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Structural Evaluation of Flexible Pavement and Rehabilitation using Falling Weight Deflectometer (FWD)

*Nitin S.Aher, #Abhishek Loya

*Student of Final year, #Professor, Transportation Engineering And Planning Dept., Sandip University, Trimbak road, Nashik, Maharashtra, India. *Ahernitin28@gmail.com, #abhishek.loya@sandipuniversity.edu.in

Abstract:- Fast development of road networks has become a trend in India and everywhere across the world. From the past few years, it has been observed that number of highways are in a phase of deteriorations, so that have to be evaluated to assess their structural condition and also to assess the remaining life of the pavement and how much more time the pavement can serve the users satisfactorily. The Falling Weight Deflectometer (FWD) is essential nondestructive devices used for structural evaluation and characterization of pavement layer systems, as it is possible to simulate the magnitude and duration of load applied by a fast moving vehicle on pavement 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.

In the present research work the pavement is evaluated using KUAB model Falling Weight deflectometer on flexible pavement. An attempt is made to evaluate the condition of a selected section of a pavement from Chalisgaon to Nandgaon (Section III) of National Highway 753 J . Based on the analysis of distress data, the pavement is evaluated by use of IRC: 115 - 2014. From the analysis rehabilitation criteria, the overlay thickness required to maintain the pavement in serviceable condition is determined.

Keywords – FWD, Falling Weight Deflectometer, Pavement.

I. INTRODUCTION

Each year, local and state agencies make substantial investments in evaluating the conditions of existing, in-service pavements. In addition to collecting functional deficiencies, structural condition of a pavement needs to be evaluated through the use of proper non destructive testing and sensor technologies so that adequate rehabilitation options can be formulated with maximum cost savings. Adequate maintenance of existing pavement structures and design/implementation of suitable rehabilitative approaches through structural capacity assessments are critical to ensuring long lasting, cost effective pavement systems.

Falling Weight Deflectometer is an impulse loading device in which a transient impulse load is applied to the pavement surface and deflection shape of pavement surface (deflection basin) is measured by a series of geophones located at different radial distance from load plate (30 or 45 cm diameter). Which provides a more complete characterization of pavement layers structural condition. The area of pavement deflection under and near the load application is collectively known as the "deflection basin". Deflection sensors (geophones; force-balance seismometers) mounted radially from the center of the load plate measure the deformation of the pavement in response to the load. Some typical offsets are 0mm, 200mm, 300mm, 450mm, 600mm, 900mm, 1200mm as shown in Fig 1.

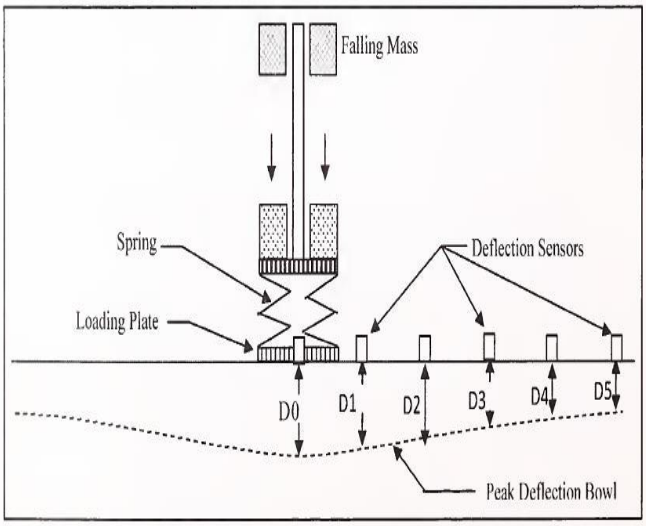

Fig. 1 Working Principle of Falling Weight Deflectometer

The deflections measured at these sensors are termed as D0, D1, D2, D3, D4, D5, D6 etc. The advantages of seismometers compared to geophones are built-in

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calibration devices and higher range (5 mm vs 2 mm). Geophones are more sensitive to disturbance immediately before the impact since the initial error is integrated. Geophones however are much cheaper than seismometers. Dynatest, Carl Bro, Jils and PaveTesting use geophones while KUAB have seismometers in their standard FWD's and geophones in their low-cost models.

This Study covers the determination of pavement surface deflections as a result of the application of an impulse load to the pavement surface. The resulting deflections are measured at the center of the applied load and at various distances away from the load. Deflections may be either correlated directly to pavement performance or used to determine the in-situ material characteristics of the pavement layers. Some uses of the data obtained from FWD include structural evaluation of load carrying capacity, load transfer efficiency and determination of overlay thickness requirements for highway pavements.The same data can be used for pavement design. This requires a more detailed analysis using the iteration technique with the help of software called KUAB PVD. You must know the actual thickness of each layer of the road. You will calculate the strain at critical points and an estimate of the remaining life of the pavement structure can then be determined which promotes good decision making about future maintenance and repair activities for that road.

The FWD is a versatile and important tool that can be useful in the management of an entire road network for the purpose of maintenance and repair planning. FWDs are also useful to help design a pavement structure or repair plan through a detailed analysis of a specific section of road.

The advantage of FWD over Benkelman Beam (BB) is that it is quicker, the impact load can be easily varied and it more accurately simulates the standard loading of trucks, both with respect to time of application of the load as well as the magnitude of the load. Therefore, using FWD deflection data one can characterize the existing pavement layers in terms of their layer moduli and required thickness of the overlay using KUAB PVD Software.

II. STUDY AREA LOCATION

The project corridor starts from Nandgaon at 103.000 km and ends at 147.425 km near Chalisgaon(Section III) of National Highway 753J. Total length of study stretch is 44.425 km. Figure 2 shows the map view of study area.The project section on NH 753J is located in Nashik District of the Maharashtra State .

Figure 2 : Study Area Location

III. FIELD SURVEY AND DATA COLLECTION

The field details for the pavement evaluation have been collected. The data are categorized as follow:

A) Functional condition suvey
B) Falling weight deflectometer(FWD) survey
C) Pavement layer types and thickness composition
D) Classified volume count

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A) Functional condition survey

For the purpose of functional evaluation the total the pavement length was divided into 81 sample units of equal size. Each sample unit is 500m x 7m. For convenience, 81 out of the 48 sample units were considered for inspection by random sampling technique. Manual distress survey is conducted to identify the presence of various distresses like rutting, potholes, patching, raveling, shoving, etc. in the pavement surface. The percentage area of each distress present in each of the inspected sample units was calculated. Each section is rated as per the IRC: 82 - 2015 guidelines. The functional condition of the pavement is assessed to be good, fair or poor based on this rating. As a result of the pavement condition survey mentioned in Table 1 shows that the pavement is in good condition

Distress Type	Input (%)	Rating as per norms	Weightage	Weighted Rating Value
Cracking (%)	2.87	2.5	1.00	2.5
Patching (%)	0.857	2.2	0.75	1.7
Pothole (%)	0.115	1.9	0.50	1.0
Settlement	0.121	2.9	0.75	2.2
Raveling (%)	0.190	2.2	0.75	1.7
Shoving	0.075	2.3	1.00	2.3
Rutting	2.480	2.6	1.00	2.6
Final rating value				2.0

Table 1: Result of Pavement Condition Survey

B) Falling Weight Deflectometer survey

For the purpose of conducting FWD survey on the study area, KUAB 70ESPGEVM FWD unit was used. The sample size or the interval at which deflection measurements made was decided as per the guidelines recommended in IRC 115-2014 for selection of deflection measurement schemes for different types of carriageways is tabulated below in table no 2. The result of pavement condition survey states that pavement is in good condition.

Type of Carriageway	Recommended measurement scheme	Maximum Spacing (m) for test points along selected wheel path for pavements of different Classification		
		Poor	Fair	Good
Single-lane two-way	i) measure along both outer wheel path.	60	130	500
Two-lane two-way single carriageway	i) measure along both outer wheel path.	60	130	500
Four-lane single carriageway	i) measure along outer wheel paths of outer lane. ii) measure along the outer wheel path of more distressed inner lane. iii) measure along the centre line of paved shoulder (in case of widening projects).	30 60 120	65 130 260	250 500 500
Four-lane Dual (divided) carriageway(Measurement scheme given for each carriageway)	i) measure along outer wheel paths of outer lane. ii) measure along the outer wheel path of inner lane. iii) measure along the centre line of paved shoulder (in case of widening projects).	30 60 120	65 130 260	250 500 500
Dual carriageways with3 or more lanes in each direction (Measurementscheme given for each carriageway).	i) measure along outer wheel paths of outermost lane. ii) measure along outer wheel path of more distressed inner lane. iii) measure along the centre line of paved shoulder (in case of widening projects)	30 60 120	65 130 260	250 500 500

Table 2:Guidelines for selection of measurement of deflection interval for FWD testing.

FWD tests were conducted at above mentioned intervals. The Deflection was measured in mm at standard configuration of geophones placed radially at 0 mm (D0), 200 mm (D1), 300 mm (D2), 450 mm (D3), 600 mm (D4), 900 mm (D5), 1200 mm (D6), respectively, starting from the centre of the loading plate. The Pavement temperature and seasonal data was auto collected by FWD testing unit during the testing. Total 85 deflection point reading was taken for 40 km length excluding bridges and cross drainage structure. Table 3 Shows the sample data collected.

S. NO	Chainage	Air Temp. ^{0}C	Pavement Temp. ^{0}C	Peak Load Applied (KN)	Peak Deflection (μm) observed at a radial distance in MM						
					D0	D1	D2	D3	D4	D5	D6
					0	200	300	450	600	900	1200
1	104.447	33.5	58.3	40	649	491	363	230	152	70	42
2	104.594	33.3	59.5	40	609	436	331	218	138	79	54
3	104.939	73.2	57.5	40	869	665	484	338	255	143	97
4	105.897	33.8	65.1	40	523	347	237	163	110	71	51

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5	106.354	35.8	58.6	40	735	581	423	270	184	108	67
6	106.844	34.8	66.2	40	708	546	402	254	164	95	69
7	107.331	35.1	64.2	40	1516	1221	968	674	443	241	155
8	107.787	34.8	60.4	40	746	558	403	260	176	102	71
9	108.334	35.0	61.3	40	536	382	305	214	141	76	48
10	108.784	34.7	61.3	40	775	563	432	285	168	79	51

Table 3: Sample data collcted from FWD testing.

C. Pavement layer types and thickness composition

In order to assess the existing crust details and to understand the existing Subgrade soil characteristics, test pit (1 m x 1 m) surveys have been carried out along the project road. The Pavement composition of the existing carriageway has been noted from the test pit surveys. In total 82 pits have been taken for entire length of road on outer lanes starting from the outside edge of the outer lane in the earthen shoulders on both side. Table 4 shows the data of test pits. There is small variation in layer thickness along the length of road.

Sr.No.	**Spot Chainage**	**Total Thickness of the core (mm)**		
		BT	GSB+WBM	SUB BASE(GSB)
1	104.400	45	235	720
2	104.500	55	230	715
3	104.750	45	235	720
4	105.000	50	250	700
5	105.250	55	240	705
6	105.500	65	255	680
7	105.750	50	235	715
8	106.000	50	240	710
9	106.250	55	250	695
10	106.500	50	260	690

Table 4: Pavement layers and thickness composition

D. Classified volume count

Classified Traffic Volume Count (CVPD) Surveys are carried out at two locations since the month of April 2018. Table 5 shows the classified volume count for seven days with average value.

FAST MOVING VEHICLES - MOTORIZED TRAFFIC									
Time interval	Mini Bus	Govt.Bus	Private Bus	LCV		2-Axle Trucks	3-Axle Trucks	MultiAxle Trucks	Total
				Passanger	Goods				
Day1	5	50	25	110	90	166	147	95	
Day 2	5	55	22	135	95	154	130	80	
Day 3	6	57	35	118	87	170	145	87	
Day 4	5	55	27	124	99	155	127	98	
Day 5	7	57	30	130	88	146	114	88	
Day 6	6	56	26	135	90	161	154	75	
Day 7	6	56	27	132	96	159	135	59	
Average	6	56	28	127	93	159	136	92	697
Commercial Vehicles (Round up)									700

Table 5: Cvpd count for 7 Days.

IV. DATA ANALYSIS

A. Design traffic

Commercial vehicle per day is calculate for 7 days and 24 hours as shown in Table 5 average cvpd is 700 (roundup).

The traffic at the end of construction of road is calculated using the formula:

$$A = P * (1 + r)^{x} \quad \text{………………(1)}$$

Where,

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A= Future traffic after construction period

x = construction period in years = 2 years

P = present traffic in cvpd = 700

A=700 ∗ (1 + 0.05)2

A=7166.25; say A = 772 cvpd

The design traffic in terms of the million standard axles to be calculated catered throughout the design life of the road should be calculated using the Equation 1 are considered as per IRC:37-2012 guidelines for road under study.

1	Lane Distribution Factor (D)	0.75
2	Initial Traffic (A)	772
3	Vehicle damage factor (F)	4.5
4	Traffic growth rate (r)	5%
5	Design life in years (n)	15
6	Terrain	Plain

Table 6 : Design Traffic

Parameters

$$N = 365 * [(1+r)^{n} - 1] / r * A * D * F \qquad \ldots\ldots\ldots\ldots (2)$$

$N = 365 * [(1+0.05)^{15} - 1] /0.05 * 772 * 0.75 * 4.5$; N = 20.52 msa

To increase the reliability of data acquired, it was assumed that design traffic will be 21 msa.

B. Identification of Subdivision

The subdivision can be made in three ways. There can be one section, manually defined subsections or subsection calculated by the KUAB program. There is no specific theory applied when the program makes the subsections. A bearing capacity indicator is selected, and its value in each test point is calculated. A number of ranges for the indicator and a minimum number of points in a subsection are defined. The program tries to find groups of adjacent test point with the value of the bearing capacity indicator within the same range.

C. E Moduli and overlay thickness

KUAB program calculates the E modules for the layers in a pavement, given the values for each layer's thickness and Poisson's ratio. It does so using an iteration procedure, where theoretical deflection values in a mathematical model are compared with the measured data, and the program adjusts the layer modules until no further improvement is obtained. The program then calculates the strains in the layers and works out which layer that according to the criteria for strain allowed will fail first and how many years this will take. Finally the program calculates the overlays required for the pavement to carry a certain load for a certain lifetime.

Equivalent thicknesses approach

This program uses the equivalent thicknesses approach. In order to calculate the compression of a certain layer the other layers are converted to layers with the same modulus as the layer we are looking at. In the equivalent pavement the deflection at the top and at the bottom of the layer is calculated according to Boussinesq, and the difference between these is the compression of the layer. The total deflection on the surface is the sum of the deflections in all layers.

For the first calculation of theoretical deflections in the mathematical model the Poisson's ratio, modulus and thickness for each layer, so called seed values, are used. The modulus value that gives the best agreement between calculated and measured deflection is selected. The sample calculated value of layer modulii are given in table 7.

Chainge	Calculated Moduli (Mpa)			
	E0: E modulus of layer 1	**E 2**: E modulus of layer 2	**E 3**: E modulus of layer 3	**Critical layer No.**
	Mpa	Mpa	Mpa	
104.447	1075	473	60	1
104.594	1013	500	58	1
104.939	974	500	60	1
105.897	609	320	50	1
106.354	955	500	200	1
106.844	851	423	50	1
107.331	1216	485	70	1
107.787	1005	500	200	1
108.334	1025	500	60	1
108.784	1001	500	112	1

Table 7: Calculated layer Moduli (Mpa).

D. Result

Required thickness of overlay corresponding to calculated layer moduli and selected range of layer moduli by using KUAB software are given in table no 8. Form below tabulated results all these sections a overlay of average thickness 125 mm is sufficient .

Chainge	**A overlay** calculated value. **In mm.**
104.447	125
104.594	125
104.939	120
105.897	110
106.354	105
106.844	130
107.331	120
107.787	110
108.334	120
108.784	115

Table 8 : Proposed Overlay Thickness

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V. Conclusion

Based on this study, it can be concluded that FWD can be used as BT and Granular layer subgrade strength evaluating tool for the construction and maintenance of the pavement.

For crust designs of flexible pavements FWd test results should be analyzed using KUAB software so that remaining life of the existing layers, layer moduli can be calculated for the realistic and economical designs.

Structural evaluation of pavements involves application of a standard load to the pavement and measuring its response in terms of deflection.

Among the equipment available for structural evaluation of pavements,the Falling Weight Deflectometer (FWD) is extensively used world-wide because it simulates,to a large extent, the actual loading conditions of the pavement .

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