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A Pneumatically Operated Laboratory Apparatus for Testing Soils under Repeated Loading

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Introduction

The performance of Highway and runway pavements depends to a great extent upon the properties of the subgrade soil. The standard tests like CBR, shear strength etc., are not of much help in analysing a pavement from fundamental consideration. Subgrade soils are subjected to repeated normal as well as shear stresses of varying magnitudes due to fast moving vehicles. The tests on soils below the pavement must be carried out under the stress system closer to that developing under moving wheel loads.

This paper describes a pneumatically operated laboratory apparatus for testing soils under a stress system which is closer to the in-situ conditions. The apparatus described in the paper is more versatile than that reported by Rao *et al.*, (1983). The frequency and the duration of the loads can be easily controlled by an electronic timer. The vertical and the lateral principal stresses in the triaxial cell can be pulsed simultaneously. Unlike the apparatus developed by Rao *et al.*, (1983) this apparatus has few moving parts and it has a long life. The loading device can also be used for flexure test of lime-soil materials or soil-cement materials under repeated loading to determine parameters for pavement design (Bhattacharya, 1983).

State of Stress in Subgrade

Doddihal and Pandey (1984) have analysed the complex nature of stress

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systems developed in the subgrade of a pavement due to moving wheel load. Figure. 1 shows a longitudinal section of a pavement consisting of several layers of different materials, upon which a wheel load is moving at a constant speed. The state of stress at a point *P* due to a wheel load at *A* is shown in Fig. 1(*a*). When the load comes to the position *B*, shear stress becomes zero and only the normal stresses act. The direction of shear stress reverses for the load position at *C* (Fig. 1 *c*). Figure 2 shows the relationship between stresses and time. σ_1 (normal stress) and σ_3 (lateral stress)

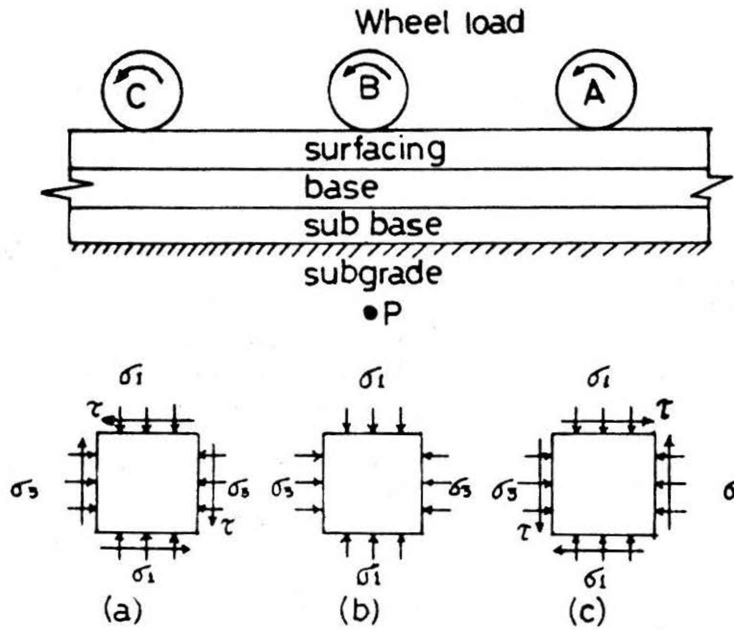

FIGURE 1 State of Stress in Subgrade

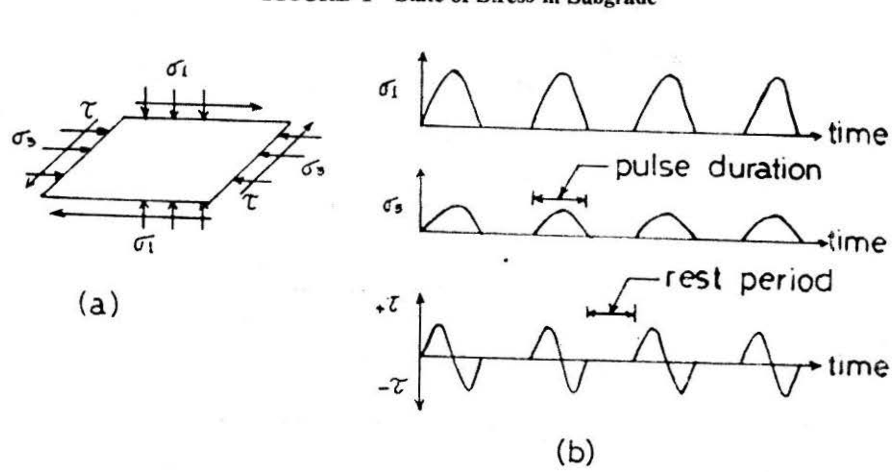

FIGURE 2 Stress Pulses due to Wheel Load

reach their maximum values simultaneously, where as shear stress reaches its maximum value before σ_1 and σ_3 reach their peaks and become zero when the normal stresses are maximum. As the normal stresses are decreasing the shear stress reverses its direction.

It is, however, difficult to simulate the reversal of shear stress in the laboratory, but the stress condition in Fig. 1(*b*) can be created in the triaxial chamber in which both vertical as well as lateral pressures may be pulsed simultaneously. Monismith *et al.* (1967) have found that the soil parameters obtained by pulsing only the normal stresses give predictions of the pavement deflections which are reasonably accurate. In the set-up described in this paper, only the normal stresses have been pulsed.

Experimental Set-up

Schematic diagram of the experimental set-up developed by the authors is shown in Fig. 3. A closeup view of the test set-up is given in Fig. 4. It consists of components such as compressor, air filter, regulator, lubricator, solenoid valve, air cylinder, timer, load measuring unit, deformation measuring unit, triaxial cell etc. Detailed description of each of these components is given below:

Compressor

Compressor capable of developing 1.2 MPa air pressure has been used to run the repeated load apparatus.

Air filter

Air line from the compressor is connected to the Air filter which removes fine dust particles from the compressed air and thereby increasing the efficiency of the air cylinder. This air filter has sintered bronze mesh which traps the finer impurities. It is of 19 mm. size and maximum operating pressure is 1.8 MPa at 48 degrees Centigrade.

Regulator

Pressure of air in the air cylinder can be controlled by a regulator. Higher load requires high pressures in the cylinder.

Lubricator

For double acting cylinder to function smoothly, the compressed air coming to air cylinder is lubricated in this unit.

Solenoid valve

Compressed air duly lubricated enters the 4-way solenoid valve through

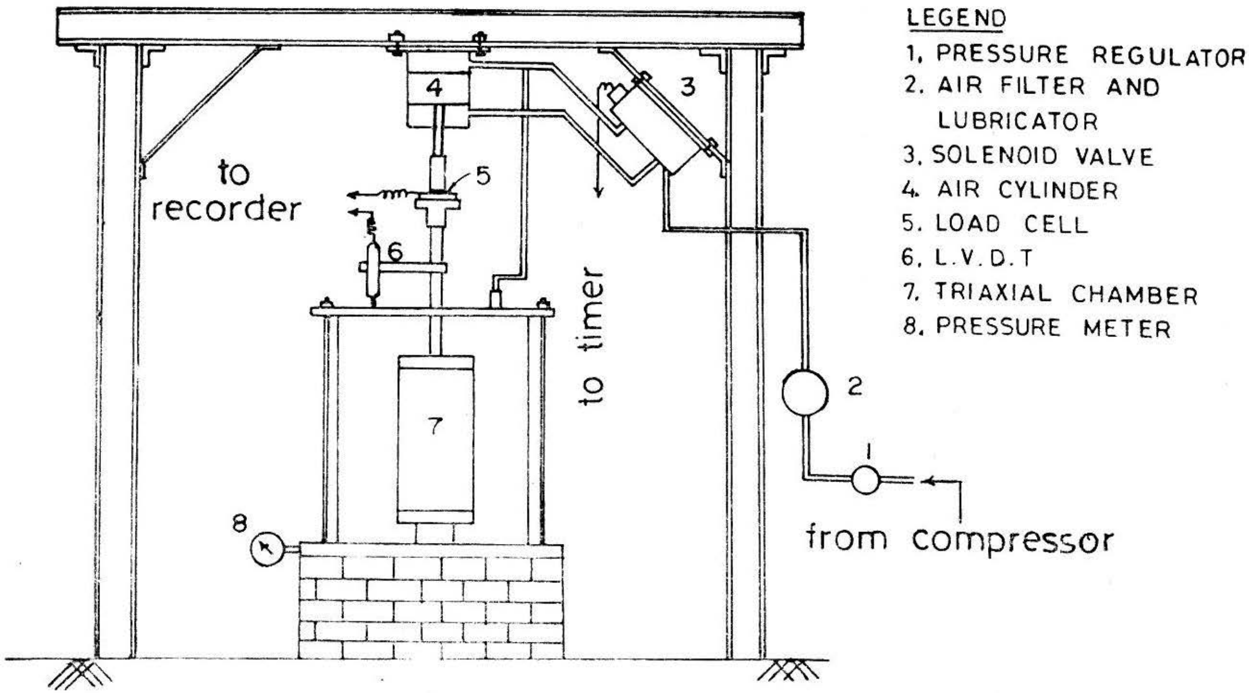

FIGURE 3 Test Set-up for Repeated Triaxial Test

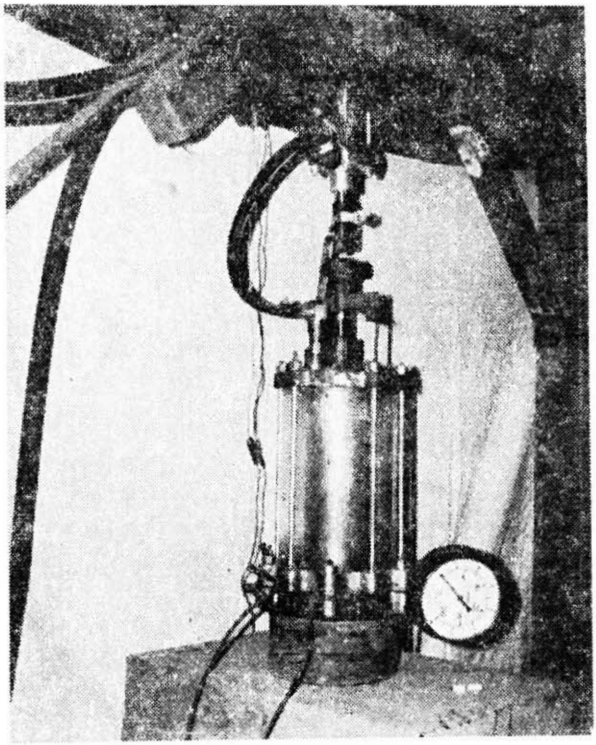

FIGURE 4 View of A Repeated Triaxial Test Set-up

its inlet. Solenoid valve plays an important role in this experimental set-up. Repeatability of load is achieved by this component. Valve operates by a 220V A.C. source through a timer. It has two outlets. The plunger moving inside opens these outlets alternatively. The frequency and duration of opening of these outlets can be controlled with the help of switches provided in the timer. It has a pressure range upto 1.05 MPa and minimum operating pressure of 0.14 MPa. The maximum frequency that can be achieved is about 500 cycles/minute. The working principle of the solenoid valve is illustrated in Fig. 5.

Air cylinder

Repeated loads applied to the test sample with the help of the regulator and a double acting air cylinder. The outlets of the solenoid valve are connected to the top and bottom inlets of the air cylinder in such a manner that when the timer is in the 'off' position, the air enters the bottom chamber of the air cylinder thereby lifting the plunger up.

An important feature to note here is that a branch is taken out from the air line connected between solenoid valve and the top chamber of air cylinder. This branch line is connected to the triaxial cell. This is done for the

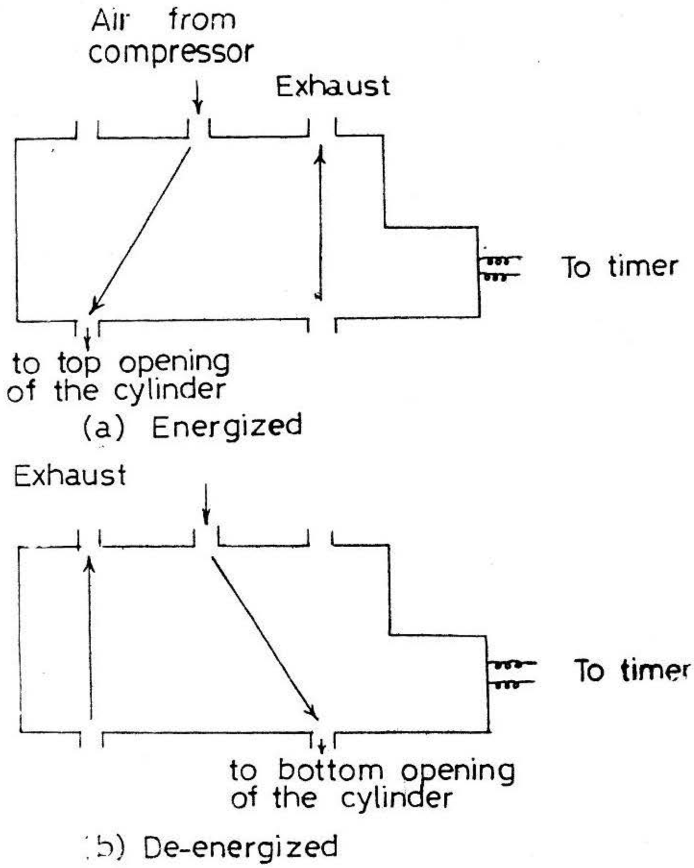

FIGURE 5 Working Principle of Solenoid Valve

reason that when timer is in 'on' position, air enters the top chamber of air cylinder thereby pushing the plunger down and also enters the triaxial cell. Thus, the vertical and lateral pressures are pulsed simultaneously. However, if test is desired to be carried out at different constant confining pressures, the above mentioned branch line has to be closed and a seperate direct connection of airline has to be provided for applying confining pressure in the triaxial chamber.

Timer

In order to simulate the actual loading time on the pavements due to the moving vehicles, a timer, fabricated at IIT, Kharagpur, has been used. It can give a loading time of 0.05 secs to 1 sec and has a frequency range of 10 to 240 cycles/min. As mentioned earlier, the operation of solenoid valve is controlled by this timer.

Load measuring unit

Load applied on the sample is measured by a load cell, which is placed over a cylinderical pedestal specially made for the purpose. The pedestal fits over the loading plunger of the triaxial cell. Load cell measures the deviatoric load on the specimen which is recorded in one of the channels of recorder. The apparatus has a load capacity of 5 KN.

Deformation measuring unit

It consists of (*i*) Linear Variable Differential Transducer (L.V.D.T) and (*ii*) Displacement meter. L.V.D.T. is used to measure the resilient deformation. It is fixed to the loading plunger of the triaxial cell by means of a clamp. L.V.D.T. is connected to a displacement meter which is further connected to a electronic pen recorder where the deformation signal from L.V.D.T. is recorded.

Triaxial cell unit

It mainly consists of perspex cylinder, specimen pedestal and loading plunger. Specimen of maximum size 100 mm dia and 200 mm long can be tested in this cell. Perspex cylinder is capable of withstanding lateral pressures upto 0.98 MPa. Specimen is placed in this cell over a bottom plate resting on specimen pedestal. The top and bottom plates are made exactly 100 mm dia and grooves are cut to seat '*O*' rings so that specimen can be placed exactly in the central position.

Calculation of Resilient Modulus

Figure 6 shows the output of the repeated triaxial test on the electronic recorder where the deviatoric stress only has been pulsed at a constant lateral

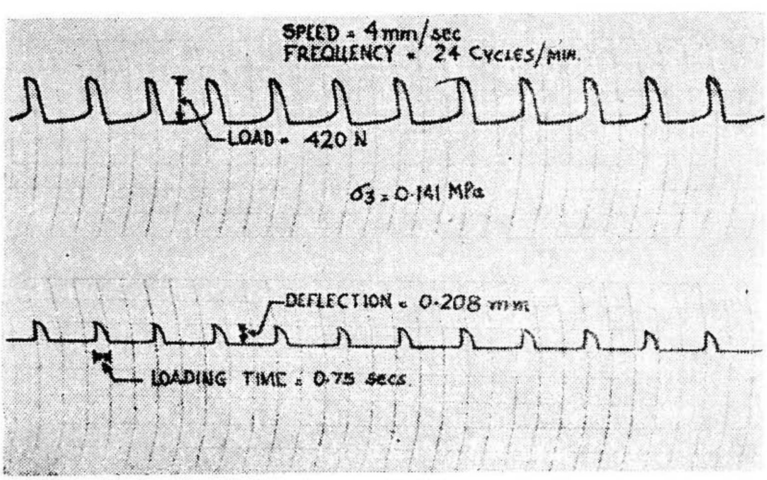

FIGURE 6 A Typical Output of the Electronic Recorder for Repeated Triaxial Test

pressure. A sample cast from the locally available laterite soil near Indian Institute of Technology, Kharagpur was tested.

The resilient modulus of soil is defined as

$$MR = \frac{\text{Deviatoric stress } (\sigma_1 - \sigma_3)}{\text{Recoverable strain}}$$

where,

MR = Resilient Modulus

σ_1 = Principal stress

σ_3 = Confining pressure

Load from Fig. 6	= 420	N.
Deviatoric stress $(\sigma_1 - \sigma_3)$	= 0.053476	MPa.
Recoverable deformation from Fig. 6	= 0.208	mm.
Height of specimen	= 200	mm.
Recoverable strain = 0.208/200	= 0.00104	

MR = 0.053476/0.00104 = 51.419231 MPa.

Cost of Apparatus

Air compressor, L.V.D.T, Load cell, Electronic recorder, Triaxial chamber etc., are normally used in all Geotechnical Engineering Laboratories. Additional items like Double acting cylinder, Solenoid valve, Timer, Filter, Regulator, Lubricator together with other accessories for pneumatic circuits do not cost more than Rs. 7,500.

Using the same principle authors have also fabricated an exerimental set-up for testing fatigue strength of lime flyash-sea sand mixture under flexture. Figure 7 gives a general view of the test set-up. The airfilter and lubricator alongwith pressure regulator can be clearly seen in the top left hand corner of Fig. 6 load cell is placed just below the loading plunger and an L.V.D.T. is placed below the sample at the center. A close-up view of the specimen under test is shown in Fig. 8.

Conclusion

As described in the paragraphs above, one can observe that this experimental set-up simulates the condition very close to the actual one and hence the resilient modulus thus obtained can be used with some reliability in design of highway pavements. Though sophisticated equipment can be obtained from abroad at higher costs, the set-up as described above can be fabricated indigenously at a comparatively low cost.

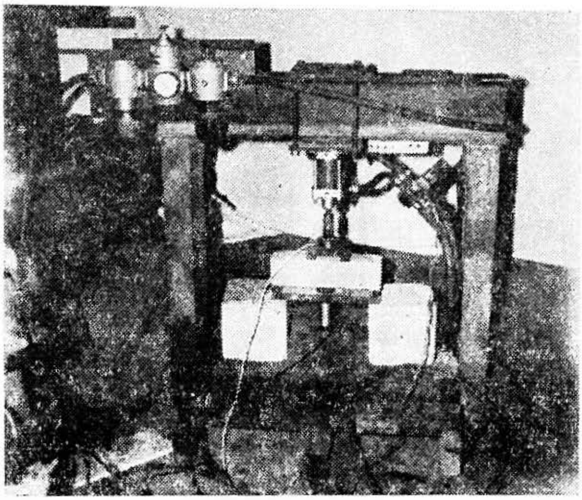

FIGURE 7 An Apparatus for Testing Beams of Sea Sand Lime—Fly Ash Mixture under Repeated Load

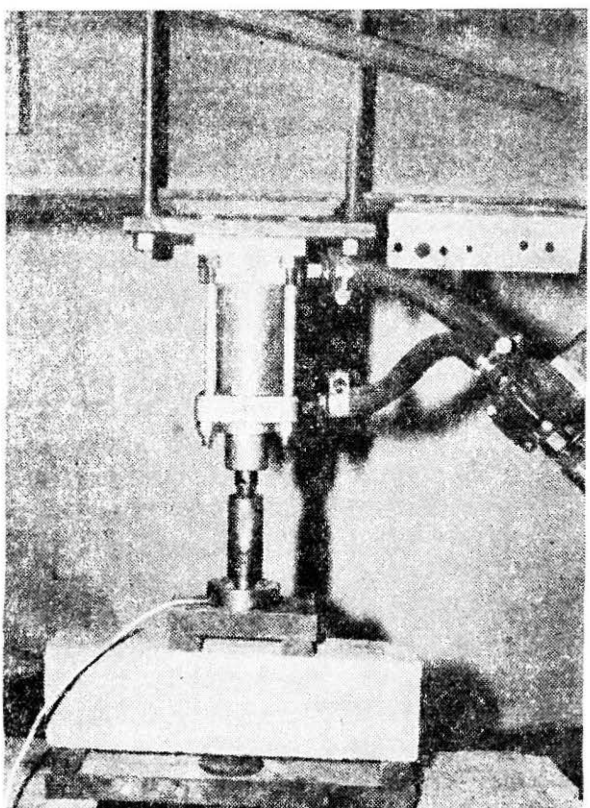

FIGURE 8 A Close up View of Sea Sand—Lime—Flyash Beams under Repeated Loading

References

BHATTACHARYA, P.G. (1983): "Static and Flexural Fatigue Strength of Lime-Laterite Soils-plain and Fibre Reinforced", *Ph.D. Thesis.*

RAO, T.S.C., DODDIHAL, S.R. and PANDEY, B.B. (1983): "Repeated Load Test Set-up for Determining Plastic Deformation Characteristics of Subgrade Soil,' *Indian Geotechnical Journal,* 13: 2: pp. 103-113.

DODDIHAL, S.R. and PANDEY, B.B. (1984): "Deformation Behaviour of Subgrade Soil and Rutting a Flexible Pavement", *Highway Research Bulletin,* No. 23, "Rigid and Flexible pavements", Indian Roads Congress, pp 1-17.

MONISMITH, C.L., SEED, H.B., MITRY, F.G. and CHAN, C.K. (1967): 'Prediction of Pavement Deflections from Laboratory Test", Proceedings *Second International conference on the Structural design of Asphalt Pavements,* Michigan, U.S.A., 1, 109-140.