0.007114	8954	0.014516	-0.002475		-0.007424
1000	8973	0.013555	-0.002311	-0.002536	-0.007383	8965	0.013960	-0.002380	-0.002626	-0.007633	8952	0.014618	-0.002492	-0.002763	-0.008017

50Kpa — SHEAR STRAIN AMPLITUDE (%)

50Kpa	0.0053					0.00986				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8853	0.019625	-0.003346	-0.003629	-0.010604	8853	0.019625	-0.003346	-0.003646	-0.010638
15	8854	0.019574	-0.003337		-0.010011	8854	0.019574	-0.003337		-0.010011
30	8854	0.019574	-0.003337		-0.010011	8854	0.019574	-0.003337		-0.010011
45	8854	0.019574	-0.003337		-0.010011	8854	0.019574	-0.003337		-0.010011
60	8854	0.019574	-0.003337		-0.010011	8854	0.019574	-0.003337		-0.010011
100	8854	0.019574	-0.003337		-0.010011	8854	0.019574	-0.003337		-0.010011
200	8854	0.019574	-0.003337		-0.010011	8853	0.019625	-0.003346		-0.010037
400	8854	0.019574	-0.003337		-0.010011	8853	0.019625	-0.003346		-0.010037
600	8853	0.019625	-0.003346		-0.010037	8853	0.019625	-0.003346		-0.010037
800	8853	0.019625	-0.003346		-0.010037	8852	0.019678	-0.003354		-0.010063
1000	8853	0.019625	-0.003346	-0.003646	-0.010638	8852	0.019678	-0.003354	-0.003751	-0.010656

50Kpa	0.03042					0.05091					0.09343				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8854	0.019574	-0.003337	-0.003751	-0.010656	8844	0.020080	-0.003423	-0.003839	-0.011118	8832	0.020687	-0.003527	-0.003946	-0.011444
15	8852	0.019678	-0.003354		-0.010063	8842	0.020181	-0.003441		-0.010322	8830	0.020788	-0.003544		-0.010632
30	8851	0.019726	-0.003363		-0.010089	8841	0.020232	-0.003449		-0.010346	8829	0.020839	-0.003553		-0.010658
45	8850	0.019777	-0.003372		-0.010115	8841	0.020232	-0.003449		-0.010346	8825	0.021041	-0.003587		-0.010761
60	8850	0.019777	-0.003372		-0.010115	8840	0.020283	-0.003458		-0.010373	8823	0.021142	-0.003604		-0.010813
100	8849	0.019827	-0.003380		-0.010141	8836	0.020485	-0.003492		-0.010477	8823	0.021142	-0.003604		-0.010813
200	8848	0.019878	-0.003389		-0.010167	8835	0.020535	-0.003501		-0.010503	8821	0.021244	-0.003622		-0.010865
400	8845	0.020030	-0.003415		-0.010244	8832	0.020687	-0.003527		-0.010580	8816	0.021496	-0.003665		-0.010994
600	8843	0.020131	-0.003432		-0.010296	8832	0.020687	-0.003527		-0.010580	8813	0.021648	-0.003691		-0.011072
800	8842	0.020181	-0.003441		-0.010322	8830	0.020788	-0.003544		-0.010632	8813	0.021648	-0.003691		-0.011072
1000	8842	0.020181	-0.003441	-0.003839	-0.011118	8829	0.020839	-0.003553	-0.003946	-0.011444	8812	0.021699	-0.003699	-0.004226	-0.012152

DATA SHEET # 3

SAMPLE 3ST#12

STTLMT is in inches

100Kpa — SHEAR STRAIN AMPLITUDE (%): 0.0053

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8565	0.034192	-0.005829	-0.006648	-0.019121
15	8565	0.034192	-0.005829		-0.017487
30	8565	0.034192	-0.005829		-0.017487
45	8565	0.034192	-0.005829		-0.017487
60	8565	0.034192	-0.005829		-0.017487
100	8565	0.034192	-0.005829		-0.017487
200	8565	0.034192	-0.005829		-0.017487
400	8565	0.034192	-0.005829		-0.017487
600	8565	0.034192	-0.005829		-0.017487
800	8565	0.034192	-0.005829		-0.017487
1000	8565	0.034192	-0.005829	-0.006688	-0.019205

100Kpa — SHEAR STRAIN AMPLITUDE (%): 0.01025

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8565	0.034192	-0.005829	-0.006688	-0.019205
15	8564	0.034243	-0.005838		-0.017513
30	8564	0.034243	-0.005838		-0.017513
45	8564	0.034243	-0.005838		-0.017513
60	8564	0.034243	-0.005838		-0.017513
100	8564	0.034243	-0.005838		-0.017513
200	8563	0.034293	-0.005846		-0.017530
400	8563	0.034293	-0.005846		-0.017530
600	8563	0.034293	-0.005846		-0.017530
800	8563	0.034293	-0.005846		-0.017530
1000	8563	0.034293	-0.005846	-0.006730	-0.019306

100Kpa — SHEAR STRAIN AMPLITUDE (%): 0.02618

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8564	0.034243	-0.005838	-0.006730	-0.019306
15	8564	0.034243	-0.005838		-0.017513
30	8563	0.034293	-0.005846		-0.017539
45	8562	0.034344	-0.005856		-0.017565
60	8562	0.034344	-0.005856		-0.017565
100	8561	0.034394	-0.005864		-0.017591
200	8561	0.034394	-0.005864		-0.017591
400	8564	0.034647	-0.005907		-0.017720
600	8554	0.034748	-0.005924		-0.017772
800	8553	0.034799	-0.005933		-0.017798
1000	8554	0.034748	-0.005924	-0.006837	-0.019598

100Kpa — SHEAR STRAIN AMPLITUDE (%): 0.04615

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8555	0.034698	-0.005915	-0.006837	-0.019598
15	8554	0.034748	-0.005924		-0.017772
30	8553	0.034799	-0.005933		-0.017798
45	8552	0.034850	-0.005941		-0.017824
60	8552	0.034850	-0.005941		-0.017824
100	8551	0.034900	-0.005950		-0.017850
200	8548	0.035153	-0.005993		-0.017979
400	8542	0.035356	-0.006027		-0.018082
600	8536	0.035659	-0.006079		-0.018238
800	8534	0.035760	-0.006096		-0.018289
1000	8533	0.035811	-0.006105	-0.006941	-0.019988

100Kpa — SHEAR STRAIN AMPLITUDE (%): 0.06651

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8548	0.035153	-0.005993	-0.006941	-0.019988
15	8544	0.035254	-0.006010		-0.018031
30	8543	0.035305	-0.006019		-0.018057
45	8542	0.035355	-0.006027		-0.018082
60	8536	0.035659	-0.006079		-0.018238
100	8535	0.035709	-0.006088		-0.018264
200	8532	0.035861	-0.006114		-0.018341
400	8525	0.036215	-0.006174		-0.018522
600	8520	0.036468	-0.006217		-0.018652
800	8516	0.036670	-0.006252		-0.018755
1000	8516	0.036670	-0.006252	-0.007048	-0.020348

50Kpa After 100Kpa	SHEAR STRAIN AMPLITUDE (%)									
	0.04795					0.09318				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8643	0.030247	-0.005157	-0.005404	-0.015973	8649	0.029943	-0.005105	-0.005427	-0.016019
15	8645	0.030146	-0.005139		-0.015418	8652	0.029792	-0.005079		-0.015237
30	8645	0.030146	-0.005139		-0.015418	8652	0.029792	-0.005079		-0.015237
45	8645	0.030146	-0.005139		-0.015418	8652	0.029792	-0.005079		-0.015237
60	8644	0.030196	-0.005148		-0.015444	8652	0.029792	-0.005079		-0.015237
100	8644	0.030196	-0.005148		-0.015444	8652	0.029792	-0.005079		-0.015237
200	8544	0.030196	-0.005148		-0.015444	8652	0.029792	-0.005079		-0.015237
400	8643	0.030247	-0.005157		-0.015470	8651	0.029842	-0.005088		-0.015263
600	8643	0.030247	-0.005157		-0.015470	8649	0.029943	-0.005105		-0.015314
800	8642	0.030297	-0.005165		-0.015496	8648	0.029994	-0.005113		-0.015340
1000	8642	0.030297	-0.005165	-0.005427	-0.016019	8646	0.030095	-0.005131	-0.005511	-0.016153

	0.01 @ 10 Hz				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	8668	0.028982	-0.004941	-0.005509	-0.016149
150	8668	0.028982	-0.004941		-0.014823
300	8666	0.029083	-0.004958		-0.014875
450	8663	0.029235	-0.004984		-0.014952
600	8664	0.029185	-0.004975		-0.014926
1000	8668	0.028982	-0.004941		-0.014823
2000	8664	0.029185	-0.004975		-0.014926
4000	8662	0.029286	-0.004993		-0.014978
6000	8658	0.029488	-0.005027		-0.015082
10000	8652	0.029792	-0.005079		-0.015237
20000	8656	0.029589	-0.005044		-0.015133
40000	8663	0.029235	-0.004984	-0.005879	-0.016489

DATA SHEET # 4

SAMPLE 3ST#12

INITIAL LENGTH = 5.866 inch
INITIAL DIAMETER = 2.850 inch

	SHEAR ST.	TOTAL			DYNAMIC			
	(%)	VERT. ST.	HOR. ST.	Evol	VERT. ST. (Ev)	HOR. ST. (Eh)	Evol	Eh/Ev
25Kpa	0.00509	-0.002147	-0.002469	-0.007085	0.000000	0.000000	0.000000	
@1000	0.00937	-0.002156	-0.002511	-0.007177	-0.000009	-0.000042	-0.000093	4.88
CYCLES	0.02862	-0.002311	-0.002536	-0.007383	-0.000155	-0.000025	-0.000205	0.16
	0.05214	-0.002380	-0.002626	-0.007633	-0.000069	-0.000090	-0.000250	1.31
	0.08738	-0.002492	-0.002763	-0.008017	-0.000112	-0.000136	-0.000385	1.22
50Kpa	0.00530	-0.003346	-0.003646	-0.010638	0.000000	0.000000	0.000000	
@1000	0.00986	-0.003354	-0.003751	-0.010856	-0.000009	-0.000105	-0.000218	12.14
CYCLES	0.03042	-0.003441	-0.003839	-0.011118	-0.000086	-0.000088	-0.000262	1.02
	0.05091	-0.003553	-0.003946	-0.011444	-0.000112	-0.000107	-0.000326	0.95
	0.09343	-0.003699	-0.004226	-0.012152	-0.000147	-0.000281	-0.000708	1.92
100Kpa	0.00503	-0.005829	-0.006688	-0.019205	0.000000	0.000000	0.000000	
@1000	0.01025	-0.005846	-0.006730	-0.019306	-0.000017	-0.000042	-0.000101	2.42
CYCLES	0.02618	-0.005924	-0.006837	-0.019598	-0.000078	-0.000107	-0.000292	1.38
	0.04615	-0.006105	-0.006941	-0.019988	-0.000181	-0.000105	-0.000390	0.58
	0.06651	-0.006252	-0.007048	-0.020348	-0.000147	-0.000107	-0.000360	0.73
50Kpa	0.04795	-0.005165	-0.005427	-0.016019	0.000000	0.000000	0.000000	
@1000	0.09319	-0.005131	-0.005511	-0.016153	0.000034	-0.000084	-0.000134	-2.44
CYCLES								

DATA SHEET # 1

SAMPLE # 4ST#1

Final Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.816154	5.6606	2.8055	0.1665	2.808	0.020404	137.4957	2.405058	117.8703	0.013726	0.4865421	0.9609282	6843	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
12/8/93	50	52	70	14.28571	5193	5.6998	2.835656	0.020831	2.8055	0.5176398	0.000609	0.284376	0.50927	410.21	704469.7	33.73001	0.000584
12/10/93	100	56	86	11.62791	4409	5.6606	2.816154	0.020404	2.8055	0.4865422	0.0006	0.280478	0.50607	503.67	1084265	51.91459	0.000417

TORSIONAL SHEAR TEST FOR 4ST#1 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 12/8/93
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	9.05	7.67	0.9957	0.991	40	2.877	5.782	0.2253	3.8005	3.0052E-04	5.9804E-03	1.0375E-01	3.2423E-04	3.0685E+01	5.1309E+05
0.01	7.35	5.59	1.999	1.984	40	2.877	5.782	0.3673	5.5453	4.9000E-04	9.7510E-03	1.5139E-01	3.2423E-04	4.4772E+01	4.5915E+05
0.025	3.952222	4.46	4.9595	4.943	20	2.877	5.782	0.9801	11.0229	1.3074E-03	2.6017E-02	3.0092E-01	3.2423E-04	8.8998E+01	3.4207E+05
0.05	6.322222	6.11	4.9595	4.943	20	2.877	5.782	1.5678	15.1009	2.0914E-03	4.1619E-02	4.1225E-01	3.2423E-04	1.2192E+02	2.9295E+05
0.1	1.418889	5.1	4.9595	9.856	2	2.877	5.782	3.5185	25.1328	4.6937E-03	9.3404E-02	6.8613E-01	3.2423E-04	2.0292E+02	2.1725E+05

Date : 12/10/93
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.93	5.59	1.999	1.984	40	2.877	5.782	0.1964	5.5453	2.6200E-04	5.2138E-03	1.5139E-01	3.2423E-04	4.4772E+01	8.5872E+05
0.01	3.11	3.89	4.9595	4.943	40	2.877	5.782	0.3856	9.6141	5.1439E-04	1.0236E-02	2.6247E-01	3.2423E-04	7.7623E+01	7.5831E+05
0.025	4.18	4.08	4.9595	9.856	20	2.877	5.782	1.0365	20.1062	1.3827E-03	2.7517E-02	5.4890E-01	3.2423E-04	1.6234E+02	5.8996E+05
0.05	6.41	5.62	4.9595	9.856	20	2.877	5.782	1.5895	27.6954	2.1204E-03	4.2196E-02	7.5608E-01	3.2423E-04	2.2361E+02	5.2992E+05
0.1	3.38	9.13	1.999	9.856	2	2.877	5.782	3.3828	44.9926	4.5126E-03	8.9801E-02	1.2283E+00	3.2423E-04	3.6327E+02	4.0452E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 4ST#1

DATE: 12/06/93

INITIAL LENGTH= 5.7823 Inch
INITIAL LVDT = 6843

STTLMT is in inches

e0 = 0.5845
V0 = 37.582 Inch^3

Vs = 23.537298 Inch^3

50Kpa — SHEAR STRAIN AMPLITUDE (%) 0.00598

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	5194	0.0834063	-0.014424	-0.006399	-0.027240
15	5193	0.0834568	-0.014433		-0.043299
30	5193	0.0834568	-0.014433		-0.043299
45	5193	0.0834568	-0.014433		-0.043299
60	5193	0.0834568	-0.014433		-0.043299
100	5192	0.0835074	-0.014442		-0.043326
200	5192	0.0835074	-0.014442		-0.043326
400	5192	0.0835074	-0.014442		-0.043326
600	5192	0.0835074	-0.014442		-0.043326
800	5192	0.0835074	-0.014442		-0.043326
1000	5191	0.083558	-0.014451	-0.006460	-0.02737

50Kpa — SHEAR STRAIN AMPLITUDE (%) 0.00975

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	5191	0.083558	-0.014451	-0.006460	-0.02737
15	5190	0.0836086	-0.014459		-0.043378
30	5189	0.0836592	-0.014468		-0.043404
45	5189	0.0836592	-0.014468		-0.043404
60	5189	0.0836592	-0.014468		-0.043404
100	5189	0.0836592	-0.014468		-0.043404
200	5189	0.0836592	-0.014468		-0.043404
400	5189	0.0836592	-0.014468		-0.043404
600	5189	0.0836592	-0.014468		-0.043404
800	5190	0.0836086	-0.014459		-0.043378
1000	5189	0.0836592	-0.014468	-0.006318	-0.027099

50Kpa — SHEAR STRAIN AMPLITUDE (%) 0.02602

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	5189	0.0836592	-0.014468	-0.006318	-0.027099
15	5184	0.0839121	-0.014512		-0.043536
30	5183	0.0839626	-0.014521		-0.043562
45	5182	0.0840132	-0.014529		-0.043588
60	5182	0.0840132	-0.014529		-0.043588
100	5175	0.0843673	-0.014591		-0.043772
200	5172	0.084519	-0.014617		-0.043851
400	5171	0.0845696	-0.014626		-0.043877
600	5170	0.0846202	-0.014634		-0.043903
800	5168	0.0847213	-0.014652		-0.043956
1000	5166	0.0848225	-0.014669	-0.006709	-0.028087

50Kpa — SHEAR STRAIN AMPLITUDE (%) 0.04162

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	5170	0.0846202	-0.014634	-0.006709	-0.028087
15	5169	0.0846708	-0.014643		-0.043929
30	5169	0.0846708	-0.014643		-0.043929
45	5169	0.0846708	-0.014643		-0.043929
60	5170	0.0846202	-0.014634		-0.043903
100	5166	0.0848225	-0.014669		-0.044008
200	5165	0.0848731	-0.014678		-0.044034
400	5163	0.0849742	-0.014696		-0.044087
600	5161	0.0850754	-0.014713		-0.044139
800	5159	0.0851765	-0.014731		-0.044192
1000	5156	0.0853283	-0.014757	-0.006638	-0.028032

50Kpa — SHEAR STRAIN AMPLITUDE (%) 0.0934

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	5158	0.0852271	-0.014739	-0.006638	-0.028032
15	5150	0.0856318	-0.014809		-0.044428
30	5143	0.0859858	-0.014871		-0.044612
45	5135	0.0863905	-0.014941		-0.044822
60	5133	0.0864916	-0.014958		-0.044874
100	5130	0.0866434	-0.014984		-0.044953
200	5123	0.0869974	-0.015045		-0.045136
400	5116	0.0873515	-0.015107		-0.04532
600	5108	0.0877561	-0.015177		-0.04553
800	5104	0.0879584	-0.015212		-0.045635
1000	5096	0.0883631	-0.015282	-0.007040	-0.029362

100Kpa — SHEAR STRAIN AMPLITUDE (%) 0.00521

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	4383	0.1244266	-0.021519	-0.007336	-0.03626
15	4383	0.1244266	-0.021519		-0.064556
30	4383	0.1244266	-0.021519		-0.064556
45	4383	0.1244266	-0.021519		-0.064556
60	4383	0.1244266	-0.021519		-0.064556
100	4382	0.1244771	-0.021527		-0.064582
200	4382	0.1244771	-0.021527		-0.064582
400	4376	0.1247806	-0.02158		-0.064739
600	4375	0.1248312	-0.021589		-0.064766
800	4375	0.1248312	-0.021589		-0.064766
1000	4375	0.1248312	-0.021589	-0.007469	-0.036526

100Kpa — SHEAR STRAIN AMPLITUDE (%) 0.01024

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	4375	0.1248312	-0.021589	-0.007469	-0.036526
15	4375	0.1248312	-0.021589		-0.064766
30	4374	0.1248818	-0.021597		-0.064792
45	4374	0.1248818	-0.021597		-0.064792
60	4374	0.1248818	-0.021597		-0.064792
100	4374	0.1248818	-0.021597		-0.064792
200	4374	0.1248818	-0.021597		-0.064792
400	4372	0.1249829	-0.021615		-0.064844
600	4372	0.1249829	-0.021615		-0.064844
800	4372	0.1249829	-0.021615		-0.064844
1000	4372	0.1249829	-0.021615	-0.007527	-0.036669

100Kpa — SHEAR STRAIN AMPLITUDE (%) 0.02752

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	4369	0.1251347	-0.021641	-0.007527	-0.036669
15	4364	0.1253876	-0.021685		-0.065054
30	4363	0.1254381	-0.021693		-0.06508
45	4362	0.1254887	-0.021702		-0.065107
60	4361	0.1255393	-0.021711		-0.065133
100	4360	0.1255899	-0.02172		-0.065159
200	4356	0.1257922	-0.021755		-0.065264
400	4353	0.1259439	-0.021781		-0.065343
600	4351	0.1260451	-0.021798		-0.065395
800	4348	0.1261968	-0.021825		-0.065474
1000	4348	0.126298	-0.021842	-0.007691	-0.037225

100Kpa — SHEAR STRAIN AMPLITUDE (%) 0.04219

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	4346	0.126298	-0.021842	-0.007691	-0.037225
15	4345	0.1263486	-0.021851		-0.065553
30	4344	0.1263992	-0.02186		-0.065579
45	4342	0.1265003	-0.021877		-0.065631
60	4342	0.1265003	-0.021877		-0.065631
100	4338	0.1267026	-0.021912		-0.065736
200	4334	0.126905	-0.021947		-0.065841
400	4332	0.1270061	-0.021965		-0.065894
600	4328	0.1272084	-0.022		-0.065999
800	4325	0.1273602	-0.022026		-0.066078
1000	4323	0.1274613	-0.022043	-0.007791	-0.037626

100Kpa — SHEAR STRAIN AMPLITUDE (%) 0.0898

CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	4324	0.1274108	-0.022035	-0.007791	-0.037626
15	4315	0.127866	-0.022113		-0.06634
30	4309	0.1281695	-0.022166		-0.066497
45	4306	0.1283212	-0.022192		-0.066576
60	4303	0.1284729	-0.022218		-0.066655
100	4294	0.1289282	-0.022297		-0.066891
200	4285	0.1293834	-0.022376		-0.067127
400	4271	0.1300915	-0.022498		-0.067495
600	4264	0.1304458	-0.022559		-0.067678
800	4259	0.1306985	-0.022603		-0.06781
1000	4254	0.1309514	-0.022647	-0.008163	-0.038973

DATA SHEET # 4

SAMPLE 4ST#1

INITIAL LENGTH= 5.782 inch
INITIAL DIAMETER = 2.877 inch

	SHEAR ST.	TOTAL			DYNAMIC			
	(%)	VERT. ST.	HOR. ST.	Evol	VERT. ST.	HOR. ST.	Evol	Eh/Ev
					(Ev)	(Eh)		
50Kpa @1000 CYCLES	0.00598	-0.014451	-0.006460	-0.027370	0.000000	0.000000	0.000000	
	0.00975	-0.014468	-0.006316	-0.027099	-0.000017	0.000144	0.000271	-8.24
	0.02602	-0.014669	-0.006709	-0.028087	-0.000201	-0.000393	-0.000988	1.96
	0.04162	-0.014757	-0.006638	-0.028032	-0.000087	0.000071	0.000055	-0.81
	0.09340	-0.015282	-0.007040	-0.029362	-0.000525	-0.000402	-0.001329	0.77
100Kpa @1000 CYCLES	0.00521	-0.021589	-0.007469	-0.036526	0.000000	0.000000	0.000000	
	0.01024	-0.021615	-0.007527	-0.036669	-0.000026	-0.000058	-0.000143	2.22
	0.02752	-0.021842	-0.007691	-0.037225	-0.000227	-0.000164	-0.000556	0.72
	0.04219	-0.022043	-0.007791	-0.037626	-0.000201	-0.000100	-0.000401	0.50
	0.08980	-0.022647	-0.008163	-0.038973	-0.000604	-0.000372	-0.001348	0.62

DATA SHEET # 1

SAMPLE # 4ST#4

Final Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.845836	5.68972	2.6544	0.2472	2.793	0.020944	126.7389	2.128287	101.6188	0.012212	0.715069	0.965542	7892	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wa Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
2/4/93	50	67	74	13.51351	6418	5.72697	2.864467	0.021358	2.6544	0.747012	0.000588	0.274555	0.50136	442.59	756775.9	36.23443	0.000677
2/7/93	100	49	91	10.98901	5673	5.68972	2.845836	0.020944	2.6544	0.713144	0.00058	0.270995	0.49819	544.17	1166622	55.85784	0.000328

TORSIONAL SHEAR TEST FOR 4ST#4 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 2/4/94
Confining Pressure = 50 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	4.26	4.32	1.999	1.984	40	2.901	5.801	0.2129	4.2854	2.8400E-04	5.6819E-03	1.1699E-01	3.3548E-04	3.3726E+01	5.9357E+05
0.01	4.05	3.42	4.9595	4.943	40	2.901	5.801	0.5019	8.4525	6.6959E-04	1.3396E-02	2.3075E-01	3.3548E-04	6.6521E+01	4.9656E+05
0.025	4.36	6.05	10	4.943	40	2.901	5.801	1.0904	14.9526	1.4546E-03	2.9102E-02	4.0821E-01	3.3548E-04	1.1768E+02	4.0436E+05
0.05	3.40	4.11	10	9.856	20	2.901	5.801	1.6975	20.2541	2.2645E-03	4.5305E-02	5.5294E-01	3.3548E-04	1.5940E+02	3.5184E+05
0.1	3.85	6.94	1.999	9.856	2	2.901	5.801	3.8447	34.2003	5.1289E-03	1.0261E-01	9.3367E-01	3.3548E-04	2.6916E+02	2.6230E+05

Date : 2/7/94
Confining Pressure = 100 kPa

Estimate Strain %	Xl (in)	Yl (in)	Xcal (volt/in)	Ycal (volt/in)	Op. Factor	d (in)	l (in)	Vp (volts)	Vt (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.005	3.05	5.04	1.999	1.984	40	2.901	5.801	0.1524	4.9997	2.0333E-04	4.0681E-03	1.3649E-01	3.3548E-04	3.9348E+01	9.6723E+05
0.01	3.79	5.3	4.9595	4.943	40	2.901	5.801	0.4699	13.0990	6.2686E-04	1.2542E-02	3.5760E-01	3.3548E-04	1.0309E+02	8.2198E+05
0.025	3.82	4.55	10	9.856	40	2.901	5.801	0.9546	22.4224	1.2734E-03	2.5477E-02	6.1213E-01	3.3548E-04	1.7646E+02	6.9264E+05
0.05	3.14	6.54	10	9.856	20	2.901	5.801	1.5683	32.2291	2.0922E-03	4.1857E-02	8.7985E-01	3.3548E-04	2.5364E+02	6.0597E+05
0.1	2.78	5.01	2	20	2	2.901	5.801	2.7783	50.1000	3.7063E-03	7.4151E-02	1.3677E+00	3.3548E-04	3.9429E+02	5.3173E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 4ST#4

DATE: 2/4/93

INITIAL LENGTH= 5.801 Inch
INITIAL DIAMETER = 2.9013 Inch

STTLMT is in Inches
INITIAL LVDT = 7892

e0= 0.8153
V0= 37.4984 Inch^3

Vs= 21.08547 Inch^3

50Kpa — SHEAR STRAIN AMPLITUDE (%)

CYCLES	0.00568 LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	0.01339 LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	6419	0.0745042	-0.012843	-0.003888	-0.020656	6415	0.0747065	-0.012878	-0.003907	-0.020693
15	6418	0.0745548	-0.012852		-0.038556	6415	0.0747065	-0.012878		-0.038635
30	6416	0.0746559	-0.012869		-0.038608	6414	0.0747571	-0.012887		-0.038661
45	6414	0.0747571	-0.012887		-0.038661	6413	0.0748077	-0.012896		-0.038687
60	6414	0.0747571	-0.012887		-0.038661	6413	0.0748077	-0.012896		-0.038687
100	6416	0.0746559	-0.012869		-0.038608	6413	0.0748077	-0.012896		-0.038687
200	6418	0.0745548	-0.012852		-0.038556	6413	0.0748077	-0.012896		-0.038687
400	6415	0.0747065	-0.012878		-0.038635	6412	0.0748582	-0.012904		-0.038713
600	6415	0.0747065	-0.012878		-0.038635	6412	0.0748582	-0.012904		-0.038713
800	6415	0.0747065	-0.012878		-0.038635	6411	0.0749088	-0.012913		-0.038739
1000	6415	0.0747065	-0.012878	-0.003907	-0.020693	6411	0.0749088	-0.012913	-0.004011	-0.020934

CYCLES	0.0291 LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	0.04531 LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	0.10261 LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	6411	0.0749088	-0.012913	-0.004011	-0.020934	6375	0.0767297	-0.013227	-0.004075	-0.021385	6354	0.0777919	-0.01341	-0.004178	-0.021783
15	6405	0.0752123	-0.012965		-0.038896	6373	0.0768309	-0.013244		-0.039733	6326	0.0792081	-0.013654		-0.040963
30	6404	0.0752629	-0.012974		-0.038922	6372	0.0768814	-0.013253		-0.039759	6320	0.0795116	-0.013707		-0.04112
45	6403	0.0753135	-0.012983		-0.038948	6372	0.0768814	-0.013253		-0.039759	6312	0.0799162	-0.013776		-0.041329
60	6402	0.075364	-0.012992		-0.038975	6371	0.076932	-0.013262		-0.039786	6308	0.0801186	-0.013811		-0.041433
100	6393	0.0758193	-0.01307		-0.03921	6369	0.0770332	-0.013279		-0.039838	6305	0.0802703	-0.013837		-0.041512
200	6390	0.075971	-0.013096		-0.039289	6364	0.0772861	-0.013323		-0.039969	6293	0.0808773	-0.013942		-0.041826
400	6386	0.0761733	-0.013131		-0.039393	6361	0.0774378	-0.013349		-0.040047	6287	0.0811807	-0.013994		-0.041983
600	6384	0.0762745	-0.013148		-0.039444	6356	0.0776907	-0.013393		-0.040178	6279	0.0815854	-0.014064		-0.042192
800	6382	0.0763756	-0.013166		-0.039498	6354	0.0777919	-0.01341		-0.04023	6274	0.0818383	-0.014108		-0.042323
1000	6374	0.0767803	-0.013236	-0.004075	-0.021385	6352	0.077893	-0.013428	-0.004178	-0.021783	6270	0.0820406	-0.014142	-0.004406	-0.022954

100Kpa — SHEAR STRAIN AMPLITUDE (%)

CYCLES	0.00407 LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	0.01254 LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	5651	0.1133496	-0.01954	-0.006458	-0.032455	5651	0.1133496	-0.01954	-0.006536	-0.032811
15	5651	0.1133496	-0.01954		-0.058619	5649	0.1134507	-0.019557		-0.058671
30	5651	0.1133496	-0.01954		-0.058619	5649	0.1134507	-0.019557		-0.058671
45	5651	0.1133496	-0.01954		-0.058619	5646	0.1136025	-0.019583		-0.05875
60	5651	0.1133496	-0.01954		-0.058619	5646	0.1136025	-0.019583		-0.05875
100	5651	0.1133496	-0.01954		-0.058619	5646	0.1136025	-0.019583		-0.05875
200	5651	0.1133496	-0.01954		-0.058619	5645	0.113653	-0.019592		-0.058776
400	5651	0.1133496	-0.01954		-0.058619	5644	0.1137036	-0.019601		-0.058802
600	5651	0.1133496	-0.01954		-0.058619	5643	0.1137542	-0.019609		-0.058828
800	5650	0.1134001	-0.019548		-0.058645	5642	0.1138048	-0.019618		-0.058854
1000	5651	0.1133496	-0.01954	-0.006536	-0.032811	5642	0.1138048	-0.019618	-0.006577	-0.032772

CYCLES	0.02548 LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	0.04186 LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	0.07415 LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	5642	0.1138048	-0.019618	-0.006577	-0.032772	5622	0.1148164	-0.019793	-0.006664	-0.033155	5594	0.1162326	-0.020037	-0.006790	-0.033643
15	5635	0.1141588	-0.019679		-0.059037	5618	0.1150187	-0.019827		-0.059482	5583	0.116789	-0.020133		-0.060398
30	5634	0.1142094	-0.019688		-0.059064	5614	0.115221	-0.019862		-0.059587	5576	0.117143	-0.020194		-0.060581
45	5633	0.11426	-0.019697		-0.05909	5612	0.1153222	-0.01988		-0.059639	5572	0.1173454	-0.020228		-0.060685
60	5633	0.11426	-0.019697		-0.05909	5612	0.1153222	-0.01988		-0.059639	5566	0.1176488	-0.020281		-0.060842
100	5632	0.1143106	-0.019705		-0.059116	5612	0.1153222	-0.01988		-0.059639	5563	0.1178006	-0.020307		-0.060921
200	5630	0.1144117	-0.019723		-0.059168	5608	0.1155245	-0.019915		-0.059744	5556	0.1181546	-0.020368		-0.061104
400	5624	0.1147152	-0.019775		-0.059325	5603	0.1157774	-0.019958		-0.059875	5548	0.1185593	-0.020438		-0.061313
600	5622	0.1148164	-0.019793		-0.059378	5595	0.116182	-0.020028		-0.060084	5542	0.1188628	-0.02049		-0.06147
800	5620	0.1149175	-0.01981		-0.05943	5592	0.1163338	-0.020054		-0.060162	5537	0.1191157	-0.020534		-0.061601
1000	5618	0.1150187	-0.019827	-0.006664	-0.033155	5591	0.1163843	-0.020063	-0.006790	-0.033643	5532	0.1193686	-0.020577	-0.007022	-0.034621

DATA SHEET # 4

SAMPLE 4ST#4

INITIAL LENGTH= 5.801 inch
INITIAL DIAMETER = 2.9013 inch

	SHEAR ST.	TOTAL			DYNAMIC			
	(%)	VERT. ST.	HOR. ST.	Evol	VERT. ST. (Ev)	HOR. ST. (Eh)	Evol	Eh/Ev
50Kpa @1000 CYCLES	0.00568	-0.012878	-0.003907	-0.020693	0.000000	0.000000	0.000000	
	0.01339	-0.012913	-0.004011	-0.020934	-0.000035	-0.000103	-0.000241	2.96
	0.02910	-0.013236	-0.004075	-0.021385	-0.000323	-0.000064	-0.000451	0.20
	0.04531	-0.013428	-0.004178	-0.021783	-0.000192	-0.000103	-0.000398	0.54
	0.10261	-0.014142	-0.004406	-0.022954	-0.000715	-0.000228	-0.001171	0.32
100Kpa @1000 CYCLES	0.00407	-0.019540	-0.006536	-0.032611	0.000000	0.000000	0.000000	
	0.01254	-0.019618	-0.006577	-0.032772	-0.000078	-0.000041	-0.000161	0.53
	0.02548	-0.019827	-0.006664	-0.033155	-0.000209	-0.000087	-0.000383	0.42
	0.04186	-0.020063	-0.006790	-0.033643	-0.000235	-0.000126	-0.000487	0.54
	0.07415	-0.020577	-0.007022	-0.034621	-0.000514	-0.000232	-0.000978	0.45

APPENDIX 4.3.3

DATA SUMMARY OF PHASE II(c) RESULTS

DATA SHEET # 1

SAMPLE # 3ST#11A

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.86433	5.778	1.9943	0.50253	2.74	0.021546	92.55952	1.3272946	61.60244	0.007763	1.7754744	0.7755292	7970	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
4/26/94	25	54	67	14.92537	7695	5.76425	2.857514	0.021393	1.9943	1.755707	0.000439	0.205278	0.43815	461.52	617248.9	29.55388	0.00066

TORSIONAL SHEAR TEST FOR 3ST#11A (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 04/26/94
Confining Pressure = 25 kPa

Estimate Strain %	Op. Factor	d (in)	l (in)	Vt(20%) (volts)	Vt(p-to-p) (volts)	Vp(p-to-p) (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.01	20	2.864	5.778	2.4660	12.3300	7.2719	4.8503E-04	9.6178E-03	1.6830E-01	3.1869E-04	5.0423E+01	5.2427E+05
0.025	2	2.864	5.778	6.0919	30.4593	2.4960	1.6648E-03	3.3012E-02	4.1577E-01	3.1869E-04	1.2456E+02	3.7732E+05
0.05	2	2.864	5.778	8.8661	44.3307	4.2964	2.8657E-03	5.6825E-02	6.0511E-01	3.1869E-04	1.8129E+02	3.1903E+05
0.1	2	2.864	5.778	12.0381	60.1907	6.9083	4.6078E-03	9.1370E-02	8.2160E-01	3.1869E-04	2.4615E+02	2.6940E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 3ST#11A

DATE: 4/26/94

INITIAL LENGTH = 5.778 inch STTLMT is in inches e0= 1.775
INITIAL DIAMETER = 2.864 inch INITIAL LVDT = -5.304 volt V0= 37.2315 inch^3 Vs= 13.4145 inch^3

25Kpa	SHEAR STRAIN AMPLITUDE (%)														
	0.01					0.03301					0.05682				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	-5.12125	0.013907	-0.002407	-0.002912	-0.008231	-5.12025	0.013983	-0.002420	-0.002917	-0.008253	-5.111375	0.014659	-0.002537	-0.002920	-0.008377
50	-5.1185	0.014116	-0.002443	-0.002903	-0.008249	-5.114375	0.014430	-0.002497	-0.002910	-0.008318	-5.107225	0.014975	-0.002592	-0.002920	-0.008432
100	-5.1185	0.014116	-0.002443	-0.002906	-0.008255	-5.113375	0.014507	-0.002511	-0.002902	-0.008314	-5.105225	0.015127	-0.002618	-0.002914	-0.008445
200	-5.11775	0.014173	-0.002453	-0.002918	-0.008289	-5.1125	0.014573	-0.002522	-0.002907	-0.008336	-5.10385	0.015232	-0.002636	-0.002912	-0.008461
400	-5.117875	0.014164	-0.002451	-0.002915	-0.008281	-5.111875	0.014621	-0.002530	-0.002904	-0.008339	-5.102075	0.015367	-0.002660	-0.002939	-0.008538
600	-5.118125	0.014145	-0.002448	-0.002906	-0.008260	-5.11075	0.014706	-0.002545	-0.002904	-0.008353	-5.101375	0.015420	-0.002669	-0.002936	-0.008542
800	-5.118	0.014154	-0.002450	-0.002898	-0.008246	-5.111025	0.014686	-0.002542	-0.002905	-0.008352	-5.100675	0.015474	-0.002678	-0.002936	-0.008550
1000	-5.1175	0.014192	-0.002456	-0.002898	-0.008252	-5.110525	0.014724	-0.002548	-0.002906	-0.008360	-5.100525	0.015485	-0.002680	-0.002950	-0.008580

	0.09137				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	-5.102025	0.015371	-0.002660	-0.003103	-0.008866
50	-5.09525	0.015887	-0.002749	-0.003082	-0.008914
100	-5.09275	0.016077	-0.002782	-0.003074	-0.008930
200	-5.091375	0.016182	-0.002801	-0.003081	-0.008963
400	-5.08975	0.016305	-0.002822	-0.003076	-0.008974
600	-5.088375	0.016410	-0.002840	-0.003080	-0.009000
800	-5.087875	0.016448	-0.002847	-0.003101	-0.009050
1000	-5.087125	0.016505	-0.002857	-0.003106	-0.009069
2000	-5.085625	0.016619	-0.002876	-0.003116	-0.009109
5000	-5.082375	0.016867	-0.002919	-0.003133	-0.009185
10000	-5.079625	0.017076	-0.002955	-0.003188	-0.009332
20000	-5.079	0.017124	-0.002964	-0.003234	-0.009431
50000	-5.084625	0.016696	-0.002890	-0.003343	-0.009576
100000	-5.089125	0.016353	-0.002830	-0.003411	-0.009652
200000	-5.091	0.016210	-0.002806	-0.003448	-0.009701
500000	-5.0905	0.016248	-0.002812	-0.003466	-0.009745
1000000	-5.08875	0.016382	-0.002835	-0.003593	-0.010021

DATA SHEET # 4

SAMPLE 3ST#11A

INITIAL LENGTH= 5.778 inch
INITIAL DIAMETER = 2.864 inch

	SHEAR ST.	TOTAL			DYNAMIC			
	(%)	VERT. ST.	HOR. ST.	Evol	VERT. ST. (Ev)	HOR. ST. (Eh)	Evol	Eh/Ev
25Kpa @1000 CYCLES	0.00962	-0.002456	-0.002898	-0.008252	0.000000	0.000000	0.000000	
	0.03301	-0.002548	-0.002906	-0.008360	-0.000092	-0.000008	-0.000108	0.09
	0.05682	-0.002680	-0.002950	-0.008580	-0.000132	-0.000044	-0.000220	0.34
	0.09137	-0.002857	-0.003106	-0.009069	-0.000177	-0.000156	-0.000489	0.89

DATA SHEET # 1

SAMPLE # 3ST#11B

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.869333	5.749333	2.0265	0.365549	2.74	0.021514	94.19361	1.484019	68.97857	0.00868	1.478683	0.677362	7510	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wav Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
4/26/94	25	57	67	14.92537	7198	5.733733	2.861547	0.02134	2.0265	1.458561	0.000448	0.209182	0.44201	455.07	611318.1	29.26991	0.000701
4/26/94	50	58	72	13.88889	6931	5.720383	2.854885	0.021191	2.0265	1.441428	0.000446	0.208209	0.441055	488.95	710679.3	34.02733	0.000618
4/26/94	100	60	78	12.82051	6391	5.693383	2.84141	0.020892	2.0265	1.407021	0.000441	0.206248	0.43911	529.53	845456.9	40.48047	0.000545

TORSIONAL SHEAR TEST FOR 3ST#11B (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 04/20/94
Confining Pressure = 25 kPa

Estimate Strain %	Op. Factor	d (in)	l (in)	Vt(20%) (volts)	Vt(p-to-p) (volts)	Vp(p-to-p) (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.01	20	2.869	5.749	2.2453	11.2264	6.2324	4.1570E-04	8.2986E-03	1.5324E-01	3.2091E-04	4.5672E+01	5.5036E+05
0.025	2	2.869	5.749	5.0916	25.4579	1.9073	1.2722E-03	2.5396E-02	3.4750E-01	3.2091E-04	1.0357E+02	4.0782E+05
0.05	2	2.869	5.749	8.4360	42.1800	4.0323	2.6895E-03	5.3691E-02	5.7576E-01	3.2091E-04	1.7160E+02	3.1961E+05
0.1	2	2.869	5.749	12.3589	61.7943	7.6796	5.1223E-03	1.0225E-01	8.4349E-01	3.2091E-04	2.5140E+02	2.4585E+05

Date : 04/20/94
Confining Pressure = 50 kPa

Estimate Strain %	Op. Factor	d (in)	l (in)	Vt(20%) (volts)	Vt(p-to-p) (volts)	Vp(p-to-p) (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.01	20	2.869	5.749	2.6139	13.0693	6.2947	4.1986E-04	8.3815E-03	1.7840E-01	3.2091E-04	5.3169E+01	6.3436E+05
0.025	2	2.869	5.749	6.6067	33.0336	2.1651	1.4442E-03	2.8829E-02	4.5091E-01	3.2091E-04	1.3439E+02	4.6616E+05
0.05	2	2.869	5.749	8.6971	43.4857	3.1669	2.1123E-03	4.2167E-02	5.9358E-01	3.2091E-04	1.7691E+02	4.1955E+05
0.1	2	2.869	5.749	12.9371	64.6857	5.8023	3.8701E-03	7.7258E-02	8.8296E-01	3.2091E-04	2.6316E+02	3.4062E+05

Date : 04/21/94
Confining Pressure = 100 kPa

Estimate Strain %	Op. Factor	d (in)	l (in)	Vt(20%) (volts)	Vt(p-to-p) (volts)	Vp(p-to-p) (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.01	2	2.869	5.749	3.1434	15.7171	0.7633	5.0911E-04	1.0163E-02	2.1454E-01	3.2091E-04	6.3941E+01	6.2914E+05
0.025	2	2.869	5.749	6.8866	34.4329	1.6706	1.1143E-03	2.2244E-02	4.7001E-01	3.2091E-04	1.4008E+02	6.2975E+05
0.05	2	2.869	5.749	10.8431	54.2157	3.0264	2.0186E-03	4.0297E-02	7.4004E-01	3.2091E-04	2.2056E+02	5.4734E+05
0.1	2	2.869	5.749	18.1103	90.5514	6.6260	4.4195E-03	8.8226E-02	1.2360E+00	3.2091E-04	3.6839E+02	4.1755E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 3ST#11B

DATE: 4/20/94

INITIAL LENGTH = 5.749 inch STTLMT is in inches e0= 1.4787
INITIAL DIAMETER = 2.869 inch INITIAL LVDT = -4.997 volt V0= 37.1762 inch^3 Vs= 14.999 inch^3

25Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00829					0.02539					0.05369					0.10225				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	-4.7875	0.015936	-0.002772	-0.001958	-0.006687	-4.785	0.016126	-0.002805	-0.002029	-0.006862	-4.7752	0.016873	-0.002935	-0.002059	-0.007052	-4.75725	0.018239	-0.003172	-0.002134	-0.007441
50	-4.785875	0.016060	-0.002793	-0.001953	-0.006700	-4.779375	0.016555	-0.002879	-0.002008	-0.006895	-4.766975	0.017499	-0.003044	-0.002076	-0.007196	-4.745625	0.019124	-0.003326	-0.002110	-0.007546
100	-4.78525	0.016107	-0.002802	-0.001982	-0.006766	-4.77825	0.016640	-0.002894	-0.002014	-0.006921	-4.763625	0.017754	-0.003088	-0.002073	-0.007234	-4.74075	0.019496	-0.003391	-0.002123	-0.007636
200	-4.785125	0.016117	-0.002803	-0.001958	-0.006719	-4.777275	0.016715	-0.002907	-0.002011	-0.006929	-4.76125	0.017935	-0.003119	-0.002085	-0.007290	-4.73525	0.019914	-0.003464	-0.002111	-0.007687
400	-4.78475	0.016145	-0.002808	-0.001966	-0.006741	-4.7754	0.016857	-0.002932	-0.002004	-0.006941	-4.75925	0.018087	-0.003146	-0.002112	-0.007370	-4.732375	0.020133	-0.003502	-0.002125	-0.007751
600	-4.785125	0.016117	-0.002803	-0.001973	-0.006750	-4.775475	0.016852	-0.002931	-0.002002	-0.006935	-4.757875	0.018192	-0.003164	-0.002089	-0.007341	-4.73065	0.020265	-0.003525	-0.002136	-0.007796
800	-4.7845	0.016165	-0.002812	-0.001968	-0.006748	-4.77425	0.016945	-0.002947	-0.001993	-0.006933	-4.757125	0.018249	-0.003174	-0.002120	-0.007413	-4.72925	0.020371	-0.003543	-0.002132	-0.007808
1000	-4.785	0.016126	-0.002805	-0.001976	-0.006756	-4.7741	0.016956	-0.002949	-0.001998	-0.006946	-4.757	0.018258	-0.003176	-0.002120	-0.007416	-4.728475	0.020430	-0.003554	-0.002131	-0.007816

50Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.00838					0.02883					0.04217					0.07726				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	-4.60775	0.029622	-0.005152	-0.003232	-0.011617	-4.604975	0.029834	-0.005189	-0.003241	-0.011671	-4.597075	0.030435	-0.005294	-0.003324	-0.011942	-4.589125	0.031040	-0.005399	-0.003324	-0.012046
50	-4.6061	0.029748	-0.005174	-0.003235	-0.011644	-4.6013	0.030113	-0.005238	-0.003251	-0.011740	-4.5946	0.030624	-0.005326	-0.003321	-0.011969	-4.580375	0.031707	-0.005515	-0.003377	-0.012269
100	-4.6062	0.029740	-0.005173	-0.003241	-0.011655	-4.60025	0.030193	-0.005252	-0.003265	-0.011782	-4.594	0.030669	-0.005334	-0.003318	-0.011971	-4.5765	0.032002	-0.005566	-0.003388	-0.012342
200	-4.606	0.029756	-0.005176	-0.003238	-0.011652	-4.599675	0.030237	-0.005259	-0.003298	-0.011855	-4.59225	0.030802	-0.005358	-0.003324	-0.012005	-4.57275	0.032287	-0.005616	-0.003376	-0.012368
400	-4.605775	0.029773	-0.005178	-0.003235	-0.011649	-4.59835	0.030338	-0.005277	-0.003305	-0.011887	-4.591125	0.030888	-0.005372	-0.003329	-0.012031	-4.568725	0.032594	-0.005669	-0.003374	-0.012417
600	-4.605775	0.029773	-0.005178	-0.003235	-0.011649	-4.5983	0.030342	-0.005277	-0.003305	-0.011888	-4.59	0.030974	-0.005387	-0.003326	-0.012040	-4.566875	0.032734	-0.005694	-0.003384	-0.012461
800	-4.60565	0.029782	-0.005180	-0.003238	-0.011656	-4.597775	0.030382	-0.005284	-0.003321	-0.011927	-4.588875	0.031059	-0.005402	-0.003324	-0.012050	-4.565675	0.032826	-0.005710	-0.003379	-0.012467
1000	-4.605875	0.029765	-0.005177	-0.003232	-0.011642	-4.597025	0.030439	-0.005294	-0.003314	-0.011922	-4.588375	0.031097	-0.005409	-0.003316	-0.012041	-4.563675	0.032978	-0.005736	-0.003397	-0.012531

100Kpa	SHEAR STRAIN AMPLITUDE (%)																			
	0.010163					0.022244					0.040297					0.088226				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	-4.247625	0.057042	-0.009922	-0.005597	-0.021115	-4.246625	0.057118	-0.009935	-0.005637	-0.021210	-4.241625	0.057499	-0.010001	-0.005634	-0.021270	-4.232875	0.058165	-0.010117	-0.005744	-0.021605
50	-4.24675	0.057109	-0.009933	-0.005614	-0.021161	-4.243	0.057394	-0.009983	-0.005632	-0.021247	-4.23875	0.057718	-0.010039	-0.005653	-0.021345	-4.218875	0.059231	-0.010302	-0.005840	-0.021983
100	-4.2465	0.057128	-0.009936	-0.005611	-0.021158	-4.242875	0.057404	-0.009984	-0.005635	-0.021254	-4.2372	0.057836	-0.010060	-0.005649	-0.021357	-4.213875	0.059612	-0.010369	-0.005856	-0.022081
200	-4.2465	0.057128	-0.009936	-0.005601	-0.021139	-4.242875	0.057404	-0.009984	-0.005635	-0.021254	-4.235375	0.057975	-0.010084	-0.005688	-0.021461	-4.20825	0.060040	-0.010443	-0.005882	-0.022207
400	-4.246125	0.057156	-0.009941	-0.005614	-0.021169	-4.242125	0.057461	-0.009994	-0.005632	-0.021258	-4.234025	0.058078	-0.010102	-0.005700	-0.021501	-4.203125	0.060430	-0.010511	-0.005883	-0.022278
600	-4.246375	0.057137	-0.009938	-0.005613	-0.021165	-4.241125	0.057537	-0.010008	-0.005632	-0.021272	-4.23295	0.058160	-0.010116	-0.005713	-0.021542	-4.200125	0.060659	-0.010551	-0.005899	-0.022348
800	-4.245875	0.057175	-0.009945	-0.005599	-0.021143	-4.241375	0.057518	-0.010004	-0.005632	-0.021268	-4.232275	0.058211	-0.010125	-0.005711	-0.021548	-4.197375	0.060868	-0.010587	-0.005889	-0.022365
1000	-4.24575	0.057185	-0.009946	-0.005602	-0.021150	-4.241625	0.057499	-0.010001	-0.005632	-0.021265	-4.231775	0.058249	-0.010131	-0.005724	-0.021579	-4.195875	0.060982	-0.010607	-0.005903	-0.022413
2000																-4.1896	0.061460	-0.010690	-0.005916	-0.022522
5000																-4.18155	0.062073	-0.010797	-0.006001	-0.022798
10000																-4.174	0.062648	-0.010897	-0.006050	-0.022997
20000																-4.1725	0.062762	-0.010916	-0.006105	-0.023127
100000																-4.180675	0.062140	-0.010808	-0.006456	-0.023721
200000																-4.17675	0.062439	-0.010860	-0.006610	-0.024080
500000																-4.16675	0.063200	-0.010993	-0.006704	-0.024401
1000000																-4.158125	0.063857	-0.011107	-0.006957	-0.025021

DATA SHEET # 4

SAMPLE 3ST#11B

INITIAL LENGTH= 5.749 inch
INITIAL DIAMETER = 2.869 inch

	SHEAR ST.	TOTAL			DYNAMIC			
	(%)	VERT. ST.	HOR. ST.	Evol	VERT. ST. (Ev)	HOR. ST. (Eh)	Evol	Eh/Ev
25Kpa @1000 CYCLES	0.00830	-0.002805	-0.001976	-0.006756	0.000000	0.000000	0.000000	
	0.02540	-0.002949	-0.001998	-0.006946	-0.000144	-0.000022	-0.000189	0.16
	0.05369	-0.003176	-0.002120	-0.007416	-0.000226	-0.000122	-0.000470	0.54
	0.10225	-0.003554	-0.002131	-0.007816	-0.000378	-0.000011	-0.000401	0.03
50Kpa @1000 CYCLES	0.00838	-0.005177	-0.003232	-0.011642	0.000000	0.000000	0.000000	
	0.02883	-0.005294	-0.003314	-0.011922	-0.000117	-0.000082	-0.000281	0.70
	0.04217	-0.005409	-0.003316	-0.012041	-0.000115	-0.000002	-0.000118	0.02
	0.07726	-0.005736	-0.003397	-0.012531	-0.000327	-0.000081	-0.000490	0.25
100Kpa @1000 CYCLES	0.01016	-0.009946	-0.005602	-0.021150	0.000000	0.000000	0.000000	
	0.02224	-0.010001	-0.005632	-0.021265	-0.000055	-0.000030	-0.000115	0.55
	0.04030	-0.010131	-0.005724	-0.021579	-0.000130	-0.000092	-0.000314	0.70
	0.08823	-0.011107	-0.006957	-0.025021	-0.000475	-0.000180	-0.000835	0.38

DATA SHEET # 1

SAMPLE # 5ST#2

Initial Data

Diam. (in)	Length (in)	Weight (lb)	w/c	Sp.Grav.	Vol. (ft^3)	Unit Wt. (pcf)	Dry Wt. (lb)	Dry Den. (pcf)	Vsolids (ft^3)	Void Ratio	Saturation	Initial LVDT	Io Dr.Plate
2.88067	5.796	2.38123	0.5087	2.865	0.021861	108.9282	1.5783323	72.20001	0.008829	1.4761214	0.9873344	8290	0.002141

Date	Confining Pressure (kPa)	Accel. a (mV)	Resonant Freq. (Hz)	Period p (mSec)	LVDT Reading	Specimen Length (in)	Diam. (in)	Vol. (ft^3)	Weight (lb)	Void Ratio	I (ft-lb/s^2)	I/Io	BETA	Shear Wave Velocity (ft/sec)	Shear Modulus (psf)	Shear Modulus (MPa)	Shear Str. Amp. (%)
4/12/94	50	79	55	18.18182	7375	5.75025	2.857932	0.021347	2.38123	1.4179481	0.000525	0.245177	0.47581	348.03	419993.2	20.10928	0.0014365

TORSIONAL SHEAR TEST FOR 5ST#2 (DATA SHEET # 2)

Kp = 0.001334 rad/volt
Kt = 0.0273 ft-lb/volt

Date : 04/13/94
Confining Pressure = 50 kPa

Estimate Strain %	Op. Factor	d (in)	l (in)	Vt(20%) (volts)	Vt(p-to-p) (volts)	Vp(p-to-p) (volts)	Alpha (rad)	Sh. Strain (%)	T (ft-lb)	Jp (ft e4)	Sh. Stress (psf)	G (psf)
0.025	20	2.881	5.796	3.1174	15.5871	1.7256	1.1510E-03	2.2881E-02	2.1276E-01	3.2602E-04	6.2665E+01	2.7387E+05
0.05	20	2.881	5.796	4.8467	24.2336	3.3684	2.2467E-03	4.4666E-02	3.3079E-01	3.2602E-04	9.7426E+01	2.1812E+05
0.1	2	2.881	5.796	8.0176	40.0879	6.9140	4.6116E-03	9.1681E-02	5.4720E-01	3.2602E-04	1.6116E+02	1.7579E+05
0.1	2	2.881	5.796	8.0246	40.1228	7.3276	4.8875E-03	9.7165E-02	5.4768E-01	3.2602E-04	1.6130E+02	1.6601E+05

Note : 1 psf = 47.88E-6 MPa

DATA SHEET # 3

SAMPLE 5ST#2

DATE: 4/8/94

INITIAL LENGTH = 5.796 inch | STTLMT is in inches | e0= 1.4761
INITIAL DIAMETER = 2.881 inch | INITIAL LVDT = -5.51 volt | V0= 37.7741 inch^3 | Vs= 15.2582 inch^3

50Kpa	SHEAR STRAIN AMPLITUDE (%)														
	0.02288					0.04467					0.09168				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
1	-4.9115	0.045570	-0.007862	-0.003795	-0.015452	-4.909375	0.045732	-0.007890	-0.003963	-0.015817	-4.90675	0.045931	-0.007925	-0.00402	-0.015964
50	-4.90825	0.045817	-0.007905	-0.003805	-0.015515	-4.907875	0.0458458	-0.00791	-0.003929	-0.015769	-4.901875	0.0463026	-0.007989	-0.004046	-0.01608
100	-4.90875	0.045779	-0.007898	-0.003767	-0.015433	-4.907875	0.0458458	-0.00791	-0.00394	-0.01579	-4.901	0.0463693	-0.008	-0.00404	-0.016079
200	-4.908875	0.045770	-0.007897	-0.003795	-0.015488	-4.907875	0.0458458	-0.00791	-0.003934	-0.015778	-4.89915	0.0465101	-0.008025	-0.004048	-0.016121
400	-4.908375	0.045808	-0.007903	-0.003776	-0.015456	-4.907625	0.0458648	-0.007913	-0.00393	-0.015773	-4.897775	0.0466148	-0.008043	-0.004029	-0.016101
600	-4.908375	0.045808	-0.007903	-0.003782	-0.015468	-4.907375	0.0458839	-0.007916	-0.00394	-0.015797	-4.89685	0.0466852	-0.008055	-0.004032	-0.016119
800	-4.90725	0.045893	-0.007918	-0.003801	-0.015521	-4.907	0.0459124	-0.007921	-0.003936	-0.015793	-4.896225	0.0467328	-0.008063	-0.004038	-0.016138
1000	-4.906875	0.045922	-0.007923	-0.003814	-0.015552	-4.906625	0.045941	-0.007926	-0.003938	-0.015802	-4.89635	0.0467233	-0.008061	-0.004024	-0.01611

	0.09717				
CYCLES	LVDT	STTLMT	VERT. ST.	HOR. ST.	Evol
5	-4.896075	0.046744	-0.008065	-0.004049	-0.016163
55	-4.89405	0.046898	-0.008092	-0.004041	-0.016173
105	-4.894425	0.046870	-0.008087	-0.004042	-0.016170
203	-4.894225	0.046885	-0.008089	-0.004047	-0.016183
504	-4.8942	0.046887	-0.008090	-0.004047	-0.016184
1002	-4.8936	0.046933	-0.008097	-0.004037	-0.016171
2005	-4.89325	0.046959	-0.008102	-0.004037	-0.016176
10002	-4.888	0.047359	-0.008171	-0.004094	-0.016359
20002	-4.885	0.047588	-0.008210	-0.004133	-0.016476
100001	-4.878125	0.048111	-0.008301	-0.004232	-0.016766
200000	-4.869875	0.048739	-0.008409	-0.004312	-0.017032
500002	-4.8589	0.049575	-0.008553	-0.004449	-0.017451
1000005	-4.85315	0.050013	-0.008629	-0.004529	-0.017687

DATA SHEET # 4

SAMPLE 5ST#2

INITIAL LENGTH= 5.796 inch
INITIAL DIAMETER = 2.881 inch

	SHEAR ST.	TOTAL			DYNAMIC			
	(%)	VERT. ST.	HOR. ST.	Evol	VERT. ST. (Ev)	HOR. ST. (Eh)	Evol	Eh/Ev
50Kpa @1000 CYCLES	0.02288	-0.007923	-0.003814	-0.015552	0.000000	0.000000	0.000000	
	0.04467	-0.007926	-0.003938	-0.015802	-0.000003	-0.000123	-0.000250	37.59
	0.09168	-0.008061	-0.004024	-0.016110	-0.000135	-0.000087	-0.000308	0.64
	0.09717	-0.008097	-0.004037	-0.016171	-0.000036	-0.000012	-0.000061	0.34

APPENDIX 5

SITE MAPS AND BORING LOGS

SAMPLES 151 #1 & 151 #4

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
GEOTECHNICAL UNIT
FOUNDATION BORING LOG SHEET 1 OF 1

PROJECT NO. 5.5151 COUNTY ROCKINGHAM GEOLOGIC PROVINCE PIEDMONT
BRIDGE ON SR 1138 (#55) OVER BELEWS
BORING LOCATION (STA.) 13+90 -L- OFFSET 15' Rt
BORING NO. EB1-B GEOLOGIST O.B. OTI GROUND WATER 0 HRS DRY 17.0 24 HRS DRY
COLLAR ELEV. 100.8' DATE STARTED 10-16-92 DRILL EQUIPMENT CME 45B
TOTAL DEPTH 21.9 DATE COMPLETED 10-16-92 8" HOLLOW STEMS, SPT

ELEV.	DEPTH	BLOW COUNT 6"	6"	6"	SAMP. NO.	SOIL DESCRIPTION	MOIST.	BPF NOTES & REMARKS
0	0.0	1	2	2	SS-11	TAN-BROWN FINE SANDY SILT. ROADWAY EMBANKMENT. (A-4)	M	4
	3.8	3	3	4	SS-12	TAN-BROWN FINE SANDY SILT ROADWAY EMBANKMENT.	M	7 ART FILL
5						EMBANKMENT ENDED @ 7.0		
	7.8	2	2	4	SS-13	GRAY-TAN FINE SANDY SILT W/ MINOR ROOT DEBRIS. (A-4) RESIDUAL	M	6 RES
10								
	12.8	1	3	3	SS-14	TAN-BROWN FINE SANDY SILT. RESIDUAL.	M	6
15						RESIDUAL END @ 17.8		
	17.8	2	2	100/.5	SUR	SOFT WEATHERED ROCK (MICA/SCHIST)	D	100 SWR
20						HOLLOW STEMS REFUSAL @ 21.9 IN HARD MICA SCHIST.		HR
25								
30								

PRELIMINARY FOUNDATION INFO.

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
GEOTECHNICAL UNIT
FOUNDATION BORING LOG SHEET 1 OF 1

PROJECT NO. 5.5151 COUNTY ROCKINHAM GEOLOGIC PROVINCE PIEDMONT
BRIDGE ON SR 1138 (#55) OVER BELEWS CRK
BORING LOCATION (STA.) 13+88 -L- OFFSET 15 Rt
BORING NO. SB1 GEOLOGIST OB OTI GROUND WATER 0 HRS. ___ 24 HRS. ___
COLLAR ELEV. 100.8 DATE STARTED 10-21-92 DRILL EQUIPMENT CME 45B
TOTAL DEPTH 7'-15.3 DATE COMPLETED 10-21-92 HOLLOW STEMS, SHELBY TUBE

ELEV.	DEPTH	BLOW COUNT 6"	6"	6"	SAMP. NO.	SOIL DESCRIPTION	MOIST.	NOTES & REMARKS
	7.0'				ST#1	SHELBY TUBE WAS PUSHED FIRM 7.0-9.0	M	
	9.2				ST#2	BOTTOM DROP .3 (9.2-10.1)	M	
	11.3				ST#3	PUSHED SMOOTH 11.3-13.3	M	
	13.3				ST#4	PUSHED SMOOTH 13.3-15.3	M.	
						ST. TERMINATED @ 15.3.		

* Supplementary Log to EB1-B.

PRELIMINARY FOUNDATION INFO.

SAMPLED 2ST#1 to 2ST# 16

GEOTECHNICAL UNIT
SOIL SAMPLE TRANSMITTAL

PROJECT NO. 4.6321302 (M-220) ROUTE CENTENNIAL PARKWAY COUNTY WAKE

PROJECT GEOLOGIST R. S. JOHNSON DATE 12-17-92

SAMPLE NO.	LOCATION	TYPE TEST	COMMENTS
2ST#1 PRIMARY ALT.FOR	STA. 22+92-L-REV. OFFSET 31' LT. SAMP.DEPTH 3.0-5.0 G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. RED-TAN, MOIST, -F.-SDY. SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 10± BPF OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
2ST#2 PRIMARY ALT.FOR	STA. 22+95-L-REV. OFFSET 31' LT SAMP.DEPTH 3.0-5.0' G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. RED-TAN MOIST, -F.-SDY SILT. SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 10± BPF OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
2ST#3 PRIMARY ALT.FOR	STA. 22+95-L-REV. OFFSET 31' LT. SAMP.DEPTH 3.0-5.0 G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. RED-TAN MOIST, -F.-SDY. SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 10± BPF OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT.HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
2ST#4 PRIMARY ALT.FOR	STA. 22+95-L-REV. OFFSET 30' LT. SAMP.DEPTH 3.0-5.0 G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. RED-TAN MOIST -F.-SDY. SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 10± BPF OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
PRIMARY ALT.FOR	STA. OFFSET SAMP.DEPTH G.W.DEPTH	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. SOIL STRUCTURE EST. BLOWS/FT. OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION

FORM G-10 REV.7-86

GEOTECHNICAL UNIT
SOIL SAMPLE TRANSMITTAL

PROJECT NO. 4.6321302 (M-220) ROUTE CENTENNIAL PARKWAY COUNTY WAKE

PROJECT GEOLOGIST R. S. JOHNSON DATE 12-17-92

SAMPLE NO.	LOCATION	TYPE TEST	COMMENTS
2ST#5 PRIMARY ALT.FOR	STA. 81+00 -L- OFFSET ℄ SAMP.DEPTH 5.0-7.0 G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. TAN, MOIST, SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 15± BPF OTHER WHERE USED: - UNDER ____ FT. HIGH EMBANKMENT - IN ____ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
2ST#6 PRIMARY ALT.FOR	STA. 81+00 -L- OFFSET ℄ SAMP.DEPTH 7.0-9.0' G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. TAN, MOIST, SDY. SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 15± BPF OTHER WHERE USED: - UNDER ____ FT. HIGH EMBANKMENT - IN ____ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
2ST#7 PRIMARY ALT.FOR	STA. 81+00 -L- OFFSET ℄ SAMP.DEPTH 5.0-7.0' G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. TAN, MOIST, SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 15± BPF OTHER WHERE USED: - UNDER ____ FT. HIGH EMBANKMENT - IN ____ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
2ST#8 PRIMARY ALT.FOR	STA. 81+00 -L- OFFSET ℄ SAMP.DEPTH 7.0-9.0 G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. TAN, MOIST, SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 15± BPF OTHER WHERE USED: - UNDER ____ FT. HIGH EMBANKMENT - IN ____ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
PRIMARY ALT.FOR	STA. OFFSET SAMP.DEPTH [redacted] G.W.DEPTH	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. SOIL STRUCTURE EST. BLOWS/FT. OTHER WHERE USED: - UNDER ____ FT. HIGH EMBANKMENT - IN ____ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION

FORM G-10 REV.7-86

GEOTECHNICAL UNIT
SOIL SAMPLE TRANSMITTAL

PROJECT NO. 4.6321302 ROUTE CENTENNIAL PARKWAY COUNTY WAKE

PROJECT GEOLOGIST R. S. JOHNSON DATE 2-15-92

SAMPLE NO.	LOCATION	TYPE TEST	COMMENTS
2ST#9 PRIMARY ALT.FOR	STA. 22+95L-REV OFFSET 32'LT. SAMP.DEPTH 3.0-5.0' G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. RED-TAN MOIST., F-SDY SILT. SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 10± BPF OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
2ST#10 PRIMARY ALT.FOR	STA. 22+95L-REV OFFSET 32'LT. SAMP.DEPTH 3.0-5.0' G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. RED-TAN MOIST,-F-SDY SILT. SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 10± BPF. OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
2ST#11 PRIMARY ALT.FOR	STA. 22+95L-REV OFFSET 33'LT. SAMP.DEPTH 3.0-5.0 G.W.DEPTH N/A	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. RED-TAN MOIST-F-SDY. SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 10± BPF OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
2ST#12 PRIMARY ALT.FOR	STA. 22+95-L-REV OFFSET 31'LT. SAMP.DEPTH 3.0-5.0 G.W.DEPTH	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. RED-TAN MOIST-F-SDY. SILT. SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 10± BPF. OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
PRIMARY ALT.FOR	STA. OFFSET SAMP.DEPTH G.W.DEPTH	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. SOIL STRUCTURE EST. BLOWS/FT. OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION

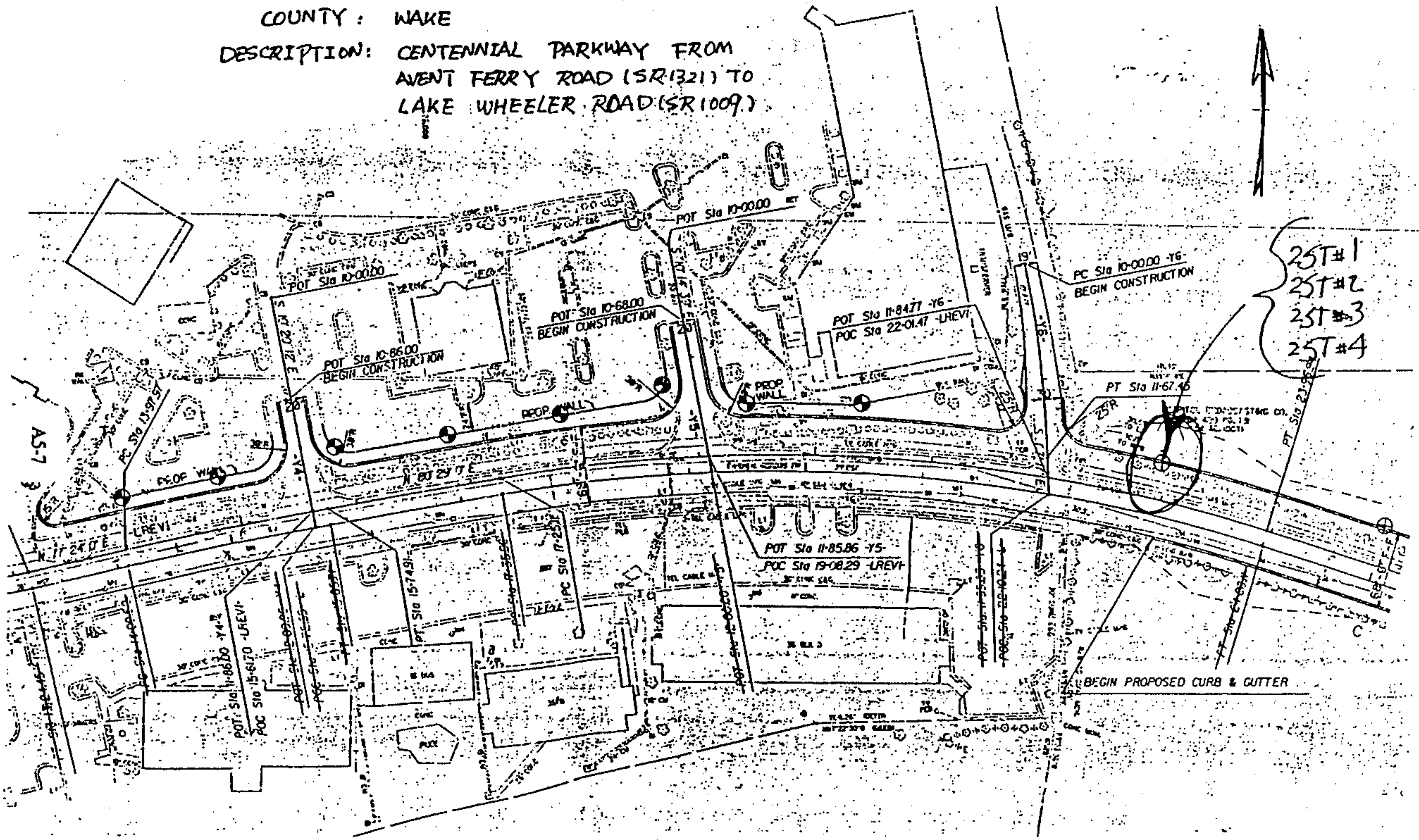
FORM 5-19 REV.7-86

SAMPLE: 2ST#1 TO 2ST#4

STATE PROJECT: 4.6321302 ID. No. M-0220

COUNTY: WAKE

DESCRIPTION: CENTENNIAL PARKWAY FROM AVENT FERRY ROAD (SR 1321) TO LAKE WHEELER ROAD (SR 1009)

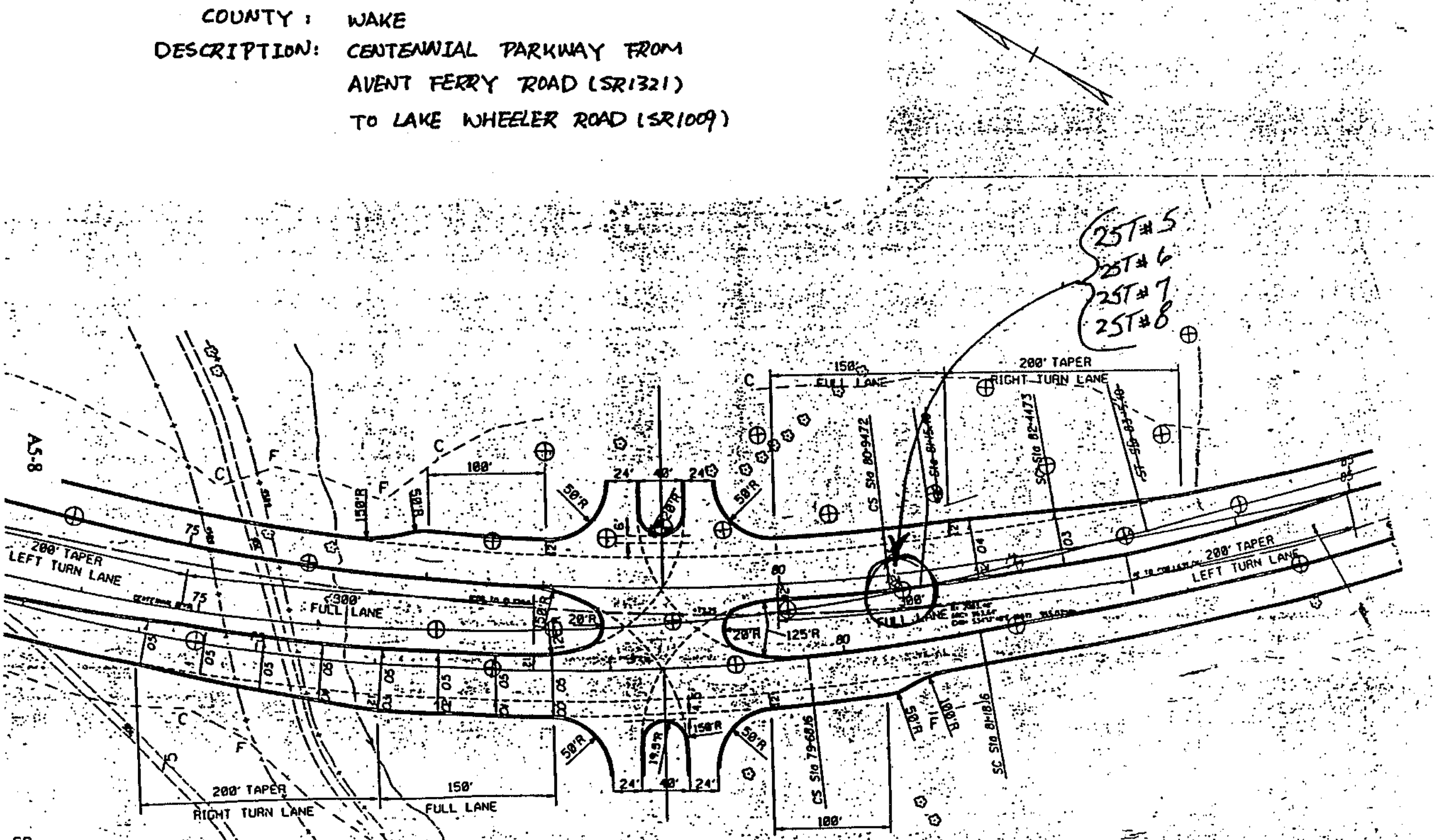


SAMPELS: 25T #5 TO 25T #8

STATE PROJECT: 4.6321302 ID. No. M-0220

COUNTY: WAKE

DESCRIPTION: CENTENNIAL PARKWAY FROM AVENT FERRY ROAD (SR1321) TO LAKE WHEELER ROAD (SR1009)



SAMPLES 3ST #1 & 3ST #2

GEOTECHNICAL UNIT
SOIL SAMPLE TRANSMITTAL

PROJECT NO. 6.409003T ROUTE US 64 COUNTY WAKE Co.

PROJECT GEOLOGIST R. S. JOHNSON DATE 5-28-93

SAMPLE NO.	LOCATION	TYPE TEST	COMMENTS
3ST#1 PRIMARY ALT.FOR	LP "D" STA. 4+50 OFFSET 70' LT SAMP.DEPTH 4.9-6.9 G.W.DEPTH NONE	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY ✓ OTHER VIBRATION TEST	SOIL DESC. BROWN-TAN-F-SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 12 TO 18 OTHER WHERE USED: • UNDER ___ FT. HIGH EMBANKMENT • IN ___ FT. HIGH EMBANKMENT • CUT SLOPE • BRIDGE FOUNDATION
3ST#2 PRIMARY ALT.FOR	LP "D" STA. 4+50 OFFSET 70' LT SAMP.DEPTH 4.1-6.1 G.W.DEPTH NONE	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY ✓ OTHER VIBRATION STUDY	SOIL DESC. TAN-BROWN-F-SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 19± OTHER WHERE USED: • UNDER ___ FT. HIGH EMBANKMENT • IN ___ FT. HIGH EMBANKMENT • CUT SLOPE • BRIDGE FOUNDATION
3ST#3 PRIMARY ALT.FOR	LP "D" STA. 4+50 OFFSET 72' LT SAMP.DEPTH 7.0-9.0' G.W.DEPTH NONE	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY ✓ OTHER VIBRATION STUDY	SOIL DESC. TAN-BROWN-F-SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 14± OTHER WHERE USED: • UNDER ___ FT. HIGH EMBANKMENT • IN ___ FT. HIGH EMBANKMENT • CUT SLOPE • BRIDGE FOUNDATION
3ST#4 PRIMARY ALT.FOR	LP "D" STA. 4+50 OFFSET 75' LT SAMP.DEPTH 4.8-6.8 G.W.DEPTH NONE	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY ✓ OTHER VIBRATION STUDY	SOIL DESC. TAN-F-SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 14± OTHER WHERE USED: • UNDER ___ FT. HIGH EMBANKMENT • IN ___ FT. HIGH EMBANKMENT • CUT SLOPE • BRIDGE FOUNDATION
PRIMARY ALT.FOR	STA. OFFSET SAMP.DEPTH G.W.DEPTH	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. SOIL STRUCTURE EST. BLOWS/FT. OTHER WHERE USED: • UNDER ___ FT. HIGH EMBANKMENT • IN ___ FT. HIGH EMBANKMENT • CUT SLOPE • BRIDGE FOUNDATION

FORM G-19 REV.7-85

GEOTECHNICAL UNIT
SOIL SAMPLE TRANSMITTAL

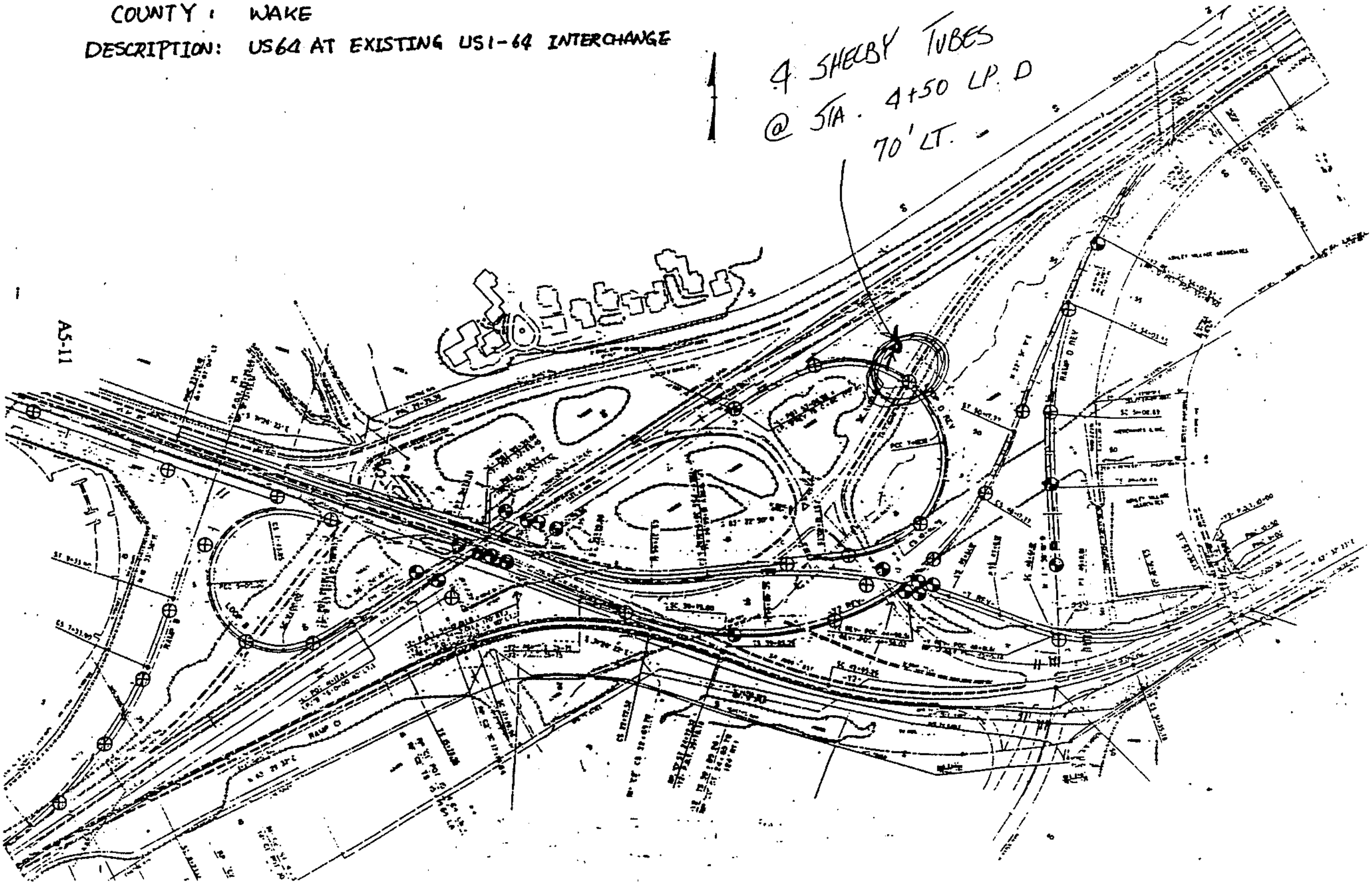
PROJECT NO. 6.409003T ROUTE US 64 COUNTY WAKE

PROJECT GEOLOGIST R. S. Johnson DATE 7/2/93

SAMPLE NO.	LOCATION	TYPE TEST	COMMENTS
3ST#5 PRIMARY ALT.FOR	STA. 4100 OFFSET 60 LT SAMP.DEPTH 4.0-6.0 G.W.DEPTH NONE	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER VIBRATION STUDY	SOIL DESC. TAN - F - SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 10 TO 12 BPF OTHER WHERE USED: * UNDER ___ FT. HIGH EMBANKMENT * IN ___ FT. HIGH EMBANKMENT ✓* CUT SLOPE 6 TO 10 FOOT * BRIDGE FOUNDATION
3ST#6 PRIMARY ALT.FOR	STA. 4100 OFFSET SAMP.DEPTH 6.0-6.0 G.W.DEPTH NONE	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER VIBRATION STUDY	SOIL DESC. TAN-BRN - F - SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 12 TO BPF OTHER WHERE USED: * UNDER ___ FT. HIGH EMBANKMENT * IN ___ FT. HIGH EMBANKMENT ✓* CUT SLOPE 8 TO 10 CUT * BRIDGE FOUNDATION
3ST#7 PRIMARY ALT.FOR	STA. 4100 OFFSET SAMP.DEPTH 3.9-5.9 G.W.DEPTH NONE	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER VIBRATION STUDY	SOIL DESC. TAN - F - SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 10 - 12 BPF OTHER WHERE USED: * UNDER ___ FT. HIGH EMBANKMENT * IN ___ FT. HIGH EMBANKMENT ✓* CUT SLOPE 8 TO 10 FEET * BRIDGE FOUNDATION
3ST#8 PRIMARY ALT.FOR	STA. 4100 OFFSET SAMP.DEPTH 4.1-6.0 G.W.DEPTH NONE	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER VIBRATION STUDY	SOIL DESC. TAN - F - SANDY SILT SOIL STRUCTURE SAPROLITE EST. BLOWS/FT. 10 - 12 BPF OTHER WHERE USED: * UNDER ___ FT. HIGH EMBANKMENT * IN ___ FT. HIGH EMBANKMENT ✓* CUT SLOPE 8 TO 10 FEET * BRIDGE FOUNDATION
 PRIMARY ALT.FOR	STA. OFFSET SAMP.DEPTH G.W.DEPTH	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. SOIL STRUCTURE EST. BLOWS/FT. OTHER WHERE USED: * UNDER ___ FT. HIGH EMBANKMENT * IN ___ FT. HIGH EMBANKMENT * CUT SLOPE * BRIDGE FOUNDATION

FORM 0-10 REV.7-85

SAMPLES: 3ST#1 TO 3ST#12
STATE PROJECT : 6.409003T R-2318D
COUNTY: WAKE
DESCRIPTION: US64 AT EXISTING US1-64 INTERCHANGE



SAMPLES 4ST#1 to 4ST#4

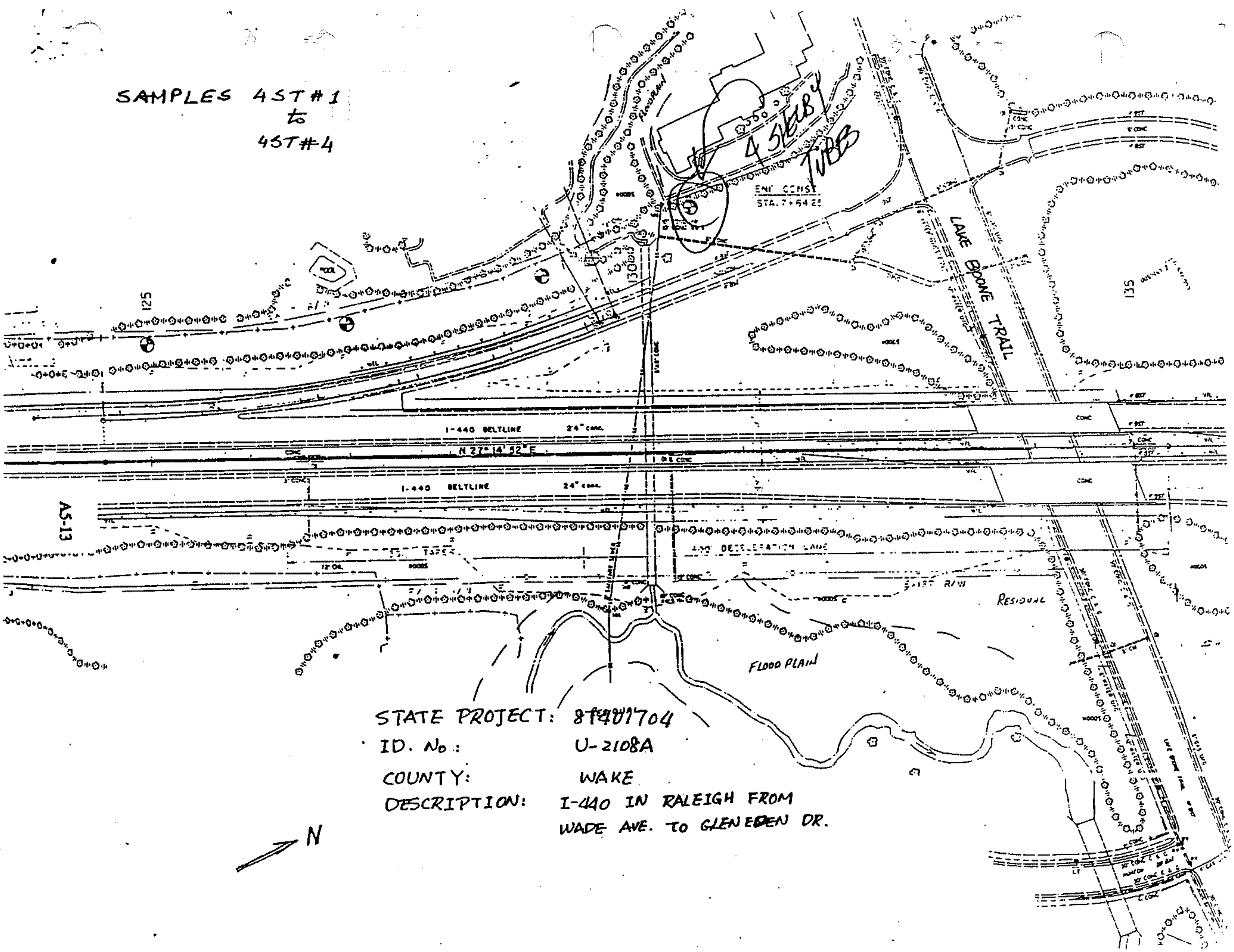
SOIL SAMPLE TRANSMITTAL

PROJECT NO. 8.T401704 ROUTE I-440 COUNTY WAKE

PROJECT GEOLOGIST R.S. JOHNSON DATE 11-22-93 VIBRATION STUDY -- NCSU

SAMPLE NO.	LOCATION	TYPE TEST	COMMENTS
4ST#1 PRIMARY ALT. FOR	STA. 143+00 OFFSET 240' LT SAMP. DEPTH 13.2 - 15.2 G.W. DEPTH 11.0'	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER VIBRATION STUDY	SOIL DESC. TAN-BRN. MIC. WET-F-SDY SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 9± BPF OTHER WHERE USED: - UNDER ____ FT. HIGH EMBANKMENT - IN ____ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
4ST#2 PRIMARY ALT. FOR	STA. 143+00 OFFSET 250' LT SAMP. DEPTH 15.3 - 17.3 G.W. DEPTH 11.0'	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER VIBRATION STUDY	SOIL DESC. TAN-BRN MIC, WET - F - SDY SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 9± BPF OTHER WHERE USED: - UNDER ____ FT. HIGH EMBANKMENT - IN ____ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
4ST#3 PRIMARY ALT. FOR	STA. 143+00 OFFSET 250' LT SAMP. DEPTH 13.0 - 15.0 G.W. DEPTH 11.0	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER VIBRATION STUDY	SOIL DESC. TAN-BRN. MIC., WET - F-SDY. SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 9± BPF. OTHER WHERE USED: - UNDER ____ FT. HIGH EMBANKMENT - IN ____ FT. HIGH EMBANKMENT. - CUT SLOPE - BRIDGE FOUNDATION
4ST#4 PRIMARY ALT. FOR	STA. 143+00 OFFSET 250' LT SAMP. DEPTH 15.4 - 17.4 G.W. DEPTH 11.0'	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER VIBRATION STUDY	SOIL DESC. TAN-BRN MIC. WET -F-SDY. SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 9± BPF OTHER WHERE USED: - UNDER ____ FT. HIGH EMBANKMENT - IN ____ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
PRIMARY ALT. FOR	STA. OFFSET SAMP. DEPTH G.W. DEPTH	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. SOIL STRUCTURE EST. BLOWS/FT. OTHER WHERE USED: - UNDER ____ FT. HIGH EMBANKMENT - IN ____ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION

FORM ... REV. 7-85


SAMPLES 4ST#1 to 4ST#4
4 SLEBY TUBB
ENT CONST STA. 7+64.22
LAKE BOONE TRAIL
125
130
135
I-440 BELTLINE
N 27° 14' 52" E
I-440 BELTLINE
TAPER
DECELERATION LANE
R/W
RESIDUAL
FLOOD PLAIN
STATE PROJECT: 8T401704
ID. No.: U-2108A
COUNTY: WAKE
DESCRIPTION: I-440 IN RALEIGH FROM WADE AVE. TO GLENEDEN DR.
N

VIBRATION STUDY: TO NCSU

SAMPLES 5ST#1 to 5ST#4

SOIL SAMPLE TRANSMITTAL

PROJECT NO. 8.U401710 ROUTE RALEIGH OUTER LOOP COUNTY WAKE

PROJECT GEOLOGIST R.S. JOHNSON DATE 3/21/94 R-2000 CA

SAMPLE NO.	LOCATION	TYPE TEST	COMMENTS
5ST#1 PRIMARY ALT.FOR	STA. 627+00 OFFSET ℄ SAMP.DEPTH 9.0-11.0 G.W.DEPTH 1.0	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY ✓OTHER VIBRATION STUDY	SOIL DESC. YELLOW -F- SANDY SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 5± OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
5ST#2 PRIMARY ALT.FOR	STA. 627+00 OFFSET ℄ SAMP.DEPTH 11.0-13.0 G.W.DEPTH 1.0'	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY ✓OTHER VIBRATION STUDY	SOIL DESC. YELLOW -F- SANDY SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 5± OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
5ST#3 PRIMARY ALT.FOR	STA. 627+00 OFFSET ℄ SAMP.DEPTH 9.0-11.0 G.W.DEPTH 1.0'	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY ✓OTHER VIBRATION STUDY	SOIL DESC. YELLOW -F- SANDY SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 5± OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
5ST#4 PRIMARY ALT.FOR	STA. 627+00 OFFSET ℄ SAMP.DEPTH 11.0-13.0 G.W.DEPTH 1.0'	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY ✓OTHER VIBRATION STUDY	SOIL DESC. YELLOW -F- SANDY SILT SOIL STRUCTURE RESIDUAL EST. BLOWS/FT. 5± OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION
PRIMARY ALT.FOR	STA. OFFSET SAMP.DEPTH G.W.DEPTH	TRIAXIAL CU UU CD CONSOLIDATION PROCTOR %COMPACT. PERMEABILITY OTHER	SOIL DESC. SOIL STRUCTURE EST. BLOWS/FT. OTHER WHERE USED: - UNDER ___ FT. HIGH EMBANKMENT - IN ___ FT. HIGH EMBANKMENT - CUT SLOPE - BRIDGE FOUNDATION

FORM G-10 REV.7-86