Repeated Load Test Set-up For Determining Plastic Deformation Characteristics of Subgrade Soil

by

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Introduction

The subgrade soils of roads and runways are subjected to repeated wheel loads resulting in permanent deformation of the soil. Excessive permanent deformation in the subgrade brings about rutting along the wheel path of the pavements. The irrecoverable deformation of soil may be predicted by carrying out repeated load triaxial shear tests under stress conditions which are very close to those found to occur in soil due to traffic loads.

The paper describes the details of a repeated load test apparatus developed by the authors for evaluating repeated load properties of subgrade soil of pavements. The apparatus is capable of applying loads for duration observed under field conditions. To illustrate the working of the machine, triaxial cyclic tests on a lateritic subgrade soil have been carried out to determine its resilient modulus and permanent deformation characteristics.

Description of apparatus

Schematic diagram of the experimental set-up developed by the authors is shown in Fig. 1 and 2. It consists of

1. Frame A (Part Nos. 1 to 6)
2. Frame B (Part Nos. 7 to 11)
3. Speed reduction unit
4. Load transmission unit
5. Vibration control and self weight balancing unit
6. Cam and wheel unit
7. Permanent deformation compensation unit
8. Triaxial cell unit
9. Deformation measuring unit
10. Load measuring unit.

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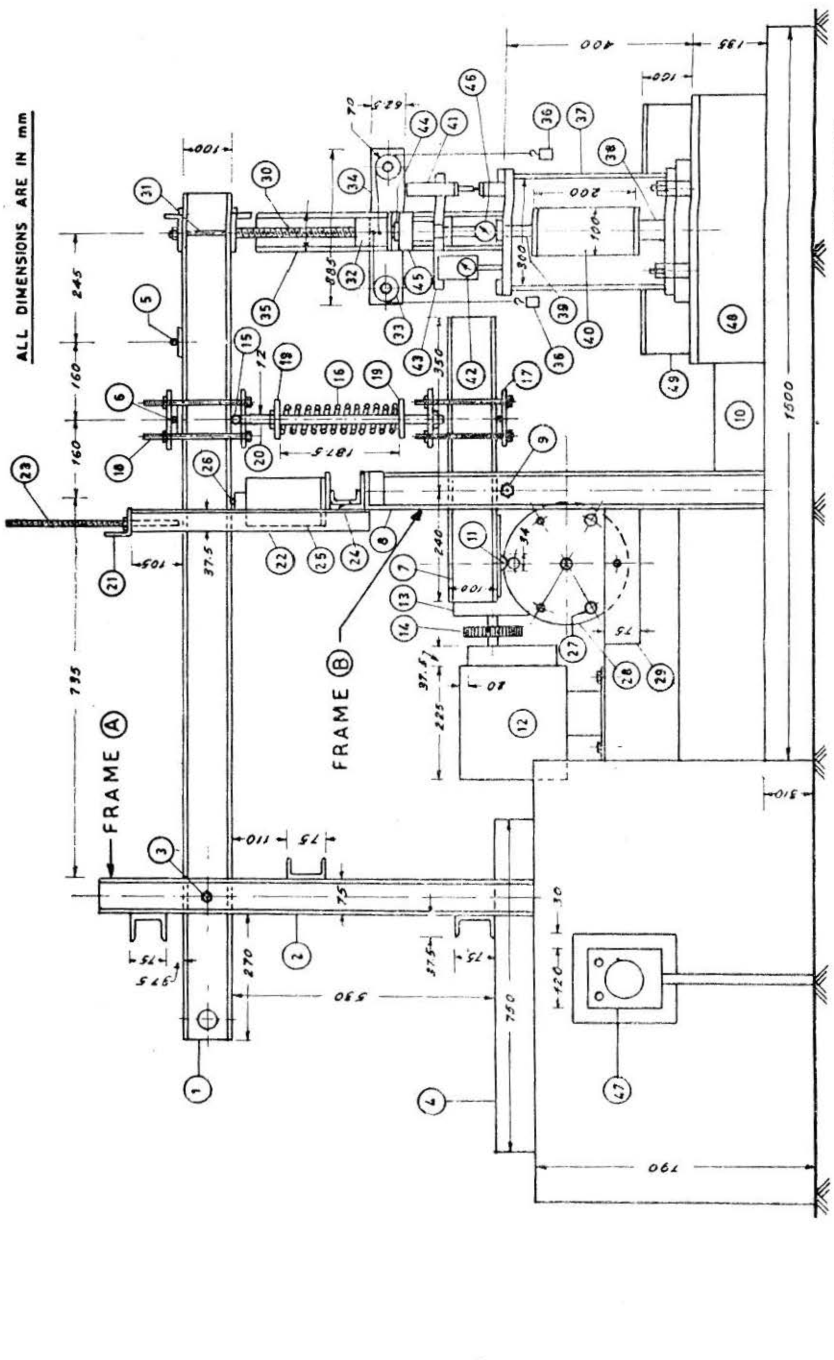

FIGURE 1 Repeated Load Test Apparatus

Legend to Figure 1

Frame A

1. I beam
2. Vertical channel
3. Hinge
4. Horizontal base channel

5 & 6. Load transfer rollers

Frame B

7. I beam
8. Vertical channel
9. Hinge
10. Horizontal channel
11. Cam.

Speed Reduction Unit

12. Motor
13. Gear Box
14. Gear wheels.

Load Transmission Unit

15. Horizontal rod of U frame
16. Springs
17. Lower clamp
18. Upper clamp
19. Sliding plates
20. Projecting rod of the U frame
21. Horizontal angle section
22. Vertical angle section
23. Threaded vertical rod
24. Angle section
25. Oil tank
26. Roller support

Cam and Wheel Unit

27. Rotating cams
28. Cam studwheel
29. Oil bath

Permanent Deformation Compensation Unit

30. Threaded rod
31. Clamping arrangement
32. Cylindrical stud
33. Smooth pulley
34. Angle section of adjustable stand
35. Vertical channel
36. Hanging weight

Triaxial Cell Unit

37. Perspex cylinder
38. Specimen pedestal
39. Loading plunger
40. Specimen.

Deformation Measuring Unit

41. L. V. D. T.
42. Dial gauge
43. Clamp

Load Measuring Unit

44. Load cell
45. Pedestal
46. Additional pressure gauge

Miscellaneous

47. Motor starter
48. Platform for triaxial cell
49. Base adjustable stand

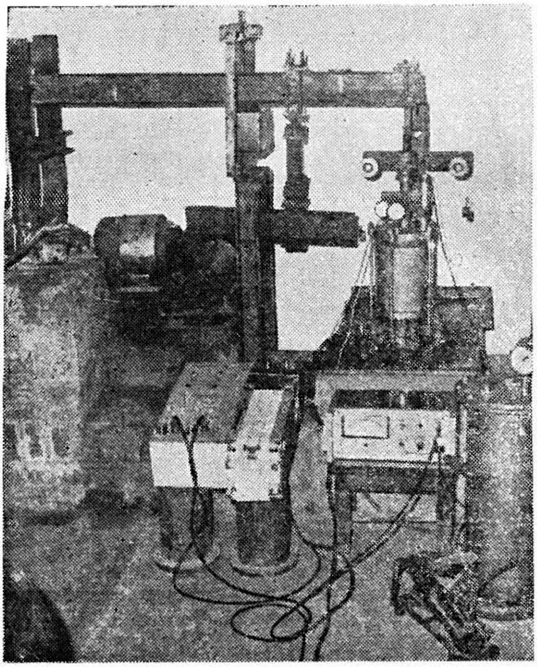

FIGURE 2. A General View of Repeated Load Test Apparatus

Detailed description of each unit is as follows :

Frame A

It consists of an I beam (1)* hinged between two vertical channels (2). These two vertical channels are welded to two horizontal channels (4), which form the base of this frame. This frame is fixed at a higher elevation than frame B.

Function of this unit is to receive the load from the frame B through the load transmission unit and to transmit it to the specimen through the permanent deformation compensation unit.

Frame B

This consists of a horizontal I beam (7) hinged between two vertical channels (8). Both the channels are welded to a horizontal channel (10). It is fixed to the foundation with rigid foundation bolts. A cam (11) is welded to a plate and the plate is fixed to the I beam of this frame by nuts and bolts.

Speed Reduction Unit

This mainly consists of motor (12) and gear box (13). The gear box consists of a worm and wormwheel arrangement. Worm is connected to the

* Numerals in parenthesis refer to the numbers marked in Figure 1.

motor and shaft of the worm wheel is connected to the cam stud wheel (28). Gear box is connected to the motor by means of two gear wheels (14). By changing the number of teeth on these gear wheels, different speed ratios can be obtained. With the gear wheels (14) of equal teeth, the cam stud wheel rotates at 20 r.p.m.

Load Transmission Unit

This consists of 'U' frame (15), springs (16) and two clamps (17 and 18). The horizontal rod of 'U' frame (15) is connected to the I beam of frame A by means of upper clamp (18). Two sliding plates (19) are arranged in such a way that they slide along the two projecting rods (20) of the 'U' frame. These two sliding plates are connected by means of a central rod to the lower clamp. The springs are placed in between these two sliding plates. One, two, or three compression springs of 225 mm length and of different stiffnesses can be used depending upon the requirement of the load. The details of this unit are shown in Fig. 3.

The function of this unit is to transmit the loading pulse from I beam of frame B to the I beam of frame A.

Vibration Control and Self-Weight Balancing Unit

This consists of two springs immersed in an oil tank (25) and a threaded rod (23) moving centrally in a horizontal angle section (21). The arrangement of springs inside the oil tank is shown in Fig. 4. The horizontal angle section is welded on the top of two vertical angle sections as seen in Fig. 2.

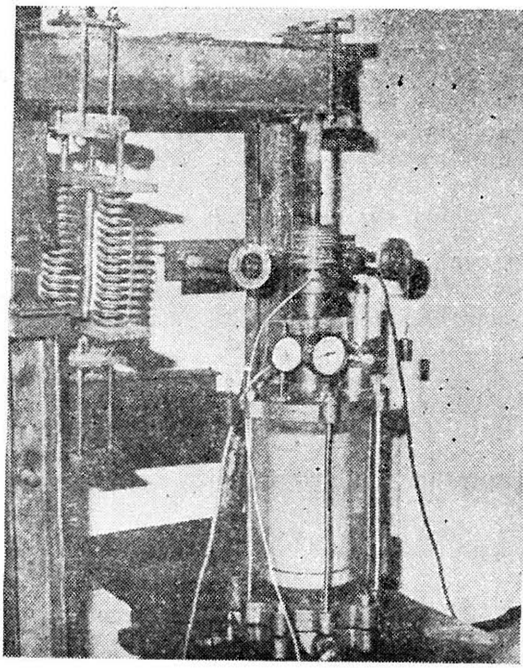

FIGURE 3 View of specimen under test

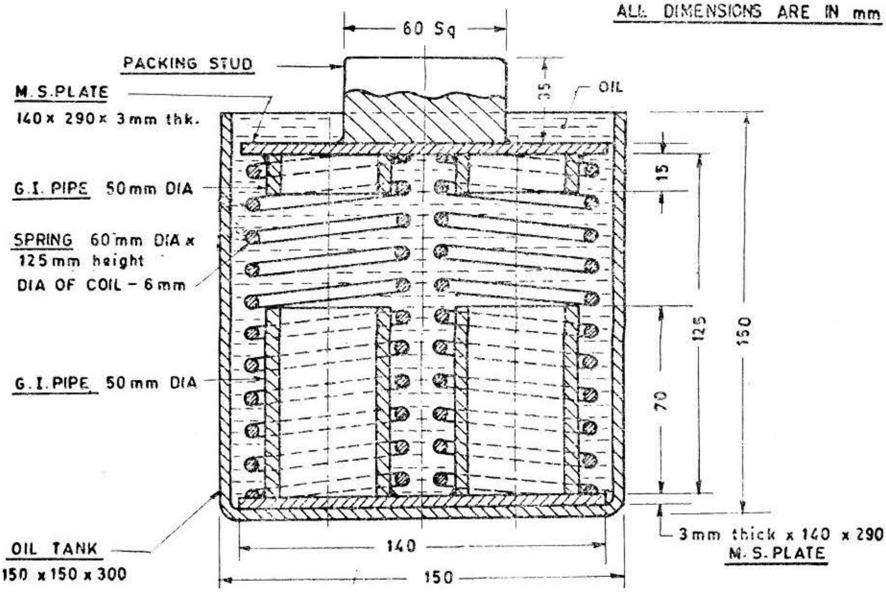

FIGURE 4 Support for Beam 1

Cam and Wheel Unit and Pulse Rates

It consists of three rotating cams (27), fitted to the cam stud wheel (28). This unit is partly immersed in an oil bath (29). Three rotating cams throw the cam (11) thrice in one revolution of the cam stud wheel. With the wheel rotating at 20 rpm, 60 pulses/min can be obtained. There is provision for fitting up to six cams in the wheel giving pulse rates ranging from 20 per minute with a single cam to 120 per minute with six cams. Details of this unit are shown in Fig. 5.

Permanent Deformation Compensation Unit

This consists of a threaded rod 25 mm in dia and 250 mm in length (30) welded to a horizontal plate. This plate is clamped to the bottom portion of I beam of frame A by a clamping arrangement (31). A cylindrical stud (32) with a bottom loading plate can move freely along threaded rod under an applied torque. Threads are wound round the stud with weights attached to them as shown in Fig. 3 and Fig. 6. Threads apply the torque so that the plate of the stud is always in contact with the load cell and fills the gap caused by permanent deformation of the specimen and ensures smooth loading which is very essential in repeated load tests.

Triaxial Cell Unit

It mainly consists of perspex cylinder (37), specimen pedestal (38) and loading plunger (39). 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 up to 0.98 MPa. Specimen (40) is placed in

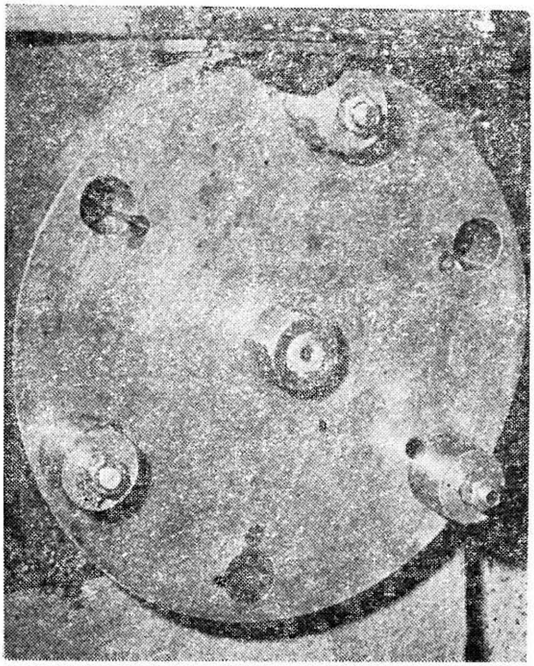

FIGURE 5 Cam and Wheel Unit

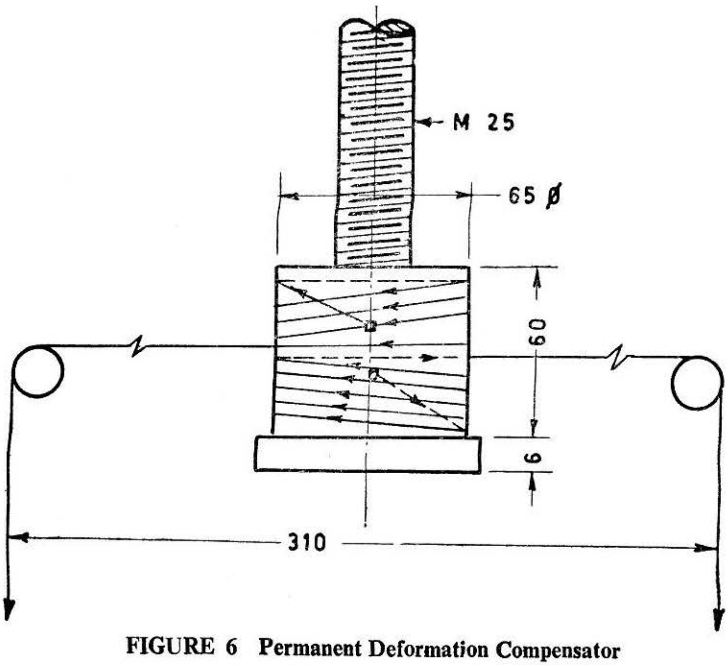

FIGURE 6 Permanent Deformation Compensator

this cell over a bottom plate resting on specimen pedestal. The top and bottom platens are made exactly 100 mm dia. and grooves are cut to seat '0' rings so that the specimen can be placed exactly in the central position.

Deformation Measuring Unit

It consists of (*i*) linear variable differential transducer (L.V.D.T.) and (*ii*) dial gauge.

L.V.D.T. (41) is used to measure the resilient and permanent deformation. A dial gauge (42) mounted upon the loading plunger is found to be more convenient for measurement of the permanent deformation for large number of repetitions. The dial gauge and L.V.D.T. are fixed to the loading plunger by means of a clamp (43). L.V.D.T. plunger rests on glass plates placed over a smooth cylindrical packing piece. The glass plates are removed as the deformation increased because the range of the L.V.D.T. is limited. The deformation signal from L.V.D.T. is recorded in one of the channels of a two channel electronic pen recorder.

Load Measuriug Unit and Load Capactiy

It consists of a load cell (44), bush (45) and pressure gauge (46). Load cell is placed over a cylindrical pedestal specially made for the purpose. The pedestal fits over the loading plunger of the triaxial cell. The arrangement is such that deformation measuring clamp would not touch this pedestal. Load cell measures the deviatoric load on the specimen which is recorded in another channel of the recorder. The apparatus has a load capacity of 3 kN.

An additional pressure gauge is fixed in the water inlet plug of the triaxial cell, after the cell is completely filled with water. This pressure gauge indicates the pressure in the triaxial cell. The details of deformation measuring unit are shown in Fig. 3.

Working of the Repeated Load Apparatus

The principle of the working of the repeated load test machine is similar to the machine developed by Grainger and Lister (1962) in U.K., though the two machines are much different in details. When the motor is switched on, cams on the cam wheel (Fig. 5) lifts the cam fixed to the underside of the lower I-beam (part 7), which in turn pulls down the upper I-beam (part 1) through compression springs (part 16) and the load is applied on the specimen by the upper I-beam. Upon unloading, the permanent deformation compensation unit immediately fills up the gap caused by permanent deformation of the specimen, and the time of loading remains constant for the next cycle. Minor adjustment of the load on the specimen can be made by actuating the beam (part 1) by means of the threaded rod (part 23). Shape of the pulse and its duration can be varied by changing the profile of the cam.

Plastic Deformation Characteristics of subgrade soil

The repeated load test apparatus has been used to test a subgrade soil obtained from Orissa Trunk Road at 25 kilometer from Kharagpur. The characteristics of soil tested are as follows :

(*i*) Field dry density = 1774 kg/m^3

(*ii*) Insitu moisture content, % = 12.45

(*iii*) Liquid limit, % = 19.51

(*iv*) Plastic limit, % = 10.88

(*v*) Plasticity index, % = 8.63

(*vi*) Optimum moisture content, % = 10·75

(*vii*) Maximum dry density = 1990 kg/m³

(*viii*) Relative compaction, % = 89.15

(*ix*) Cohesion = 0.117 MPa

(*x*) Angle of internal friction = 2.5°

Repeated load triaxial tests have been carried out for serveral combinations of vertical deviatoric pressures and lateral pressures on 100 mm diameter and 200 mm high soil samples moulded at insitu moisture content and field dry density. Some typical results for deviatoric stresses of 0.042 0.056 and 0.07 MPa and confining pressure of 0.014 MPa are illustrated in Fig. 7. Only the vertical stress has been pulsed. The deformations and load pulses obtained by this set-up is shown in Fig. 8. The load pulses are approximately sinusoidal and are very close to those in Fig. 9 obtained by Grainger and Lister (1962), in the subgrade of pavements caused by a loaded wheel moving on a pavement. Similar vertical stress pulses were obtained by Hofstra and Valkering (1972) also from field tests.

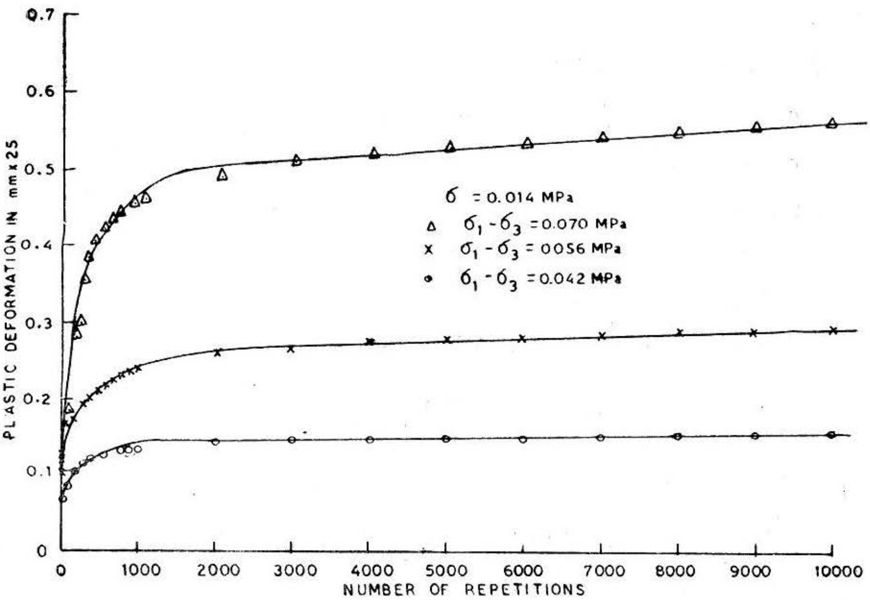

FIGURE 7 Plastic Deformation vs. Number of Repetitions

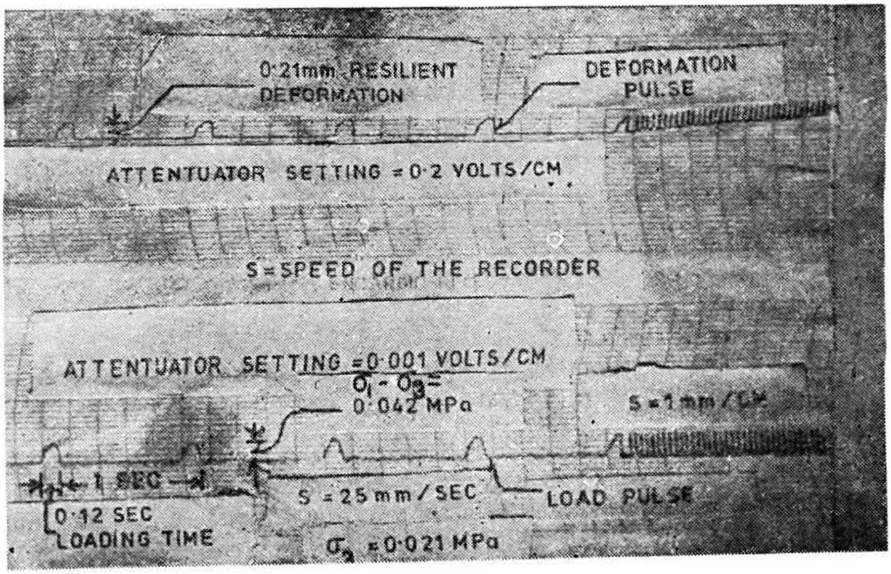

FIGURE 8 Deformation and Load Pulses

Calculation of Resilient Modulus

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 = vertical principal stress

σ_3 = confining pressure

Deviatoric stress ($\sigma_1 - \sigma_3$) from Fig. 8 = 0.042 MPa

The corresponding recoverable deformation = 0.21 mm

Height of the specimen = 200 mm.

Recoverable strain = 0.21/200 = 10.5×10^{-4} mm/mm

$$MR = \frac{0.041}{10.5 \times 10^{-4}} = 40 \; MPa$$

Cost of apparatus

The total cost of the load frame including springs, 1.5 HP motor and gear box works out to be around Rs. 6500/- only. No imported parts are required. Other units like triaxial assembly, electronic recorders, LVDT and load cells are being manufactured in India by various firms and cost about

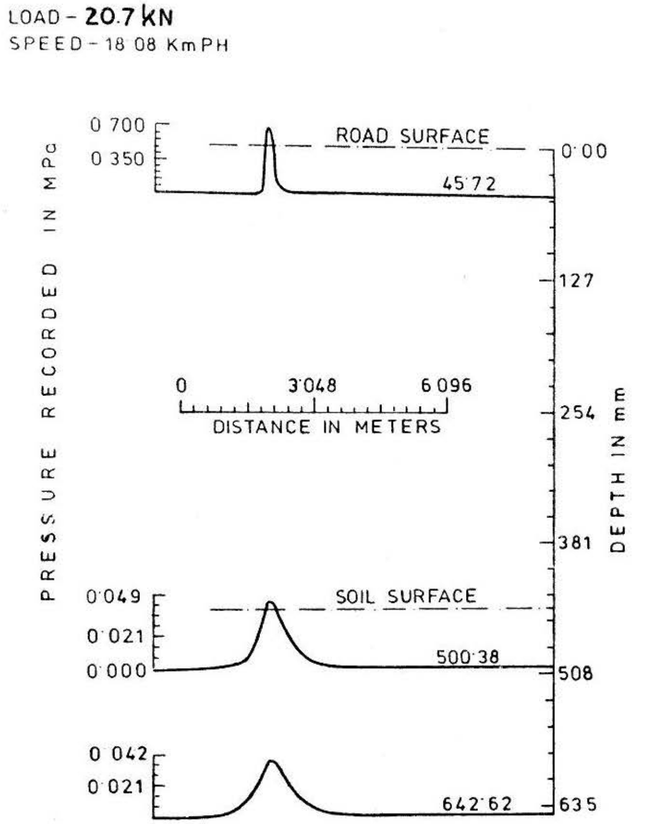

FIGURE 9 Measured Magnitudes and Shaped of stress Pulse in Road Structure (after Grainger and Lister, 1962)

Rs. 50.000/-. Cost of any imported repeated load apparatus exceeds Rs. 3,00,000-.

Conclusion

The repeated load set-up described above gives load pulses that are similar to those developed due to traffic loading. Though better equipment with sophisticated electronic controls are available abroad at a higher cost, the apparatus described above can be fabricated at a low cost.

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