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A Comparison of Flexible Overlay Design Using FWD and BBD Techniques

Pramod Kumar[1] and Praveen Aggarwal[2]

[1]*M.Tech Student, Deptt. Of Civil Engineering, National Institute of Technology, Kurukshetra, Haryana-136119, India*
[2]*Professor, Deptt. Of Civil Engineering, National Institute of Technology, Kurukshetra, Haryana-136119, India*
E-mail: [1]pkumar16393@gmail.com, 2praveen@nitkkr.ac.in

Abstract—*Fast development of road network is a requirement of industrialization and population growth in all developing countries along with development of new roads. There is a requirement of strengthening the existing pavements for higher design traffic. Higher design traffic is a result of increase in traffic volume and increase in axle load (VDF). Most of the Indian pavements are flexible in nature. Earlier flexible overlay design was carried using Benkelman Beam techniques. Recently Indian Road Congress has adopting Falling Weight Deflectometer for flexible overlay design. In this paper Delhi to Meerut Expressway NH-24 Package-1 (starts from chainage km 0.000 to km 8.716) is selected for the study. FWD and BBD tests has been conducted at section starts from chainage km 6.400 and ends at chainage km 7.900 and the FWD test results are analyzed using KGP-BACK software and IIT-PAVE software as per IRC 115-2014. Equation 6.2 and 6.5 given in IRC 37-2012 are used to calculate the allowable strains which later compared with the calculated strains from IIT-Pave for computing remaining life of existing pavement. BBD test results are analyzed as per IRC 81-1997. An overlay thickness has been proposed based upon FWD and BBD. And also, comparison of its results.*

Keywords*: Design Traffic; Falling Weight Deflectometer (FWD); Overlay thickness, KGP-BACK; IIT-PAVE.*

1. Introduction

Like all other structures pavement also fail at certain point of time. Combined effects of traffic loading and environment causes deterioration of every pavement, no matter how well-designed/constructed it is. For the purpose of strengthening flexible overlay is quite common over flexible pavements. In overlay design method, the response of a pavement to a test load is observed. Structural response of a pavement can be measured in terms of stresses, strains and surface deflections. Surface deflection is the most common parameter used in almost all overlay design system, as it is very easy to measure. There are two Non-destructive techniques to measured surface deflection of flexible pavement that is Benkelman Beam deflection (BBD) and Falling Weight Deflectometer (FWD). BBD was one of the first methods developed for measuring deflections on pavements, is economical, readily available and has been widely used worldwide, however, its performance is slow, has high degree of uncertainty in collecting data. Another drawback associated with BBD is, it operates under a static load which does not really represent the effects exerted by moving vehicles, presenting low reliability of results. On the other hand, FWD is more expensive, has a high performance, is automated and operates under a dynamic load, this is the most efficient equipment and advanced technically that exists to measure the deflections of a pavement structure simulating the action of a moving load.

2. Objectives

The research entitled flexible overlay design using FWD technique has following main objectives.

1. To collect FWD data from selected road.
2. To calculate the elastic modulus of existing pavement layers.
3. To determine remaining life of existing pavement.
4. To determine Overlay thickness for a design life, and
5. Comparison with BBD results.

3. Study Stretch

The selected study stretches on Delhi to Meerut Expressway NH-24 Package-1. Starts from Nizamuddin bridge chainage km 0.000 (28.602075,77.265329) and ends at Delhi- U.P. border chainage km 8.716 (28.632371, 77.338012). The FWD tests has been conducted on predefined points on this road section and subsequent overlay thickness design is carried out. Total length of study stretch is 1.5 km. Figure 1 shows the map view of study area.

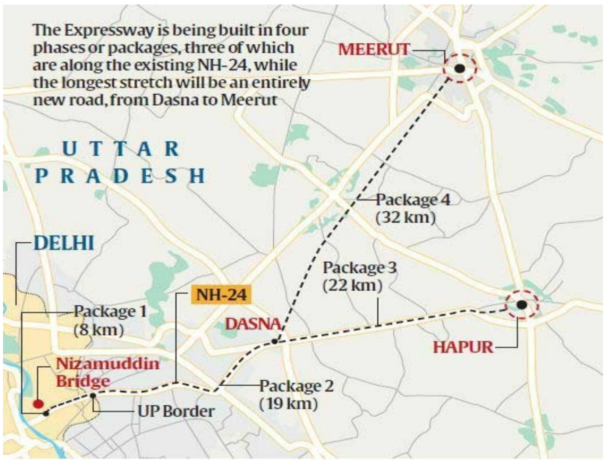

Figure 1. Study area Delhi to Meerut Expressway

4. Data collection and Analysis

4.1. Falling weight deflectometer

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

a. Falling Weight Deflectometer (FWD) survey

b. Thickness of pavement layers.

c. Pavement surface temperature and season at the time of FWD testing, and

d. Design traffic

4.1.1. Falling Weight Deflectometer survey

For the purpose of conducting FWD survey on the study area, GEOTRAN FWD was used. The area under study is six lane divided carriageway so the measurement scheme given for each lane and for good condition of pavement are mentioned in table 1.

Table 1: Deflection Measurement Scheme as per IRC 115-2014

Types of Carriageway	Recommended Measurement Scheme	Maximum spacing (m) for test points along selected wheel path for pavement of different classification		
		Poor	Fair	Good
Dual carriageways with three or more lanes in each direction	Measure along outer wheel path of outer lane	30	65	250
	Measure along outer wheel path of more distressed inner lane	60	130	500
	Measure along the centerline of paved shoulder (in case of widening projects)	120	260	500

FWD tests were conducted at above mentioned intervals. The deflection was measured in micrometer at standard configuration of geophones placed radially at 0mm, 300mm, 600mm, 900mm, 1200mm, 1500mm, 1800mm, and 2100mm respectively, starting from the centre of loading plate. The pavement temperature was collected at every test location during FWD testing. Total 15 deflection point reading was taken for 1.5km as shown in table 2.

Table 2: Following deflection values recorded during FWD testing

		Observed deflections (µm) normalized at 40KN									
Chainage (km)	**Pressure (Mpa)**	**0**	**300**	**600**	**900**	**1200**	**1500**	**1800**	**2100**	**Pavement Temp. (^{0}C)**	**Remarks**
7.900	0.566	714	478	346	247	133	102	54	44	30	PS (R)
7.400	0.566	386	249	189	148	93	63	48	40	30	PS (R)
6.900	0.566	152	107	91	78	60	46	36	28	30	PS (R)
6.400	0.566	261	175	141	110	70	48	38	30	30	PS (R)
7.900	0.566	903	606	227	118	71	49	42	33	34	OL (R)
7.650	0.566	167	122	78	52	38	29	24	21	34	OL (R)
7.400	0.566	125	94	68	50	44	29	24	20	34	OL (R)
7.150	0.566	474	334	191	107	68	50	39	35	34	OL (R)
6.900	0.566	103	96	89	80	68	64	59	56	34	OL (R)
6.650	0.566	329	244	159	106	68	48	37	29	34	OL (R)
6.400	0.566	234	170	114	82	62	43	35	29	34	OL (R)
7.900	0.566	356	239	133	73	44	33	28	24	28	IL (R)
7.400	0.566	151	101	60	36	24	18	16	14	28	IL (R)
6.900	0.566	563	373	273	209	127	85	67	54	28	IL (R)
6.400	0.566	124	72	53	43	35	30	25	21	28	IL (R)

4.1.2. Pavement layers types and thickness composition

There various layers are mentioned in table 3.

Table 3: Existing Pavement crust details

Chainage	**Pavement layer thickness (mm)**		
	Bituminous	**Non-Bituminous**	**Total**
6.400 Km to 7.900 Km	300mm	320mm	620mm

4.1.3. Design traffic

Design traffic on this road section for overlay design is 45 msa.

4.1.4. KGP BACK Application

KGP BACK is a genetic algorithm-based model for back calculation of layer moduli provided along with IRC 115. It used linear elastic theory for the analysis of pavement in its forward calculation algorithm. KGP BACK application is used for calculating the elastic modulus values of existing pavement layers.

Followings inputs are required by the KGP BACK software for the analysis (table 4 and table 5)

Table 4: Input parameters for KGPBACK software.

Parameters	**values**
Single wheel load	40000 N
Contact pressure	0.566 MPa
Number of deflections measuring geophones	8
Radial distance of Geophones (mm)	0 300 600 900 1200 1500 1800 2100
Measured deflection (mm)	Normalized deflection as mentioned in table.
Poisson's ratio values	0.5, 0.4, 0.4 (Bituminous layer, granular layer and Subgrade respectively)

Table 5: Elastic Modulus range for pavement layers as per IRC 115-2014

Layers	**Lower Limit**	**Upper limit**
Bituminous layer	750 MPa	3000 MPa
Granular layer	500 MPa	1000 MPa
Sub-grade	20 MPa	100 MPa

Table 6: Back-calculated elastic modulus of pavement layers

Chainage (km)	Back-calculated elastic modulus before correction (Mpa)			Elastic modulus after correction (Mpa)		
	Bituminous layer	Granular layer	Sub-grade	Bituminous layer	Granular layer	Sub-grade
7.900	750	100	86.2	605.57	72.93	74.18
7.400	969.9	110.9	100	783.12	85.39	86.65
6.900	2903.2	479.3	100	2344.12	382.79	86.65
6.400	1354.8	286.9	100	1093.90	246.70	86.65
7.900	**785.2**	100.4	99.8	751.50	73.40	86.47
7.650	2872.4	486.7	100	2749.10	387.56	86.65
7.400	2986.8	498.8	99.8	2858.59	395.30	86.47
7.150	811.6	113.3	100	776.76	88.07	86.65
6.900	2982.4	498	99.7	2854.38	394.79	86.38
6.650	963.3	123.1	100	921.95	98.79	86.65
6.400	2454.5	468.7	100	2349.14	375.91	86.65
7.900	776.4	146.9	99.9	577.14	123.59	86.56
7.400	2942.8	491.8	100	2187.56	390.83	86.65
6.900	756.6	103.5	80.5	562.43	76.98	68.90
6.400	2993.4	498.4	100	2225.17	395.05	86.65

4.1.5. Remaining life

According to IRC:115-2014 guidelines, 15th percentile moduli (table 7) are used to calculate remaining life of existing pavement in terms of fatigue and rutting life as given in equation 1 and 2 respectively.

Fatigue criteria for bituminous layer,

Nf= 0.711 x 10-4x(1/Ɛt) ^3.89x(1/MR) ^0.854 _equation 1.

Rutting criteria for subgrade layer,

N = 1.14 x 10-8 x (1/Ɛ) ^3.89 _equation 2.

Table 7: 15th percentile elastic modulus values for Bituminous layer, Granular layer and subgrade.

Bituminous layer	Granular layer	Sub-grade
780.91 MPa	107.37 MPa	80.85 MPa

Tensile srain at bottom of bituminous layer and horizontal strain at upper layer of subgrade are used to calculate fatigue and rutting life. IIT-PAVE software is used to compute these strain values as shown in table 9. Following input parameters are required by IIT-PAVE as given in table 8.

Table 8: Input parameters for IIT-PAVE

Parameters	Values
Number of layers	3 or 4
Elastic modulus (MPa)	As per table 7
Poisson's ratio	0.5, 0.4, 0.4
Thickness of layers (mm)	As per table 3
Single wheel load, Tyre pressure (kpa)	20000, 0.566
For bituminous mix	3000Mpa, VG-40 @ 350C (table 7.1 of IRC:37-2012)

Table 9: Remaining life of existing pavement

Design traffic	Chainage (KM)		Tensile strain from IITPAVE (in micron)	Horizontal strain from IITPAVE (in micron)	Remaining fatigue life (in MSA)	Remaining rutting life (in MSA)	Remarks
	From	To					
45 MSA	7.400	7.900	221.7	251.5	39.5	293.8	Unsafe
	7.600	7.900	302.1	306.5	15.2	119.8	Unsafe

4.1.6. Propose Overlay thickness as per IRC:115-2014

The combination of existing pavement and overlay will be analyzed as a four-layer system to ensure that fatigue and rutting criteria are satisfied for the design traffic. Trial overlay thickness are selected and tensile strain at bottom of the existing bituminous layer and horizontal strain at top of subgrade layer has been computed using the thickness and moduli of various layers as inputs in IIT PAVE. Proposed overlay thickness mentioned in table 10.

Table 10: Overlay thickness and Remaining life

Chainage (KM)		After Overlay				Overlay thickness in terms of BC	Remarks
From	To	Tensile strain from IITPAVE (in micron)	Horizontal strain from IITPAVE (in micron)	Remaining fatigue life (in MSA)	Remaining rutting life (in MSA)		
6.400	7.900	157.2	180.8	47	1312	60 mm	3000 Mpa, VG-40 @350C
7.600	7.900	158.6	179.4	46	1359	105 mm	

4.2. BBD SURVEY

The deflection in the pavement is measured using BBD technique. The procedure followed is as per IRC:81-1997. Digital dial gauge which shows direct deflection reading has been used for the experiment. All the necessary data like pavement temperature, soil type, moisture content, etc. were collected during testing. The track placed at above 0.6m offset and reading were taken for every 25m in. The readings are mentioned in table 11.

Soil: Clay

Moisture content: 7%

Temperature: 27°C

Annual rainfall: less than 1300mm

Classification of road: NH

Table 11: Benkelman beam deflection data and characteristics deflection

Chainage (KM)	Dial gauge reading (mm)			Average deflection	Corrected deflection	Characteristic deflection
	Initial	Intermediate	Final			
7.600	10.089	10.032	10.006	0.31732	0.556248	2.51*
7.625	10.044	9.993	9.912	0.73542	1.141588	
7.650	10.023	9.915	9.875	0.5288	0.85232	
7.675	10.177	9.963	9.912	0.82682	1.269548	
7.700	10.229	9.719	9.668	1.41882	2.098348	
7.725	10.000	9.904	9.815	0.88798	1.355172	
7.750	10.280	9.726	9.683	1.44426	2.133964	
7.775	10.000	9.965	9.912	0.48446	0.790244	
7.800	10.000	9.964	9.915	0.45518	0.749252	
7.825	10.120	10.087	10.045	0.39444	0.664216	
7.850	10.149	9.554	9.512	1.51844	2.237816	

* Being NH Characteristics deflection = Mean deflection +2*Standard Deviation

4.2.1. Proposed Overlay thickness as per IRC:81-1997

An overlay thickness is taken from curves given in fig 9 (in IRC:81-1997) on the basis of characteristics deflection and design traffic as mentioned in table 12.

Table 12: Overlay thickness

Design Traffic	Chainage (KM)		Overlay thickness (mm)	
	From	To	BM	BC/DBM
	7.600	7.900	220	154

5. Conclusion

1. Remaining life of existing pavement is lower than design traffic therefore an overlay is required to carry design traffic in future.
2. The overlay thicknesses in terms of BC/DBM were found, it is 60mm from FWD results for stretches starts from chainage km 6.400 to end at chainage km 7.900 and 105mm for stretches from chainage km 7.600 to km 7.900.
3. An overlay thickness was also computed for stretches from chainage km 7.600 to km 7.900 on the basis BBD results. It is 154mm in terms of BC/DBM. Which is much more than overlay thickness from FWD results.
4. BBD technique is required more time and more manpower because it is totally manually operated, whereas FWD is software-based technique. BBD is labour intensive and more time consuming

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