Development of an Impact Apparatus for Evaluation of Elastic Modulus of Pavement Layers

R. Srinivasa Kumar*, Santosh Kumar†, A. Das‡, K.S. Reddy@, M. Mazumdar§, and B.B. Pandey¶

Introduction

A flexible pavement can be modeled as an elastic layered system in which each layer is characterized by its elastic properties (Elastic modulus and Poisson's ratio) and thickness. Usually flexible pavements comprise of bituminous bound surface course, granular base and subgrade. The structural soundness of the pavement is a function of the material properties. Repeated application of traffic loading causes deterioration of different pavement layers. The structural deterioration can be evaluated in terms of the resulting change in the elastic properties of different layers. Bituminous bound layer deteriorates due to the progressive development of cracks. The moduli of the remaining two layers (granular and subgrade) vary seasonally due to the variation in moisture content.

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* Research Scholar, Department of Civil Engineering, Indian Institute of Technology, Kharagpur – 721302, India.

† Ex-M.Tech. Student, Department of Civil Engineering, Indian Institute of Technology, Kharagpur – 721302, India.

‡ Senior Research Fellow, Department of Civil Engineering, Indian Institute of Technology, Kharagpur – 721302, India.

@ Associate Professor, Department of Civil Engineering, Indian Institute of Technology, Kharagpur – 721302, India. E-mail: ksreddy@civil.iitkgp.ernet.in.

§ Associate Professor, Department of Civil Engineering, Indian Institute of Technology, Kharagpur – 721302, India.

¶ Professor, Department of Civil Engineering, Indian Institute of Technology, Kharagpur – 721302, India.

Any test equipment selected for evaluation of pavements must be able to apply load to the pavement in a manner similar in terms of the magnitude and loading time to that applied by traffic load. With many of the pavement evaluation equipment (such as Benkelman Beam) only the maximum deflection is measured. The loading used is usually static or applied at creep speed. It is very difficult to make predictions about the functioning of various pavement layers with the help of a single deflection. Hence, it is desirable to obtain information about the deflection bowl. The characteristics of the deflection bowl can be utilized to estimate the in-situ material properties and the remaining life of the pavement with reasonable accuracy.

This paper discusses the details of an impact type apparatus developed for the evaluation of pavement layers.

Theoretical Consideration

If a layered pavement system is subjected to a uniformly distributed load acting over a circular area, the shape of the resulting surface deflection profile depends on the E1, E2, and E3 values of the three layers of the pavement as shown in Fig.1.

From the pressure distribution pattern shown in Fig.1, it is clear that for the points on the surface layer beyond 'B', the deflection depends upon E3 only since layers 1 and 2 are not stressed at this distance. For points between A and B, deflection depends on both E2 and E3. While all the layers affect the deflection at radial distances lying within 'A'. The surface deflections for a normal pressure of 560 kN/sq.m. applied over circular contact area of radius 150 mm (for h1 = 70 mm and h2 = 500 mm) are shown in Figs.2 and 3. Computer program (FPAVE developed in the Civil Engineering Department of IIT Kharagpur) was used to compute the surface profiles of the pavement for various combinations of E1, E2 and E3.

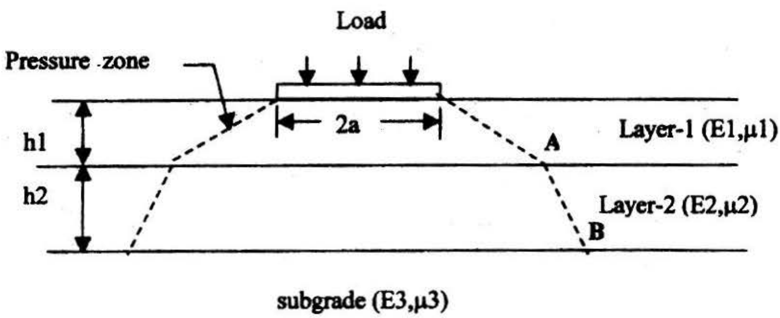

FIGURE 1 : Load Distribution in the Pavement System

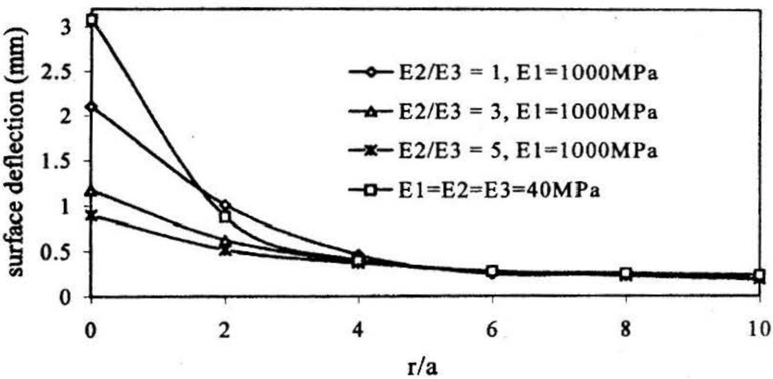

FIGURE 2 : Surface Deflections for E3 = 40 MPa

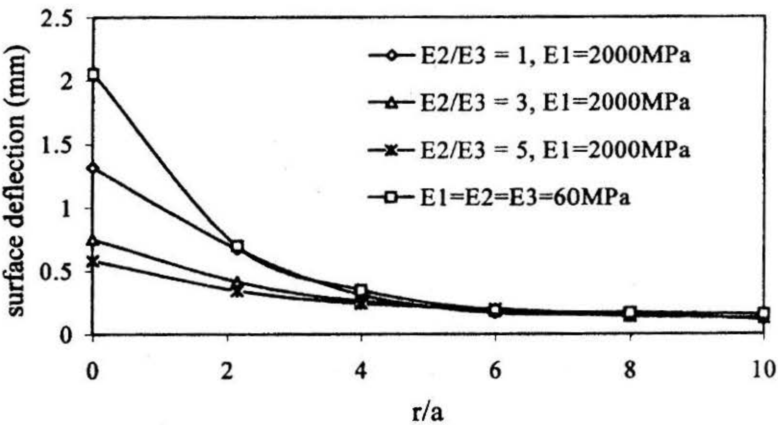

FIGURE 3 : Surface Deflections for E3 = 60 MPa

Figures 2 and 3 clearly indicate that for radial distances greater than $5a$, the surface deflection depends only on E3 and not on E2 and E1. Hence, if surface deflection is measured at a distance of $r > 5a$, subgrade modulus (E3) can be uniquely determined from the elastic half space solution. The values of E2 can be determined from the deflection measured at a location between A and B (Fig.1) and analyzing the pavement as a three layered system. After E2, and E3 are known, E1 can be determined using a three layer analysis from the central deflection. Thus, if surface deflection profile is known, moduli values of different layers can be determined by selecting the deflection values at appropriate points.

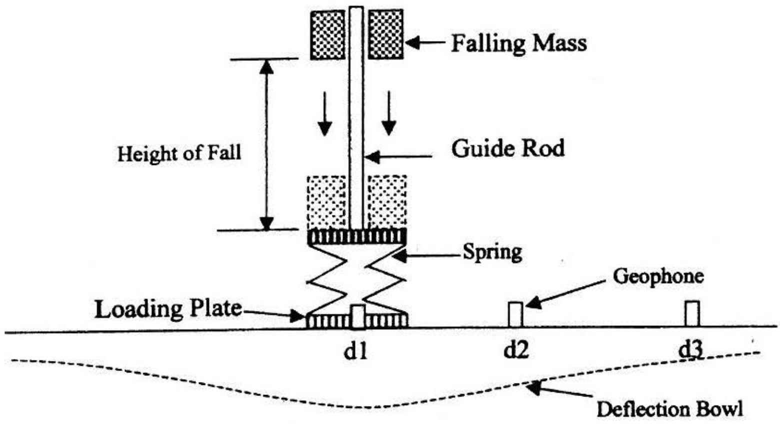

FIGURE 4 : Working Principle of the Impact Apparatus

Working Principle of the Impact Apparatus

The working principle of the equipment developed in the present investigation is illustrated in Fig.4. In this equipment, an impulse load with a short loading time is applied to the road surface by means of a mass falling on a set of springs. With proper choice of the dropping mass, stiffness of the spring and the height of fall, impulse load and the duration of the impulse can be varied. The deflection of the pavement surface is measured at a number of points at different radial distances by means of geophones.

The details of the impact testing equipment developed in the present investigation are given in Fig.5. The following paragraphs present a brief description of various components of the equipment.

Loading Plate

A mild steel plate of 300 mm diameter having a thickness of 37 mm is used as the loading plate. Three load cells are placed on the loading plate to measure the magnitude of load applied to the pavement. A rubber sole of 10 mm thickness is attached to the loading plate with an adhesive to allow the load assembly to exert pressure resembling that applied by truck tires on pavements. As it is desired to measure the pavement deflection at the center of the load also, a central hole of 50 mm diameter is made in the loading plate to place the central geophone.

Top Plate

Top plate is a 20 mm thick mild steel plate, which transfers the load

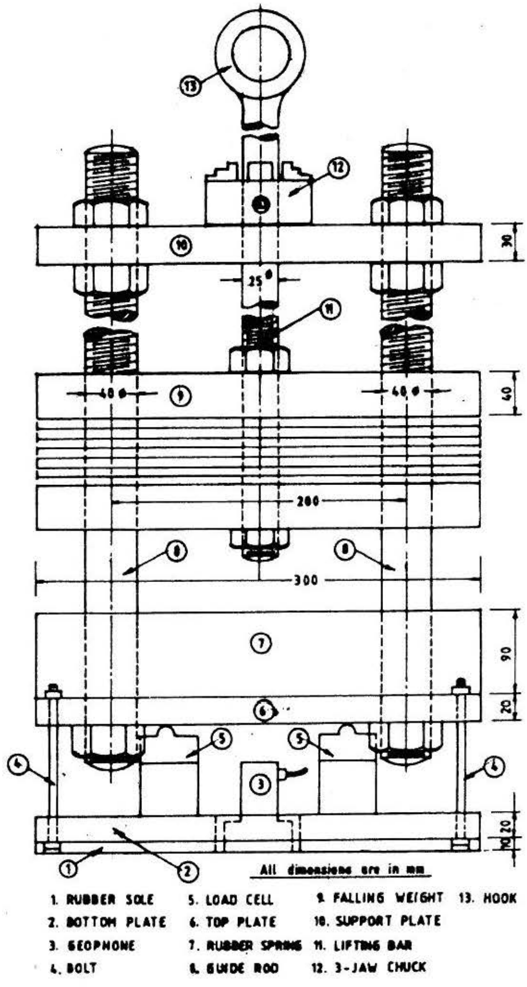

FIGURE 5 : Components of Impact Apparatus

to the load cells. It is connected to the loading plate by means of three 10mm diameter bolts.

Loading Assembly

The falling mass consists of five steel plates of diameter 300 mm, each weighing about 25 kg. 300 mm diameter, 22 mm thick rubber sheets are used as spring. Number of sheets can be varied to change the stiffness of the spring system. The combination of four rubber sheets arranged in series was found to have a spring constant of 2.9×10^6 N/m. The loading time obtained with this arrangement is in the range of 20-25 milliseconds.

Guide Rods

Two vertical rods, each of 40 mm diameter and 1.2 m length, guide the fall of the mass on the rubber springs. Apart from guiding the fall, they also help in lifting the whole assembly and shifting it from one location to another during field testing.

Support Plate

A 150 × 300 × 25 mm size rectangular support plate slotted at the center, supports the guide rods. The lift rod is raised or lowered through the central slot for lifting the mass and for allowing it to drop. When the mass is lifted, the bar is held by a chuck fixed on the rectangular plate. When the jaws of the chuck are loosened, the mass falls freely on the rubber spring.

Lifting System

In order to lift the falling mass as well as the entire equipment, a lift system consisting of a chain, pulley block and tripod is used.

Mobile System

A trolley of size 1.22 m × 1.83 m × 0.46 m has been fabricated to carry the equipment. It has been designed with suitable shock absorbers and leaf springs (Kumar, 1997). The trolley can be towed at a speed of 30 kmph by a car or jeep. A clearance of 0.4 m height is maintained between the wheel axle and the road surface. A central square opening (460m × 460m) was made in the floor of the trolley to allow lowering and lifting of the impact apparatus. A 610 × 610 × 60 mm mild steel plate is used to cover the hole and to hold the equipment.

Load and Deflection Measurement

Load applied on the pavement surface is measured with the help of three load cells, located at 120° from each other. The surface deflections are measured using three geophones placed at radial distances of 0, 600, and 1200 mm. The data from load cells and geophones are collected using a data acquisition system and personal computer.

Load Measurement

Three stainless steel diaphragm type load cells were fabricated for measuring the load. The structural section of the load cell is shown in

TABLE 1 : Values of K for different a1/b ratios.

a1/b	1.25	1.5	2	3	4	5
K	0.115	0.220	0.405	0.703	0.933	1.330

Fig.6. The maximum allowable tensile stress (S_{max}) can be obtained (Timoshenko and Krieger, 1959) using the following expression.

$$S_{max} = [KP]/h^2 \quad (1)$$

where P = maximum load,

h = thickness of the circular upper plate, and

K = a factor, which is a function of the 'a1/b' ratio.

The value of 'K' for an 'a1/b' ratio of 1.733 is obtained from Table 1. The values of a1, b and D of the load cell were taken as 12.5, 6.25 and 50 mm respectively.

Capacity of each load cell was found to be 1634 kg, and the total capacity of the three load cells together is 4902 kg. Four resistance strain gauges 120 ohms, 2.0 gauge factor were fixed to the interior of the steel section (Fig.6) in tension and compression zones. The output voltage from the load cells, which is in the order of milli-volt is amplified using an Instrumentation Amplifier AD 524 (Gayakwad, 1997) with a gain of 1000.

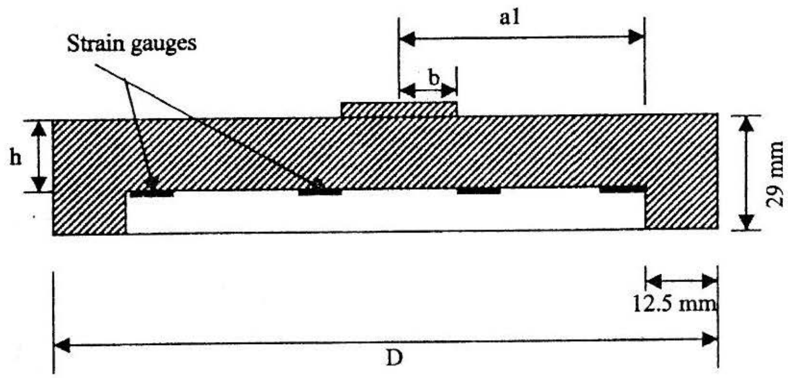

FIGURE 6 : Structural Details of Load Cell

TABLE 2 : Calibration Factors of Load Cells

Load Cell	Calibration Factors (kN/volts)
1	8.00
2	6.09
3	6.80

Load cell Calibration

The load cells were calibrated by applying known loads and correlating the corresponding outputs (Volts). The calibration factors are given in Table 2.

Deflection Measurement

Geophones measure the velocity response of the pavement surface when it is subjected to impulse loading. To get the magnitude of deflection from this response, the signals were integrated with respect to time. The resulting output is calibrated against known deflections to obtain calibration factor. An integrating circuit consisting of IC OP-07 (Gayakwad, 1997) and some suitable resistors was designed to obtain the deflections. The geophone output was connected to the integration circuit and the output from the circuit is connected to a screw terminal board to interface with the PCL 208 A/D data acquisition card interfaced with a personal computer. The geophones were calibrated individually with the help of a Linear Variable Differential Transformer (LVDT).

Calibration of LVDT

Known amount of displacement was given to the LVDT probe with a micrometer and the resulting output (Volt) is measured. The plot of known

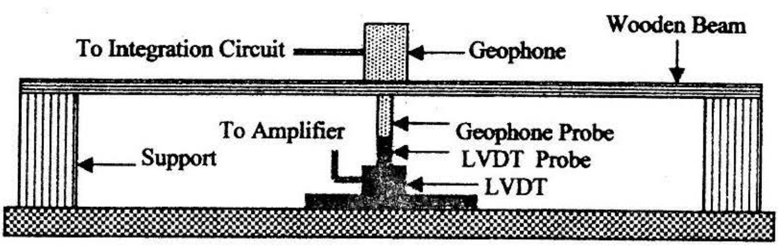

FIGURE 7 : Laboratory Setup for Calibration of Geophone

displacement vs. corresponding output from LVDT yielded a calibration factor of 0.16 mm/volt. The set-up shown in Fig.7 was used to calibrate the Geophones with the help of LVDT.

Geophone was kept centrally over the LVDT over a wooden beam supported at its ends. A known weight was allowed to fall on the beam from different heights. The deflection was measured by the LVDT and the corresponding geophone response was recorded. Calibration factors were obtained from the LVDT and geophone outputs. Typical results from the calibration was shown in Table 3. The average calibration factors (mm/volts) obtained for geophone1, geophone2 and geophone3 are 0.130, 0.115, and 0.117 respectively.

Pavement Evaluation using Impact Apparatus

The indigenously designed and fabricated equipment was used to evaluate pavement sections at five test locations near KM 135 of NH-6. The test locations were chosen at 10 m spacing. The trolley was positioned on the pavement surface such that the centre of the bottom plate is nearly 1.0 m inwards from the pavement edge. In order to produce a force level of about 40 kN, a falling mass of 100 kg with a 280 mm height of fall was used. Geophones were positioned at required radial distances with the help of a measuring bar. Power supply was provided in the field with a petrol generator. A typical set of signals obtained from one of the test locations is presented in Fig.8. The load and deflections for the five different locations are given in Table 4.

Backcalculation of Layer Moduli

The methodology discussed under 'Theoretical consideration' section was followed for backcalculating layer moduli from measured deflections. The pavement section at the test site consisted of 100 mm bituminous layer and 540 mm Water Bound Macadam (granular base course) over subgrade. Using the backcalculated moduli, surface deflections were calculated for the selected radial distances using layered elastic theory. These deflections are presented in Table 4. It is observed that the computed deflection values were reasonably close to the measured deflections. The small differences between the measured and calculated deflections are due to the non-linearity of the pavement materials.

Acknowledgement

The authors gratefully acknowledge the help rendered by the Executive Engineer of NH division, Midnapore, West Bengal, during field tests on NH-6 near Kharagpur.

TABLE 3 : Calibration Details for Geophone-1.

Sl.No.	LVDT					GEOPHONE			Calibration Factor [6/9]
	INITIAL		FINAL		Deflection [5-3]	INTEGRATED OUTPUT			
	Output (+) (V)	Needle Position (mm)	Output (-) (V)	Needle Position (mm)	(mm)	Low (-) (V)	High (+) (V)	Difference [7+8] (V)	(mm/V)
1	2	3	4	5	6	7	8	9	10
1	2.50	0.77	1.45	1.52	0.75	2.40	4.18	6.58	0.11398
2	2.10	0.88	2.97	1.75	0.87	2.30	3.82	6.12	0.14216
3	1.96	0.92	5.35	2.17	1.25	3.00	6.01	9.01	0.13873
4	1.42	1.05	5.91	2.32	1.27	3.00	6.47	9.47	0.13411
5	1.34	1.05	4.86	2.02	0.97	3.10	4.49	7.59	0.12780
6	1.06	1.08	5.20	2.15	1.07	3.30	5.49	8.79	0.12173
						AVERAGE CALIBRATION FACTOR			0.12975

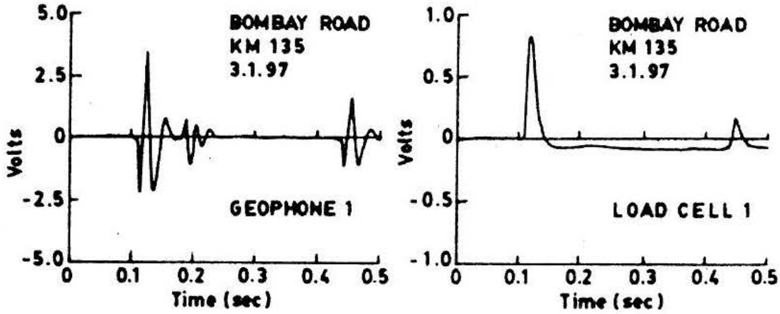

FIGURE 8 : Typical Signals from Geophone and Load Cell

TABLE 4 : Back Calculated Layer Moduli

Sl. No.	Load (kN)	Measured Deflections (mm)			Backcalculated Modulus Values (MPa)			Calculated Deflections (mm)		
		d1	d2	d3	E1	E2	E3	d1	d2	d3
1	37.23	0.62	0.24	0.10	1300	145	78	0.63	.019	0.10
2	36.29	0.72	0.25	0.10	645	140	74	0.73	0.19	0.10
3	36.36	0.94	0.28	0.10	345	107	75	0.94	0.20	0.10
4	36.36	0.70	0.23	0.09	670	140	84	0.70	0.17	0.09
5	36.36	0.75	0.22	0.08	500	130	92	0.75	0.16	0.08

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Notations

E1 = elastic modulus of surface layer

E2 = elastic modulus of granular layer

E3 = elastic modulus of subgrade

h1 = thickness of the surface layer

h2	=	thickness of the granular layer
a	=	radius of load contact area
m1, m2, m3	=	Poisson's ratio of the surface layer, granular layer and subgrade
d1, d2, d3	=	surface deflections measured at 0, 600 and 1200 mm radial distances from the loading plate
S_{max}	=	maximum allowable tensile stress
P	=	maximum load
h	=	thickness of the upper plate of the load cell
K	=	a factor
a1	=	a dimensional parameter as shown in Fig.6
b	=	a dimensional parameter as shown in Fig.6
D	=	load cell diameter