Design, Fabrication and Performance of an Oscillatory Shear Box

by

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Introduction

ONE of the important problems facing the Civil Engineering Profession to-day (1971), is the aseismic design of foundations of large installations. For a rational solution of this problem an intimate knowledge of "stress-deformation and strength characteristics" of soils under dynamic loads is essential.

During an earthquake, an upward propagation of shear waves takes place through the earth's crust. As a result, the elements of soil are subjected to repeated reversals of shear stresses in addition to the sustained (static) stresses that were acting before the earthquake. Thus, the elements are subjected to simple shear deformations as shown in Figure 1. So, to study the strength characteristics of soils under earthquake loading, the stress and deformation patterns on a typical element of soil can be simulated on a laboratory apparatus and the resulting strains due to applied shear stresses noted.

Earlier investigations were aimed at studying the effects of increased rates of stress applications on the strength of soil. But, when these rates were pretty fast, they were better known as transient tests. The first classical study of this type was reported by Casagrande and Shannon (1948). They used the impact of a swinging pendulum to apply transient loads axially to a triaxial soil specimen. Similar studies using different devices were conducted on sands and clays by Taylor and Whitman (1954), *Seed and Lundgren (1954) and Nash and Dixon (1961).* The results indicate that, there is no marked effect of rate of loading on the strength of cohesionless soil, while there is an increase of up to 150 percent in the strength of cohesive soil over its static strength, when tested under transient loads.

But, impact loads with single significant load pulse, do not simulate earthquake loads, which have many significant load pulses. So, for better simulation, repeated loads were proposed. A strain control type of set-up proposed by Kondner (1962) and subsequently improved upon by Kondner,

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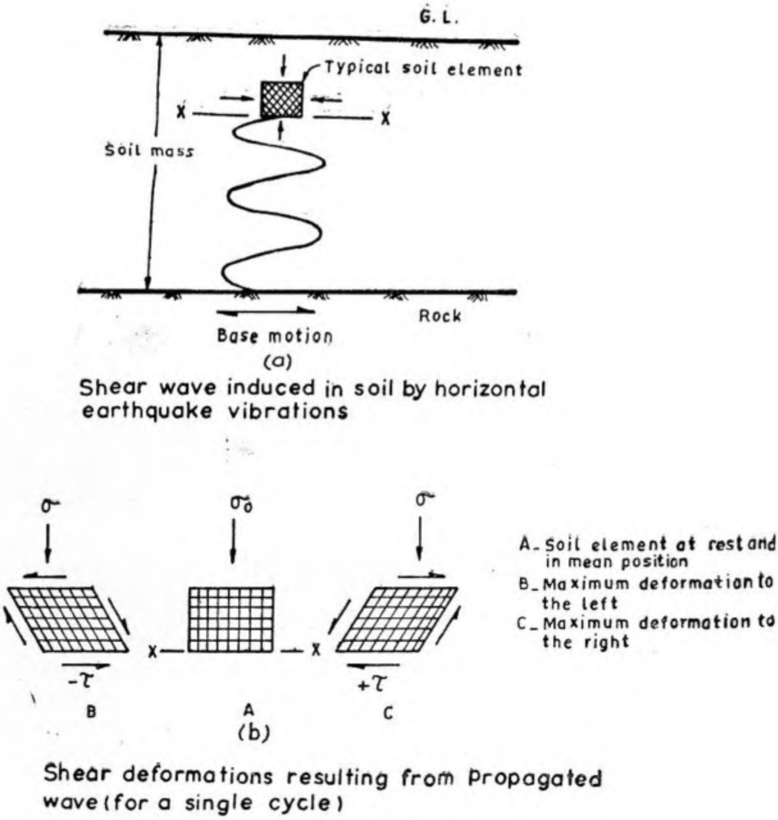

FIGURE 1 (a and b) :

Krizek and Haas (1966) is called as vibratory unconfined testing equipment. Here, a clay sample is subjected to axial stress (sustained) by spring loading. The dynamic sinusoidal strain is imposed by exciting the base of the sample using an electro-magnetic exciter. They have reported that the equipment worked satisfactorily.

Stress control type equipments were proposed by Seed and Fead (1960), Morgason and Wilson (1966) and Akai and Yamaguchi (1968). Among these, the first is the most versatile, with best control over the testing conditions. Here, axial dynamic stresses are produced by varying air pressure over a double acting piston attached to a loading yoke resting over the triaxial soil specimen. Solenoid valves are used for controlling air pressures. A similar unit can be used to produce dynamic chamber pressure also. The set-up has a good control over the stress function and has been used successfully by Seed and his associates since 1966.

But, there are some disadvantages associated with triaxial testing. The plain strain conditions presumed to be prevailing under field conditions are never ideally achieved in triaxial testing. Neither the intermediate principal stress is always equal to major of minor principal stress in field. The rotation of principal plane with sustained and dynamic loads under field loading conditions cannot be simulated in a triaxial set-up.

In order to improve upon these drawbacks, Peacock and Seed (1968) proposed a dynamic simple shear testing equipment. They utilized a modified Roscoe simple shear box, on which dynamic shear forces are applied by a double acting piston with controlled compressed air pressure with control using solenoid valves. It has a good control over the variables involved in testing.

This apparatus is superior to the triaxial type, because, it simulates the earthquake forces in a better way. The rotation of failure plane is achieved with this set-up as desired, in addition to the simple shear stresses and strains. The results obtained with such testing have shown that the strength estimate using triaxial set-up are on the unsafe side.

But even this equipment has some disadvantages. Uses of electronic equipments and compressed air appliances have rendered it complicated. It has a high initial cost also. The supervision and operation needs skilled persons. Therefore, it is not suitable for large scale adoption in laboratory. So, there is a need for a simple, cheep, robust and "easy to work" type of set-up. The aim of this work is to provide such a set-up.

Design Considerations

The dynamic strength of soil is affected by the following factors :

(1) Sustained normal stress.

(2) Oscillatory normal stress.

(3) Sustained shear stress.

(4) Oscillatory shear stress.

(5) Number of stress cycles.

(6) Frequency of stress cycles.

(7) Form of stress function.

(8) Type of test.

(9) Failure criteria.

Of these, items 1, 4, 5, 6 and *7* have been considered in the design and items 8 and 9 in the interpretation of test results. Items 2 and 3 have not been considered in the present design because of the following reasons.

If it is desired to determine the strength of soil in a deposit with a horizontal surface during an earthquake the stress condition given in Figure 1 will have to be simulated. This is because there are no shear stresses on horizontal planes before the occurrence of a dynamic phenomenon. Also the normal stresses do not alter during this case. This condition only has been satisfied in the present test set-up. However, it may be mentioned here that with a simple modification the case of oscillating shear forces being superimposed on any sustained shear stress can also be covered in this apparatus.

The proposed set-up has the following units :

(1) Oscillatory shear box.

(2) Facility to apply normal stress.

(3) Facility to apply oscillatory shear stress.

(4) Device to measure dynamic loads.

(5) Device to measure dynamic displacements.

These are explained one by one in the following paragraphs :

As explained previously, the shear strains are the results of the applied earthquake forces. So, it is logical to have a stress control unit. To produce simple shear deformations, a modified Roscoe shear box—Roscoe (1953) is utilized. The oscillatory shear box has six separate pieces (Figure 2). Two tilting sides are supported through ball hinges housed in two fixed vertical sides. The tilting sides are connected at their lower ends by screwed connecting links, to keep the distance between the face always to be 6 cm. The base plate of the box rests over two ball trains moving in V-grooves and capable of moving in either directions about its mean position, under the action of oscillatory shear forces. The top plate rests over the soil sample and also in the plane of the four ball hinges. The edges of top and base plates in contact with titling sides are champhered at 45° to facilitate the rotation of the titling sides. The box is designed to house a sample of 6 cm × 6 cm × 2 cm thickness. The maximum possible shear deformation is 20 percent of the length of sample. When

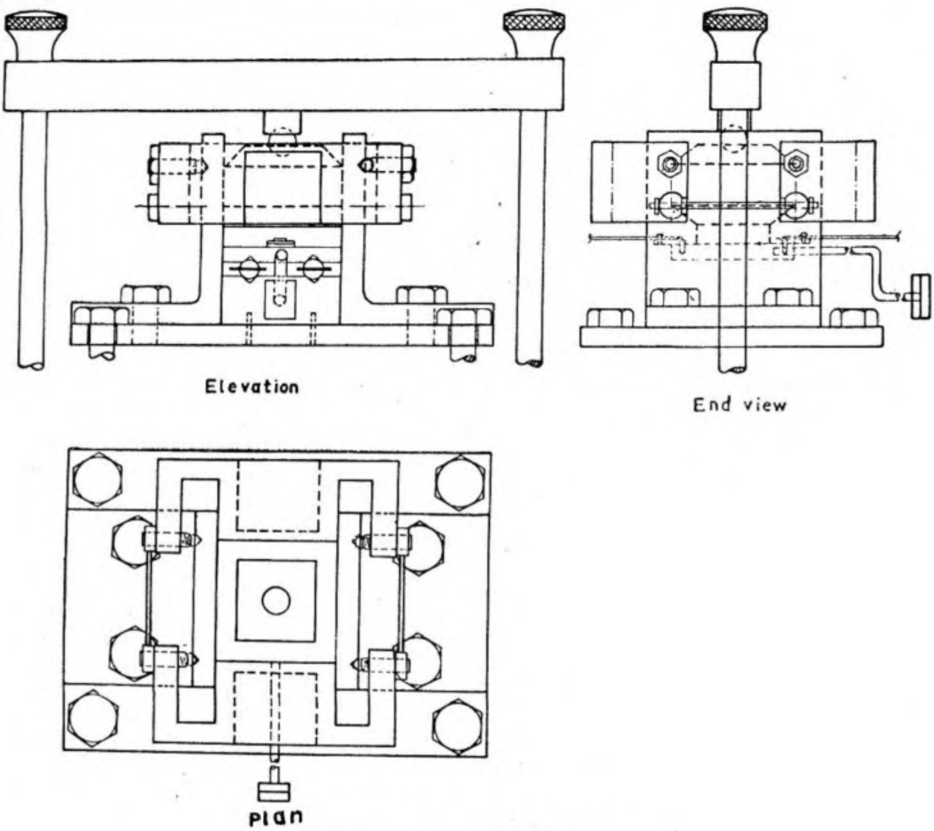

FIGURE 2 : Oscillatory shear box.

the base plate moves under the action of oscillatory forces, the sample undergoes simple shear deformations.

To apply normal stress conventional ball-yoke-hanger system is used. For larger normal loads reaction loading using suitable lever action is employed.

Even though an earthquake gives rise to an erratic earthquake force function, for simplicity of analysis, it is assumed to be a simple mathematical function which is taken to be a rectangular force function in this case as shown in Figure 3.

The facility to apply oscillatory shear force consists of flexible string systems, loading hangers, lifting and lowering mechanism and a driving mechanism, Figures 4 and 5. The mechanism for applying oscillatory shear force consists in hanging two equal weights on either side of the box. When the second is lifted the first hangs free. This is repeated alternately at any desired frequency to produce the required oscillatory shear force.

The flexible string system consists of a load gauge, a brass tape passing over a pulley, a weight, a turn-buckle, and a chain attached to a load hanger. The chain is kept flexible because it is expected to lose all the tension as soon as the load is lifted above the free hanging position. Turn-buckle interrupts any twist of the loading hanger. The weight keeps the string taught and straight. The flat brass tape passing over pulley further arrests any stray twist from being transmitted to the sensitive load gauge.

Loading hanger supports the weights required to produce the desired dynamic stress levels. The weights are arrested from movements by using suitable locking nuts. The lateral sway of hangers is arrested by providing guides.

The loading hangers are lifted and lowered gradually by means of a pair of platforms, which are moved by two eccentric cams with their eccentricities at 180° phase difference and mounted on the same shaft. To render the platforms horizontal, they are provided with levelling screws. To prevent the lateral sway of the platforms, four vertical rods at the four corners are fixed, which move in the well greased bushes fixed to the base. *For jerk-free smooth movements of the platforms,* the cam should be as small and as smooth shaped as possible, because cams are suitable

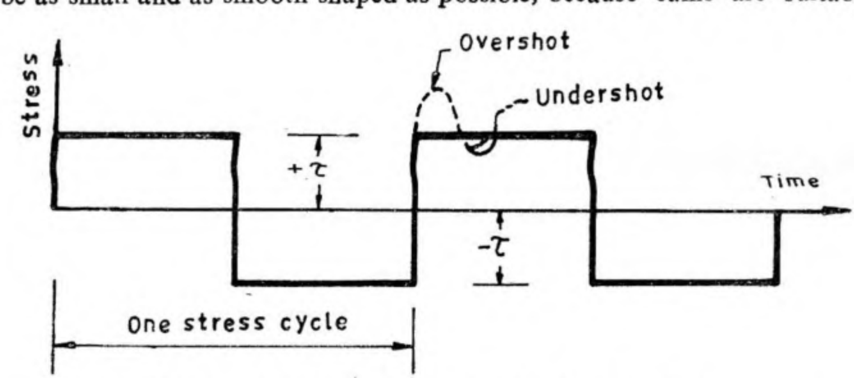

FIGURE 3 : The type of stress function considered in design of the apparatus.

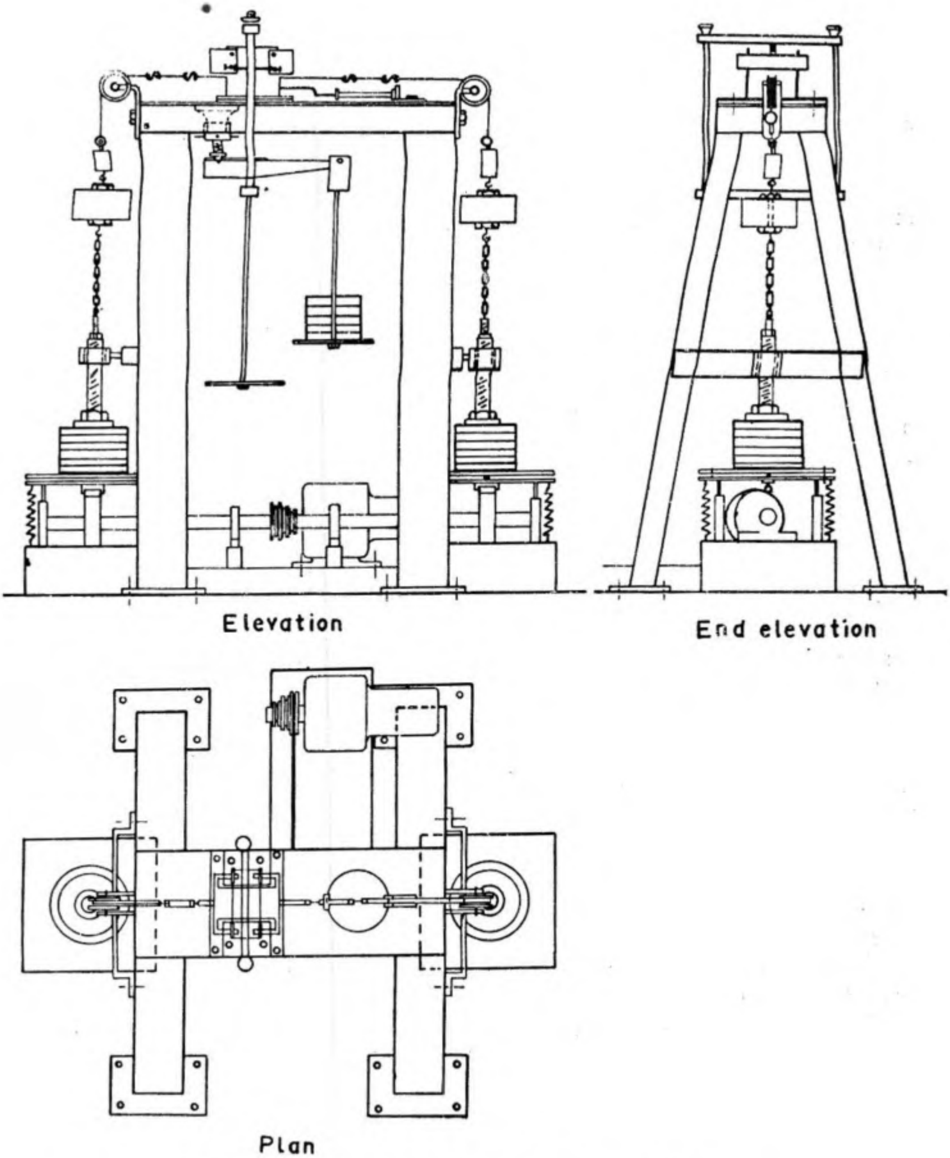

FIGURE 4 : Complete set-up of oscillatory shear box.

for slow circumferential speeds only. But, to avoid appreciable deformations to the desired wave-form, it should be as large as possible. So a compromise was struck by choosing a cam of maximum radius of 10·5 cm and a minimum radius of 3 cm cut out of a circular plate. To reduce frictional resistance the platforms keep contact with the cams through rollers.

An electric motor drives the shaft through a belt and a stepped pulley mechanism. Speeds of 10½, 21 and 42 rpm are obtainable.

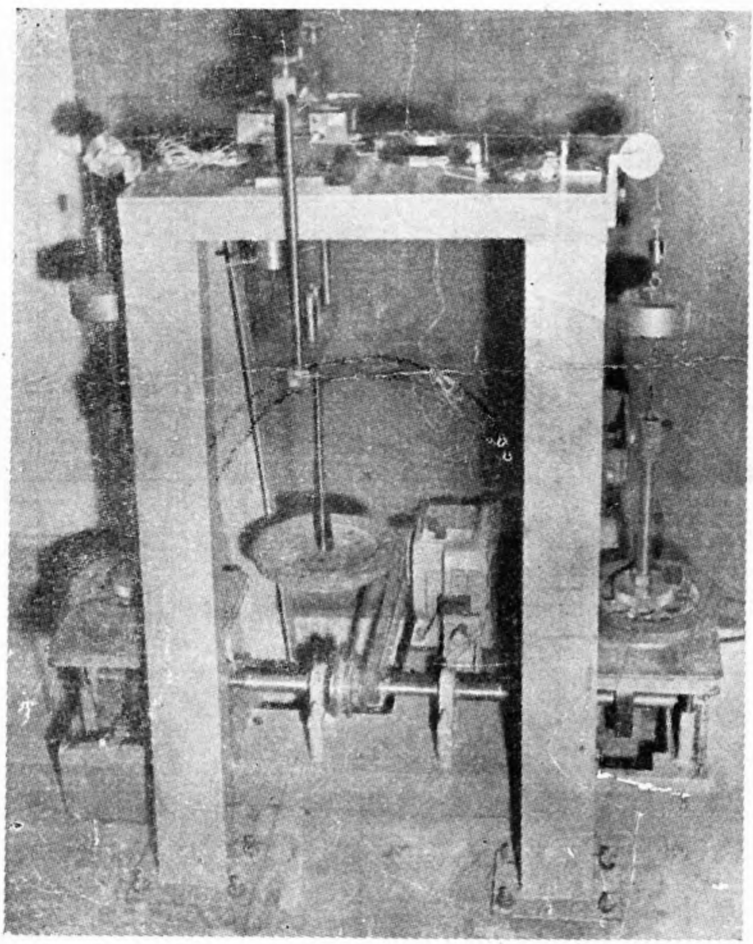

FIGURE 5 : Oscillatory shear apparatus.

The dynamic load measuring device is essentially a thin strip of a metal plate with arrangement to secure it to movable base and the flexible string at its ends. Strain-gauges are pasted upon them. The strains in the load gauge are measured initially against known loads. Different gauges were used for different load intensities. The load versus strain calibration curves were straight lines for all gauges, in the working range of loads (Figure 6).

The displacement measuring device is a ring of clock spring on which four strain-gauges are mounted at two diametrically opposite ends. The displacement of the ring is calibrated against the strains in the ring. Here again the ring gave a straight calibration curve in the working range. It has a sensitivity less than 0·1 percent strain of the sample (Figure 7).

To calibrate the gauges and also to record the dynamic loads and displacements, universal amplifiers with pen recorders were used giving directly the plot of the dynamic quantity measured.

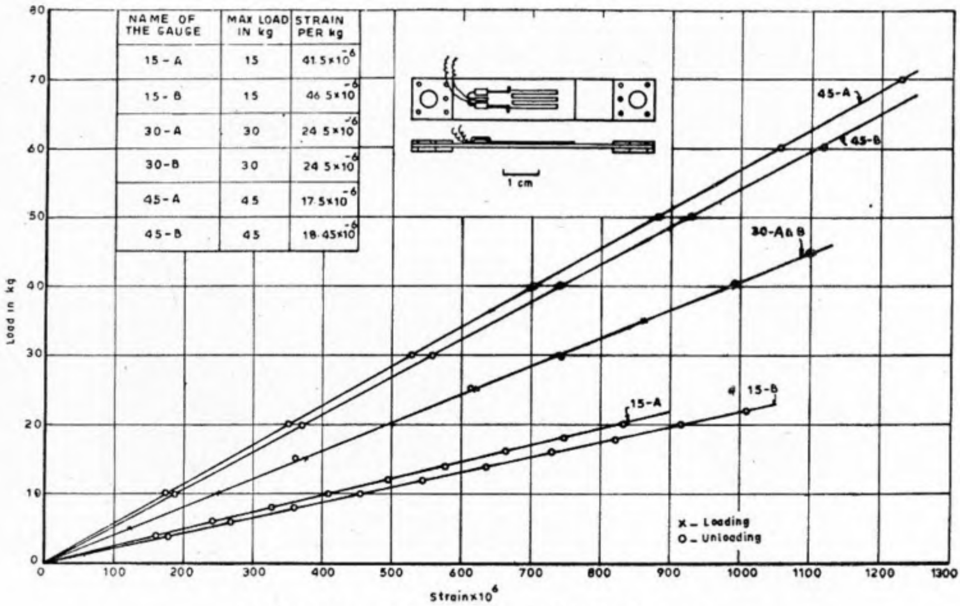

FIGURE 6 : Calibration curves for load gauges.

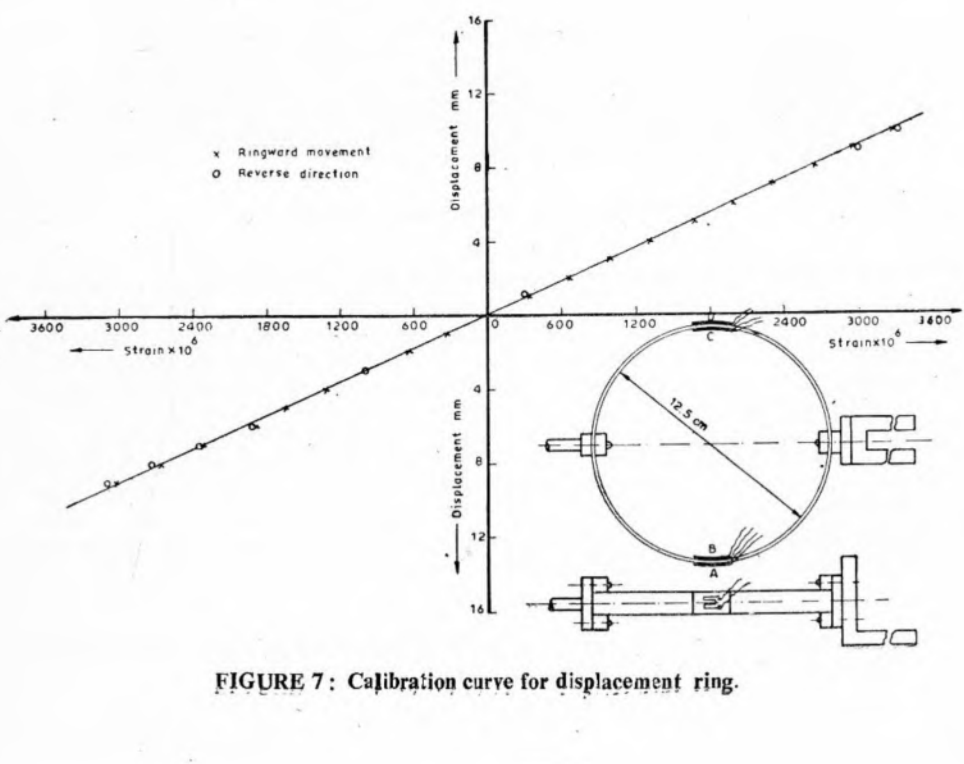

FIGURE 7 : Calibration curve for displacement ring.

Performance

To study the performance of the set-up, a few tests were conducted using the apparatus. Air dried Badarpur sand was used at its loosest density. The samples were prepared by loosely pouring the dry sand using a funnel.

To compare these results direct shear tests were also conducted at the same density.

The angle of shearing resistance obtained from the simple shear box is very much comparable to that obtained from direct shear tests. The value of 'ϕ' obtained from simple shear tests is, however, slightly larger than that obtained by direct shear (Figure 8). This is quite expected because of the phenomenon of progressive shear associated with direct shear tests.

In the dynamic tests, the sample was subjected to different oscillatory stresses, for a given normal stress and this was repeated for different normal stresses. The test was run till the strains reached a steady value. The record of dynamic loads and the displacements are obtained for each test.

In the dynamic tests the load function plots obtained are quite satisfactorily representative of the assumed rectangular stress function. As can be seen from Figure 9, only small vibrations occur when the load is let to hang freely. The displacement record shows practically no vibrations in the record (Figure 9).

With the limited test results available the following observations can be made. Figure 10 shows the relationship between the amplitude of strains

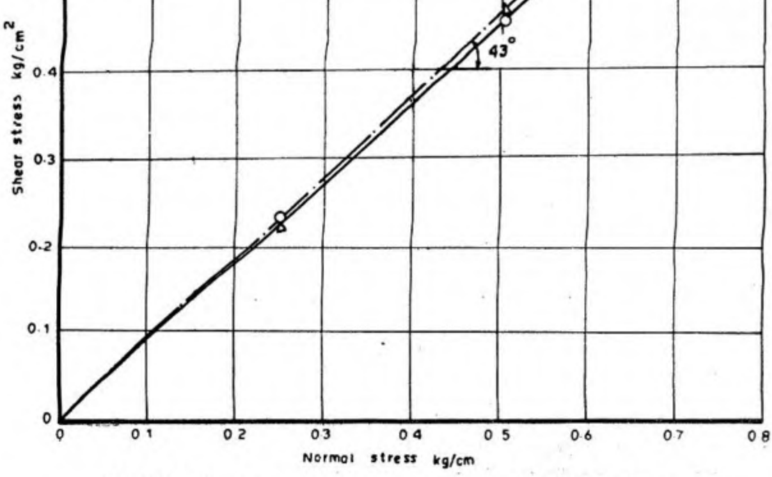

FIGURE 8 : Angle of shearing resistance in static tests.

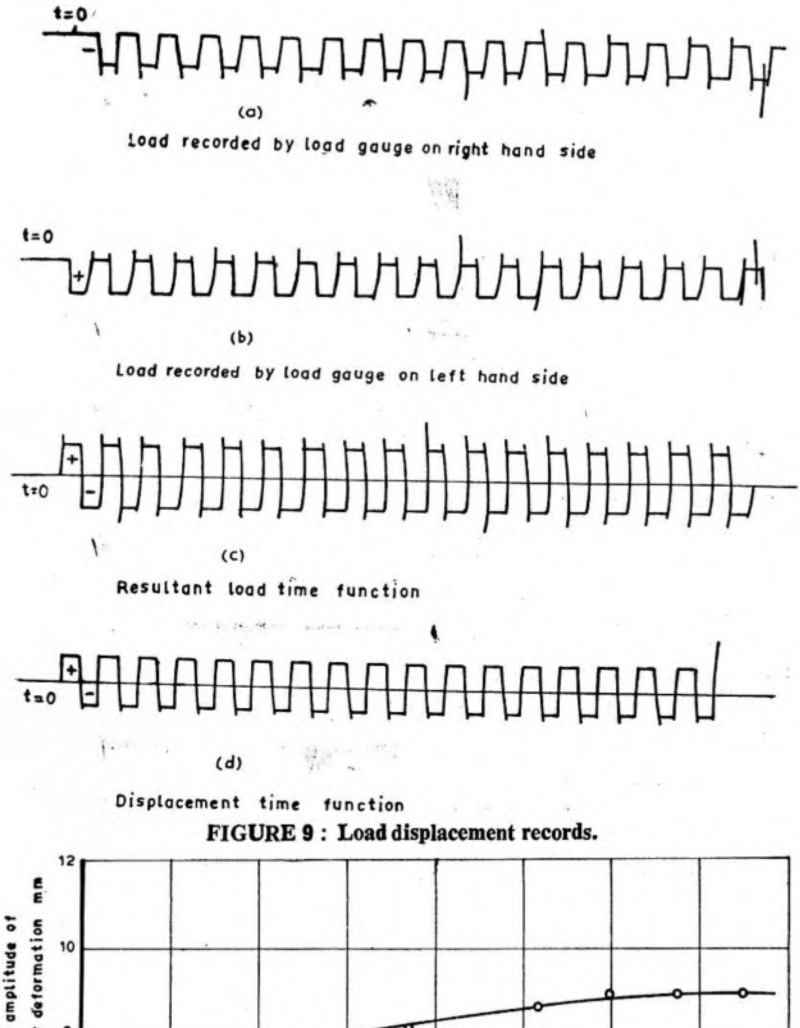

FIGURE 9 : Load displacement records.

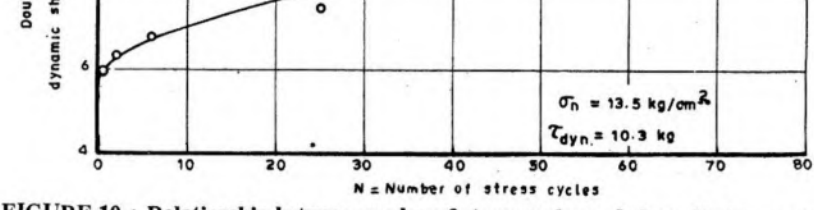

FIGURE 10 : Relationship between number of stress cycles and shear displacements.

and number of cycles. Most of the strain occurs the first few cycles of the stress application and soon the strain amplitude reaches a constant value.

Figure 11 shows the variation of amplitude of dynamic displacement with the amplitude of dynamic shear stress for different normal stresses. It is seen that the shapes of curves are similar to those of static stress-strain curves.

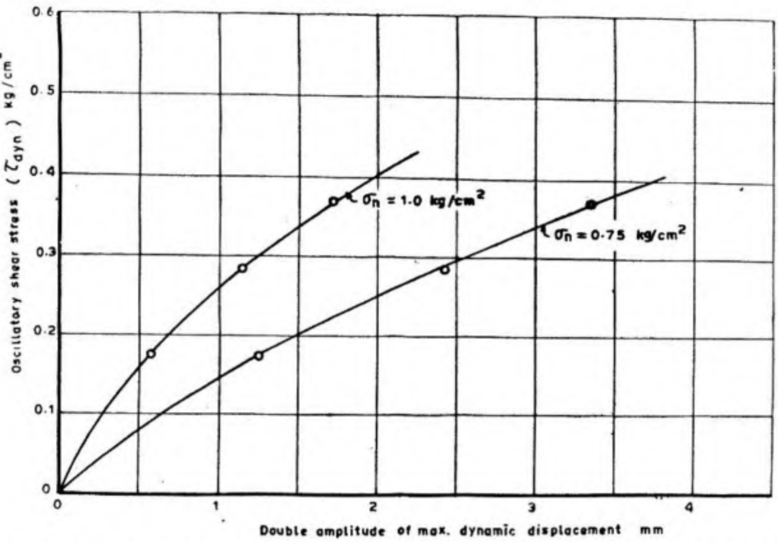

FIGURE 11 : Curves of dynamic shear stress versus dynamic shear displacement.

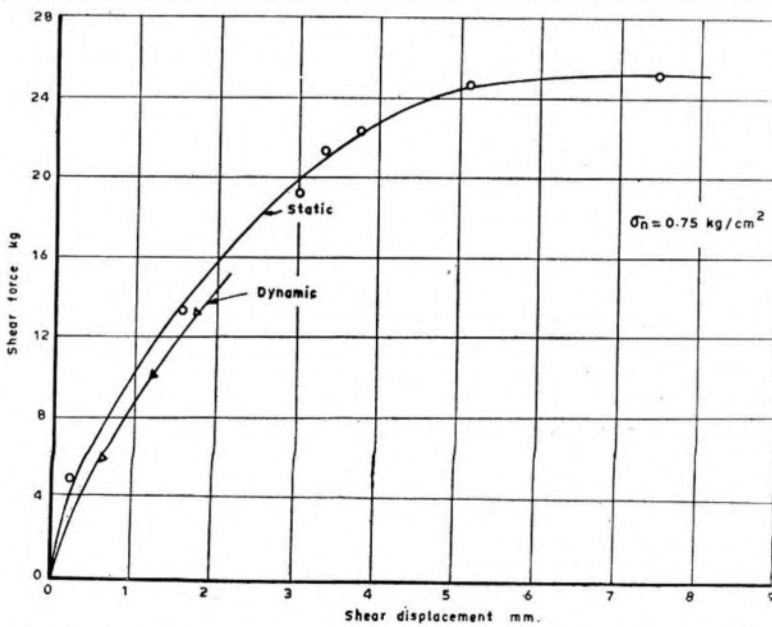

FIGURE 12 : Comparison between static and dynamic strengths of soil under same normal load.

Figure 12 shows the stress-strain curves for the static and dynamic tests for the same normal stress. In dynamic tests, steady state amplitude of deformations was used for each shear stress levels adopted. It is observed that even though the curve for dynamic tests falls belew that for static tests the two curves are very much comparable with only little more deformation under dynamic conditions. This is quite anticipated as the effects of rates of loadings do not affect strength of sand very much under dry condition, (Casagrande and Shannon, 1948).

Further tests on Kandla clay are under way (Krishna, Prakash, Nandakumaran and Chandrasekaran, 1971).

Conclusion

In conclusion it can be said that the set-up is very simple robust and the cost will be comparatively small particularly if manufactured on a large scale. The basic purpose of producing simulated earthquake stresses is well achieved. In fact, with few more additional facilities it can serve all the purposes served by the sophisticated set-up proposed by Seed and Peacock for studying the strength of soils under earthquake loading conditions.

A few of the shortcomings are that the set-up has no arrangement to measure pore pressures for studying liquefaction characteristics of sands. Facility to apply oscillatory normal stress which can easily be accomplished in the existing set-up would greatly enhance the utility of the set-up. Similarly, an arrangement to vary the forms of the stress pulses would also be quite desirable.

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