

**EVALUATION OF FLEXIBLE PAVEMENTS IN INDIA USING AN INDIGENOUS FALLING WEIGHT DEFLECTOMETER**

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## **ABSTRACT**

Use of Falling Weight Deflectometer (FWD) for the evaluation of pavements is gaining popularity in many countries, as it is possible to simulate the magnitude and duration of load applied by a fast moving vehicle on highways using this equipment. However, the use of FWD in India has been very limited so far because of its high cost and due to the difficulties encountered in maintaining the equipment.

This paper presents the details of a FWD system designed and developed by the Transportation Engineering Section of the Civil Engineering Department of Indian Institute of Technology, Kharagpur, India for structural evaluation of pavements. Salient features of backcalculation algorithm used in the evaluation system are presented. Details of structural evaluation of some highways carried out as a part of a research program sponsored by the Ministry of Road Transport and Highways (MORT & H), Government of India, are also given in the paper.

## **INTRODUCTION**

Many of the existing National Highways in India are being widened and strengthened. Also new highways and expressways are being constructed to handle the demand of the rapidly increasing traffic volumes. With the increase in demand for efficient road network, awareness to use rational or mechanistic pavement and overlay design procedures is also increasing. Properties of different layer materials such as elastic moduli and Poisson ratio are essential inputs for mechanistic design of new pavements and overlays. The properties of these materials can be determined by conducting laboratory tests on representative samples by selecting appropriate laboratory test procedure that closely simulates field conditions. Alternatively, the properties of these materials can be estimated from empirical relationships developed from field evaluation of in-service pavements.

The thrust of many of the structural evaluation methods used is to use equipment capable of simulating the loading conditions produced by fast moving traffic loads. The structural response commonly measured with these equipment is the surface deflection. The equipment differ from one another in terms of the magnitude and time of loading pulses applied to the pavement. Measured deflections are used either to estimate the overlay requirement from previously developed empirical relationships or to backcalculate layer properties for use in analytical evaluation methods. Among the equipment available for structural evaluation of pavements, Falling Weight Deflectometer (FWD) is extensively used worldwide because it simulates, to a large extent, the actual traffic loading conditions. Deflections measured with FWD are used for estimating the moduli of various pavement layers using a back-calculation procedure. The computed moduli are, in turn, used for the analysis of in-service pavements and for the estimation of their remaining lives. Number of backcalculation programs are available for determining pavement moduli from measured surface deflection (1).

This paper presents the salient features of a FWD system used by the Transportation Engineering section of IIT, Kharagpur. The system, consisting of a Falling Weight Deflectometer, Data Acquisition system and backcalculation software, has been developed through sustained research efforts made during the last one decade. Salient features of the equipment, software and details of structural evaluation of some sections on Indian highways are presented in this paper.

## **FALLING WEIGHT DEFLECTOMETERS**

FWD is an impulse-loading device, where a mass is allowed to fall on the pavement to give transient impulse load and the resultant surface deflection bowl is measured using velocity transducers (geophones). Features of some of the commercially available models of Falling Weight Deflectometers are given in the following paragraphs.

### **Dynatest Falling Weight Deflectometer**

Dynatest manufactures two FWD Test systems, model 8000 and 8081 (2). These two are complete with back-up battery and all other accessories for evaluation of pavements and for other applications of road

and airport pavements respectively. Both the models are trailer mounted and have the capability to apply loads of the order 7 to 120 kN (Peak) and 30 to 240 kN (Peak) respectively.

### **Phonix FWD**

The Phonix model ML- 10000 produces a dynamic impulse load of 10.2 to 102.3 kN<sup>6</sup>. It consists of three to six deflection transducers in adjustable mounts along a 2400 mm raise/lower bar. The equipment is available as trailer and vehicle built-in models.

### **KUAB 2M-FWD**

This FWD is available in two models (2), which are trailer mounted. For the models 8833 and 8714, the loading range is 14 to 150 kN and 7 to 65 kN respectively. The impulse force is created by means of a two - mass system of force generation in which a falling weight is dropped onto a second weight buffer combination and the load is transmitted to the segmented loading plate resting on the pavement surface. The loading plates are available in diameters of 300 and 450 mm.

FWDs have the ability to simulate the load pulses generated by fast moving commercial vehicles. Data can be acquired rapidly. However, there are certain drawbacks with the equipment. They are i) very costly to procure and ii) regular maintenance is also costly. Because of its high initial cost and maintenance problems, use of FWD for pavement evaluation has not been extensive in India. In the recent revision of Indian Roads Congress code of practice for flexible pavement design (3), mechanistic approach has been incorporated. Elastic properties of pavement materials are necessary inputs in the revised design procedure. Estimation of these properties of in-service pavement layers is important in the design of overlays. As already mentioned earlier, FWD is the most suitable equipment available for the evaluation of the in-service pavements. Hence the need for developing a low cost FWD system was considered to be very crucial for the advancement of pavement technology in India. Keeping this in view, the Transportation Engineering Section of the Civil Engineering Department of Indian Institute of Technology, Kharagpur, India developed a FWD system for pavement evaluation.

### **IITKGP FWD SYSTEM**

IITKGP FWD system consists of FWD equipment, data acquisition system and software for analysis.

#### **IITKGP FWD Model-I**

The first model of FWD was designed and fabricated (4) in the year 1997. A photograph of FWD model I is shown in Figure 1. This model is mounted in a trailer, which can be towed with the help of a jeep. With this model, it is possible to apply a load of magnitude ranging from 20 kN to 65 kN with a loading time of about 25-30 milli-seconds. This loading time is similar to that produced by a vehicle moving at 50 to 60 km/h. Rubber pads of suitable stiffness were used as spring system to obtain loading time of 25 milli-seconds (5). Six surface deflections are measured at radial distances of 0, 300, 600, 900, 1200 and 1500mm with the help of geophones.

A chain and pulley arrangement is used for lifting and lowering the mass whereas a chuck arrangement is made for holding the mass at any desired height. Load cell and geophones measure the magnitude of load and deflections respectively. Load and deflection signals are recorded in the computer with the help of a data acquisition system.

Extensive field studies were carried out using this equipment and the results are highly satisfactory. The equipment was tested for its repeatability of test results. A number of identical experiments were conducted with the equipment to investigate the consistency of the test results. The deflections were normalized to correspond to 40 kN load. The results are given in Table 1. As can be seen from the table, measurements made using this equipment show good repeatability.

Though the first model performed well, it has some shortcomings. All operations such as lifting of mass and placing of geophones on the pavement surface are done manually and hence it requires longer time for data collection. Also, towing the equipment mounted in trailer for longer distances and maneuvering

it on heavily trafficked two lane two way highways in India was found to be difficult. Keeping these practical difficulties in consideration, another model (IITKGP FWD model-II) which is fully automatic in its operation, has been designed and developed in the year 2001(6).

### **IIT KGP FWD Model II**

In this model, all the operations are automated and deflection data is collected through data acquisition system. The equipment is housed inside a covered vehicle so that maneuverability of the equipment on heavily trafficked highways becomes greater. Also, the equipment is protected from rain, dust, etc. The major components of this equipment are: -

- Mass
- Cylinders for rising, lowering of mass and geophone frame and also for catching and releasing the load
- Hydraulic system
- Geophone frame fitted with seven geophones
- Arrangement for holding the mass
- Provision for holding the mass at any position in between 100 to 800 mm.
- Programmable Logic Circuit (PLC)

Figure 2 shows the FWD equipment fitted inside a van.

The main advantage of this device is that it can be fabricated locally at lower cost. It will be easier to maintain the indigenous model if the need arises. Table 2 presents the data collected to illustrate the repeatability of results obtained using this equipment.

### **Data Acquisition System**

A commercially available PCL-208 data acquisition card (7) with built-in Analog-Digital (A/D) converter having 8 channels was used for data acquisition. The amplified signals from the load cell and geophones are connected to the data acquisition system by a 24-pin connector through the screw terminal board. The card was installed inside a personal computer. The system offers facility to acquire data at different sampling rates. The maximum A/D sampling rate is 60,000 Hz in Direct Memory Access (DAM) mode. LABTECH NOTE BOOK software (8) was used for data acquisition. The deflection and load signals are amplified, integrated using the electronic circuitry and recorded in the computer.

### **BACKGA Program for Backcalculation of Pavement Layer Moduli**

A Genetic Algorithm based program, BACKGA (9), has been developed for backcalculation of effective moduli of pavement layers. When used as inputs to elastic layered theory, effective layer moduli produce responses (deflections) similar to those observed in field. ELAYER (10) a program developed for the analysis of layered pavement systems, is used for forward calculation of surface deflections in BACKGA. Inputs to BACKGA program include:- measured deflections, radial distances at which deflections are measured, layer thicknesses, Poisson ratio values of different layers, applied load and loading plate radius. It is also necessary to give practical ranges for different moduli to be estimated. Population size, number of generations up to which the GA will run, probabilities of crossover and mutation, are the main GA related inputs. By choosing a suitable objective function and optimal GA parameters, the pavement layer moduli values can be backcalculated accurately.

### **STRUCTURAL EVALUATION OF IN-SERVICE PAVEMENTS**

This section presents the analysis of the deflection data collected from a few sections of National Highways in Eastern India using IITKGP FWD model II. Table 3 presents the details of the layer thicknesses and measured deflections. The deflections were measured after the monsoon of year 2001. Figure 3 shows a view of the evaluation of National Highway No.6 using IITKGP FWD model-II.

For backcalculation of layer moduli, pavements were considered as three-layer systems with bituminous surfacing, granular base and subgrade. Table 4 presents the backcalculated moduli obtained using BACKGA program for different layers. The table also gives the error term representing the differences between the deflections measured and those computed using the backcalculated moduli.

## CONCLUSIONS

Salient features of FWD models developed by Indian Institute of Technology, Kharagpur, India for structural evaluation of Indian highways have been presented in this paper. The development of an indigenous FWD was necessary for the advancement of pavement technology in India and for the adoption of rational design approaches. The two FWD models were found to yield reliable and satisfactory performance. It is expected that FWD based pavement evaluation system developed by IIT, Kharagpur will be helpful in the popularization of use of rational tools in the design and evaluation of pavements.

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Figure 1 IITKGP FWD Model-I

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**Figure 1 IITKGP FWD Model-I**



**Figure 2 IITKGP FWD Model-II**



**Figure 3 Field Evaluation of National Highway-6 using IITKGP FWD Model-II**

**Table 1 Reproducibility of FWD Deflection data for IITKGP FWD Model I**

Sl. No	Normalized deflections(mm) at different radial distances (mm)						Test load (N)
	0	300	600	900	1200	1500	
1	1.30448	0.76329	0.46563	0.32641	0.23401	0.19305	40047.3
2	1.29836	0.75901	0.45975	0.32266	0.23411	0.19014	39962.4
3	1.30165	0.76543	0.46656	0.32595	0.22983	0.18592	40102.1
4	1.30314	0.76405	0.46624	0.32662	0.22879	0.19314	40284.7
5	1.30247	0.76425	0.46524	0.32476	0.23254	0.19125	40231.4
6	1.29965	0.76204	0.46448	0.32093	0.23271	0.19057	39879.5
7	1.30355	0.75972	0.46352	0.32294	0.23591	0.18957	40217.2
8	1.30225	0.76045	0.46708	0.32641	0.23368	0.19162	40326.2
9	1.30014	0.76301	0.46527	0.32715	0.23525	0.19241	40282.4
10	1.30241	0.76244	0.46458	0.32422	0.23452	0.19205	40092.1
11	1.30322	0.76125	0.46387	0.32584	0.23282	0.19242	40311.8
12	1.30271	0.76358	0.46225	0.32266	0.23405	0.19258	40362.2
M*	1.30200	0.76237	0.464539	0.324713	0.233185	0.191227	40174.9

M\*-Mean

**Table 2 Reproducibility of FWD Deflection data for IITKGP FWD Model II**

Sl. No	Normalized deflections (mm) at different radial distances (mm)							Test load (N)
	0	300	600	900	1200	1500	1800	
1	0.71032	0.37804	0.23167	0.16117	0.11481	0.09831	0.07651	416510
2	0.71240	0.37754	0.23981	0.16232	0.11873	0.10122	0.07789	413570
3	0.71563	0.38032	0.23298	0.16723	0.11558	0.09960	0.08023	409923
4	0.71786	0.37937	0.23995	0.16273	0.11925	0.09654	0.07650	395018
5	0.71395	0.37793	0.23869	0.16620	0.11854	0.09830	0.08127	419446
6	0.71920	0.37520	0.23668	0.16498	0.11390	0.09698	0.07759	417810
7	0.71803	0.37994	0.23157	0.16579	0.11926	0.10023	0.07437	409825
8	0.71092	0.38011	0.23495	0.16849	0.11287	0.09432	0.07865	410028
9	0.71442	0.37164	0.23859	0.16181	0.11825	0.09674	0.07640	407390
10	0.71381	0.37652	0.23694	0.16338	0.11762	0.09859	0.07754	406985
M*	0.71465	0.37766	0.23618	0.16441	0.11688	0.09808	0.07769	410650

M\*-Mean

**Table 3 Details of the Test Sections Considered**

Sl No	Location-Km	Surface Deflections (mm) measured from 0,300,600,900,1200 and 1500 mm from the centre of the load						Thickness (mm)	
		D0	D1	D2	D3	D4	D5	H1	H2
1	NH-6-134.780	0.76731	0.36051	0.22755	0.19893	0.16770	0.13272	145	550
2	NH-6-134.940	0.60569	0.39485	0.25141	0.22643	0.17492	0.14680	145	562
3	NH-6-150.060	0.64771	0.39042	0.23120	0.18571	0.13698	0.10896	170	535
4	NH-6-150.240	0.84632	0.46717	0.24755	0.16679	0.11150	0.09148	170	535
5	NH-6 -151.210	0.98480	0.55491	0.31387	0.23405	0.16869	0.13527	170	535
6	NH-6-151.090	0.71117	0.41902	0.23350	0.18665	0.11978	0.09051	170	540
7	NH-60-15.200	1.37950	0.83172	0.48249	0.32422	0.26635	0.21001	130	440
8	NH-60-19.490	1.16992	0.70851	0.43621	0.33329	0.26914	0.19766	140	455

\*NH- National Highway

**Table 4 Backcalculated Layer Moduli**

Problem No	Backcalculated Moduli (MPa)			RMS error * in deflection (%)
	E1	E2	E3	
1	300.01	201.05	62.69	1.191
2	997.26	214.51	51.19	1.060
3	722.87	145.38	68.39	0.691
4	582.60	80.94	77.95	0.524
5	406.06	88.45	53.08	1.192
6	800.19	94.70	78.94	1.880
7	445.74	80.63	34.54	1.885
8	494.33	93.76	37.24	1.115

\* 
$$RMS\ Error = \sqrt{\sum_{i=1}^n (d_i - d_c / d_i)^2 / n} \times 100$$
 where  $d_i$  is measured deflection  
 $d_c$  is calculated deflection,  $n$  is the number of deflection measurements