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Structural Evaluation of Flexible Pavement using Falling Weight Deflectometer

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Abstract—This In recent years, one of the non-destructive test method to evaluate pavements is Falling Weight Deflectometer (FWD) method. In order to provide high quality and consistent material stiffness data for the Mechanistic-Empirical Pavement Design the deflection results obtained at radial distance in between 0 and 1800 mm, through geophone in FWD is highly useful. The main objectives of this study are to analyse the FWD test results of flexible pavement in NH-8 it starts from Kamrej 0.000 Km and ends at Chalthan 16.350 Km, to forecast the pavement structural capacity and subsequent overlay design. Collected data comprises, FWD deflection basin, test pit data and pavement condition survey, classified volume survey and weather data. These surface deflections basins are later used to evaluate the structural capacity of the existing pavement. KGPBACK was used for back-calculation.

***Keywords*— Structural Evaluation, Falling Weight Deflectometer, Overlay Design, Flexible Pavement, KGPBACK Software, IITPAVE.**

I. INTRODUCTION

Proper evaluation of the present structural strength condition of existing pavements is critical. This can be accomplished using non-destructive testing device that is Falling Weight Deflectometer. The subsequent deflection basin is measured by a series of sensors. Pavement deflection measurements are the primary means of evaluating a flexible pavement because the magnitude and shape of pavement deflection is a role of traffic. Deflection measurements can be used in backcalculation methods to determine bituminous, granular and subgrade modulus of elasticity.

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". 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 using backcalculation procedures with the help of mechanistic structural models. Once the pavement layers are characterised in terms of their present resilient moduli, overlays can be designed using empirical mechanistic procedures.

II. STUDY AREA LOCATION

The selected study stretch is on NH-8. Starts from Kamrej chainage 0.000 km and ends at Chalthan chainage 16.350 km. the structural condition evaluations and subsequent overlay thickness design is carried out. Total length of study stretch is 16.350 km. Figure 1 shows the map view of study area. This highway is a part of golden quadrilateral. The area under study is located in surat district of Gujarat state.

III. DATA COLLECTION

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

- Pavement condition survey
- Falling weight deflectometer(FWD) survey
- Pavement layer types and thickness composition
- Classified volume count

A. Pavement condition survey

Visual observation survey of the existing pavement was carried out. Each lane of the carriageway and shoulder should be divided separately into blocks of 50 m length and one lane width i.e. 3.5 m and distress recorded for each block. Similarly, cracking, rutting and other distress also recorded for each block sub section. The format for pavement condition survey for identifying sections of uniform performance is as per appendix-I in IRC:115-2014. Weightage for each type of distress is as per weightage of highways given in IRC:82-2015. As a result of the pavement condition survey mentioned in Table 1 shows that the pavement is in good condition

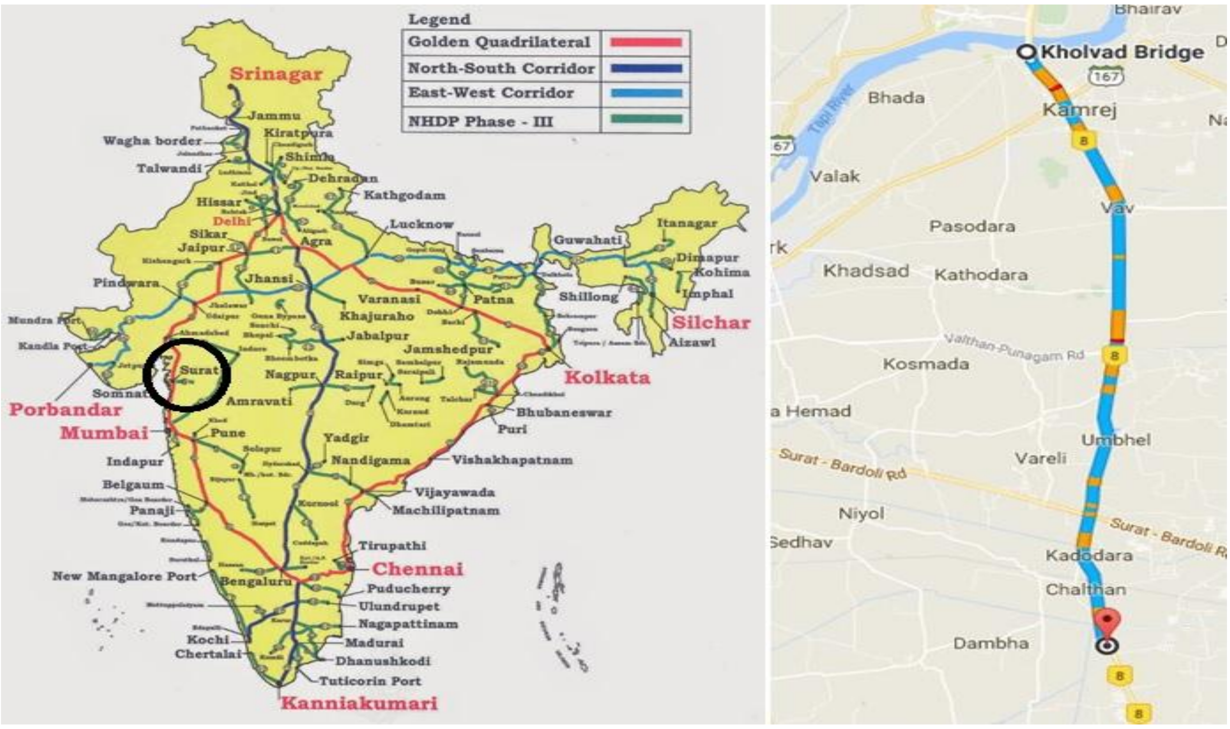


Figure 1 : Study Area Location

Table 1 : Result of Pavement Condition Survey

Distress Type	Input (%)	Rating as Per Norms	Weightage	Weighted Rating Value
Cracking (%)	0.78	2.9	1.00	2.9
Ravelling (%)	0.31	2.7	0.75	2.0
Potholes (%)	0.22	1.9	0.50	0.9
Shoving (%)	0.33	1.8	1.00	1.8
Patching (%)	0.7	2.3	0.75	1.7
Settlements (%)	0.2	2.8	0.75	2.1
Rut Depth (%)	0.1	3.0	1.00	3.0
Final Rating				2.1
Condition				Good

B. Falling Weight Deflectometer survey

For the purpose of conducting FWD survey on the study area, Dynatest FWD 8082 was used. The result of pavement condition survey states that pavement is in good condition, in order increase the reliability of the data collection it was assumed that pavement is in fair condition as per Table-1 of IRC:115-2014 mentioned as Table 2. The area under study is four lane divide carriageways so the measurement scheme given for each carriageway and fair condition of pavement are mentioned in Table 3.

Table 2 : Criteria for Classification of Pavement Sections

Classification	Pavement Condition
Good	Isolated cracks of less than 3.0 mm width in less than 5% area of total paved surface AND average rut depth less than 10 mm.
Fair	Isolated or interconnected cracks of less than 3.0 mm width in 5 to 20% area of total paved surface AND/OR average rut depth between 10 to 20mm.
Poor	Wide interconnected cracking of more than 3.0 mm width in 5 to 20% area (include area of patching and raveling in this) of paved area OR cracking of any type in more than 20% area of paved surface AND/OR average rut depth of more than 20 mm.

Table 3 : Spacing (meter) between two test points along outer wheel paths

Shoulder Lane	Outer Lane	Inner Lane
260	65	130

Table 4 : Deflection Measurement Scheme (IRC:115-2014)

Type of Carriageway	Recommended Measurement Scheme	Maximum Spacing for Test points along selected wheel path for pavements of different classification (meters)		
		Poor	Fair	Good
Four lanes Dual (Divided) carriageway (Measurement Scheme given for each carriageway)	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 centreline of the paved shoulder	120	260	500

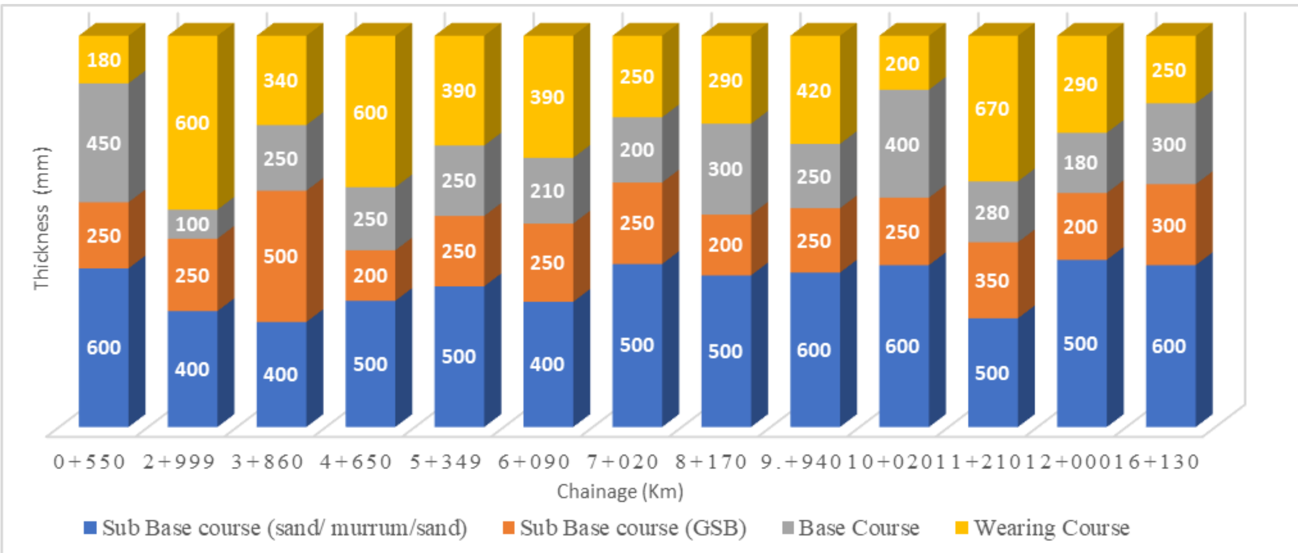
FWD tests were conducted at above mentioned intervals. The Deflection was measured in mm at standard configuration of geophones placed radially at 0 mm (D_1), 200 mm (D_2), 300 mm (D_3), 450 mm (D_4), 600 mm (D_5), 900 mm (D_6), 1200 mm (D_7), 1500 mm (D_8), and 1800 mm (D_9) respectively, starting from the centre of the loading plate. The Pavement temperature was collected at every half an hour during the testing. Total 335 deflection point reading was taken for 16.350 km length excluding bridges and cross drainage structure. Table 5 Shows the sample data collected.

Table 5 : Data Collected from FWD survey

Chainage in Kilometre	D_1 0 mm	D_2 200 mm	D_3 300 mm	D_4 450 mm	D_5 600 mm	D_6 900 mm	D_7 1200 mm	D_8 1500 mm	D_9 1800 mm	Pavement Temperature
0.08	0.232	0.211	0.197	0.177	0.156	0.120	0.093	0.073	0.057	37
0.104	0.239	0.218	0.204	0.183	0.161	0.124	0.096	0.075	0.058	33
0.165	0.264	0.225	0.197	0.165	0.139	0.100	0.073	0.055	0.045	34
0.230	0.360	0.306	0.265	0.216	0.175	0.118	0.081	0.059	0.046	34
0.233	0.238	0.203	0.177	0.149	0.125	0.090	0.066	0.050	0.040	33

C. Pavement layer types and thickness composition

Cut the road section is the best way to know the pavement layer thickness and composition. Test pits of 1.2 m x 1.2 m is excavated up to depth of 1.5 m at 13 locations along the study stretch. The test pits are excavated along the outer lanes starting from the outside edge of the outer lane in the earthen shoulders exposing pavement layers sufficiently to note the condition and thickness of each layer. Graph 1 shows the data of test pits. There is wide variation in layer thickness along the length of road.



Graph 1 : Test Pit Data

D. Classified volume count

The commercial vehicle per day counted from 24 hours and 7 days classified volume count. Table 6 shows the classified volume count for seven days with average value. The cvpd taken for design is 6500(roundup).

Table 6 : cvpd Calculation for 7 Days

Date	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Average
cvpd	4058	7582	6624	5302	7218	7521	7052	6480

IV. Data Analysis

Measured surface deflections is normalized to a standard load of 40 kN, in addition to other inputs such as radial distances at which deflections are measured, contact pressure, layer Thicknesses, E moduli upper and lower boundary value of different layers, applied peak, Poisson's ratio, are used to backcalculate the elastic moduli of different layers of the existing pavement using an appropriate backcalculation technique. KGPBACK program is used for backcalculation of moduli. The backcalculated E moduli is subjected to temperature and seasonal correction, the E moduli after temperature correction is shown in Table 7 (sample). Seasonal correction is not applied to data because the data collection is done in monsoon season when the subgrade is in weakest condition.

Table 7 : E moduli After Temperature Correction

Chainage km	E Bituminous MPa	E Granular MPa	E Subgrade MPa
0.080	3265.35	425.7	99.8
0.104	2745.64	389.0	98.7
0.165	2706.99	436.3	100.0

A. Identification of homogeneous section

Calculation of the remaining life of pavement and the strengthening requirement in terms of bituminous overlay will be done on the basis of the back calculated Moduli of pavement layers, it is wise to find homogeneous sections for the Determination of structural design. However, as variation in crust composition noticed was major, so it was decided to carry out homogeneous section based on test pit data. The homogenous section was mentioned in Table 8.

As there are multiple data points in each homogeneous design sections, multiple E values are there for each section. IRC: 115 -2014 mandates to use 15th percentile E values for each section in order to have safe design.15th percentile of corrected E values of BT layer is mostly towards the higher end of input range of 750 MPa to 3000 MPa and same is true for 15th percentile E values of Granular and Subgrade layer. This suggest that together the high values of existing crust thickness and the deflection data may warrant only functional overlay. So, need to restrict the E bituminous to 1500 MPa if greater than 1500 MPa as per IRC:115-2014 appendix-iii.8.4. Section wise 15th percentile E bituminous values restricted to 1500 MPa along with E granular and E subgrade are given in Table 8.

Table 8 : Homogeneous Sections

Section No.	Homogeneous section Design Chainage (Km)		Length (Km)	Bituminous Thickness (mm)	Granular Thickness (mm)	E1 MPa Bituminous	E2 MPa Granular	E3 MPa Subgrade
	From	To						
1	0.100	0.600	0.500	180	450	1500	162.88	98.93
2	2.230	2.970	0.740	600	100	1500	462.75	99.80
3	3.830	3.940	0.110	340	750	1500	495.06	99.80
4	3.941	4.990	1.049	600	450	1500	443.59	99.80
5	4.991	5.954	0.963	390	500	1500	486.36	99.80
6	5.955	6.991	1.036	390	460	1122	397.38	99.80
7	6.992	7.370	0.378	250	450	1500	360.42	99.80
8	8.060	9.000	0.940	290	500	1338	489.52	99.80
9	9.700	10.060	0.360	200	650	1500	491.24	99.80
10	11.200	12.270	1.070	290	380	1500	489.25	99.75
11	14.000	14.980	0.980	250	600	1500	493.54	99.85
12	15.900	16.350	0.450	250	600	1159	164.72	99.78

B. Remaining life of pavement

The residual life of pavement is calculated using the rutting and fatigue model. Certain parameters are being used to calculate remaining life of pavement i.e. Pavement layer modulus, thickness and Poisson ratio of each pavement layer exist on road, tyre load and tyre pressure, fatigue and rutting point depth of analysis. The compressive strain at the top of subgrade and tensile strain at the bottom of bituminous layer are calculated using IITPAVE software, at critical depth and radial distance is shown in Table 9.

Table 9 : Remaining Life of Pavement

Section no.	M_R	ε_t in micron	ε_z in micron	Fatigue Life in msa	Rutting Life in msa
1	1500.000	237.50	183.80	17.304	1217.744
2	1500.000	36.85	59.82	24324.606	197574.344
3	1500.000	65.4	38.71	2636.504	1421363.638
4	1500.000	29.70	36.27	56294.385	1909406.338
5	1500.000	55.64	51.73	4897.019	381790.254
6	1122.040	71.03	100.20	2426.911	19058.342
7	1500.000	71.01	65.71	1896.072	129069.411
8	1338.300	87.07	108.30	945.593	13397.510
9	1500.000	88.99	58.85	788.044	212774.488
10	1500.000	60.71	110.00	3488.232	12484.096
11	1500.000	70.93	54.72	1904.404	295928.089
12	1159.910	186.60	114.40	55.081	10450.403

C. Design traffic

Commercial vehicle per day is calculate for 7 days and 24 hours as shown in Table 6 average cvpd is 6500 (roundup). The traffic at the end of construction of road is calculated using the formula:

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

Where,

A= Future traffic after construction period

x = construction period in years = 2 years

P = present traffic in cvpd = 6500

$$A=6500*(1+0.05)^2$$

$$A=7166.25;\ \text{say } A = 7200 \text{ cvpd}$$

The design traffic in terms of the million standard axles to be 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.

Table 10 : Design Traffic Parameters

Lane Distribution Factor (D)	0.75
Initial Traffic (A)	7200
Traffic growth rate (r)	5 %
Design life in years (n)	9
Terrain	Plain
Vehicle damage factor (F)	4.5

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

$$N = \frac{365*[(1+0.05)^9-1]}{0.05}*7200*0.70*4.5\ ;\ N = 98 \text{ msa}$$

To increase the reliability of data acquired, it was assumed that design traffic will be 100 msa instead of 98 msa. So according to the design traffic section number 1, and 12 fails in fatigue life. Those section which are fail in either rutting or fatigue needs to be overlay of suitable thickness.

V. OVERLAY DESIGN

The allowable strain is to be calculated. Tensile strain at the bituminous layer bottom is given by Equation 3 and the compressive subgrade strain on the subgrade top is given by Equation 4 are considered as important parameters for pavement design to limit fatigue and rutting in the bituminous layers and non-bituminous layers respectively. Table 11 shows the computed strain using Equation 3 and 4 respectively.

$$N_f = 0.711*10^{-04}*[1/\mathcal{E}_t]^{3.89}*[1/M_R]^{0.854} \quad \ldots\ldots\ldots\ldots (3)$$

$$N = 1.41*10^{-08}*[1/\mathcal{E}_v]^{4.5337} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

Table 11 : Allowable Strain in micron

Section no.	Design MSA	M_R	Fatigue in micron	Rutting in micron
1	100	1500.00	151.2923	318.9973
2	100	1500.00	151.2923	318.9973
3	100	1500.00	151.2923	318.9973
4	100	1500.00	151.2923	318.9973
5	100	1122.04	151.2923	318.9973
6	100	1500.00	161.2489	318.9973
7	100	1338.30	151.2923	318.9973
8	100	1500.00	151.2923	318.9973
9	100	1500.00	151.2923	318.9973
10	100	1500.00	151.2923	318.9973
11	100	1159.99	151.2923	318.9973
12	100	1500.00	160.0781	318.9973

As per IRC:87-2013, the thickness of bituminous overlay for pavement strengthening shall not be less than 50 mm bituminous concrete, after attending to the requirements of profile corrective course if any. As minimum overlay of 50 BC is required for strengthening section as per IRC SP: 84 – 2014, it is now required to check the Fatigue Strain & Rutting strain at critical locations and compare the same with allowable strains for each section. IITPAVE software is used for the purpose of calculating tensile strain(Єt) at the bottom of bituminous layer and the compressive subgrade strain(Єv) at the top of subgrade. Here combining in-service pavement with functional overlay of 50 BC is taken as a 4-layer system. The modulus value of the bituminous overlay material may be selected as per the guidelines given in IRC: 37-2012 (Table 7.1) is 3000 MPa for 35-degree centigrade temperature and BC and DBM material overlay. Poisson ration for Bituminous layer is considered 0.5 and for other layers 0.4. The maximum strain was adopted to compare with allowable strain. Table 12 shows the comparison of allowable strain and computed strain from IITPAVE software at critical location.

Table 12 : Comparison of Allowable and Computed Strain

From km	To km	Fatigue Strain from IITPAVE in micron	Allowable Fatigue Strain in micron	Rutting Strain from IITPAVE in micron	Allowable Rutting Strain in micron	Fatigue	Rutting
0.100	0.600	173.5	151.2923	139.5	318.9973	Unsafe	Safe
2.230	2.970	31.88	151.2923	51.89	318.9973	Safe	Safe
3.830	3.940	50.38	151.2923	33.85	318.9973	Safe	Safe
3.941	4.990	25.16	151.2923	31.94	318.9973	Safe	Safe
4.991	5.954	44.12	151.2923	48.33	318.9973	Safe	Safe
5.955	6.991	55.68	161.2489	55.31	318.9973	Safe	Safe
6.992	7.370	89.05	151.2923	117.0	318.9973	Safe	Safe
8.060	9.00	66.24	151.2923	57.37	318.9973	Safe	Safe
9.700	10.060	94.81	151.2923	55.01	318.9973	Safe	Safe
11.200	12.270	65.56	151.2923	110.1	318.9973	Safe	Safe
14.000	14.980	73.31	151.2923	51.97	318.9973	Safe	Safe
15.900	16.350	139.5	160.0781	110.5	318.9973	Safe	Safe

The section from 0.100 to 0.600 has tensile strain greater than the allowable tensile strain. Hence functional overlay is not sufficient enough as it shall result in fatigue failure. As minimum thickness of single layer is of 50 mm, next iteration is carried out for this section with structural overlay thickness of 60, 65, 70 and 75 mm. It was found to be safe at 75 mm overlay. Table 13 shows the comparison of allowable and computed strain for 75mm overlay thickness.

Table 13 : Thickness Revision For 0.100 To 0.600 Section

From km	To km	Fatigue Strain in micron	Allowable Fatigue Strain in micron	Rutting Strain in micron	Allowable Rutting Strain in micron	Fatigue	Rutting
0.100	0.600	149.000	151.292	125.0	318.997	Safe	Safe

VI. CONCLUSION

This paper presented partial findings from a recently completed study at Kamrej-Chalthan section of NH-8 for structural evaluation of flexible pavement using falling weight deflectometer. Total 16.350 km section is selected for study. FWD tests were conducted on these road segments to determine the structural conditions of the existing pavement. Accordingly, assessment the structural conditions of existing pavements and subsequently recommend required thickness values from FWD-based critical pavement responses computed and compared to computed values for the pre-established fatigue and rutting damage models. The M-E overlay design method successfully identified structural deficiencies in the original pavement configurations through FWD and resulted in reliable overlay solutions. After providing functional overlay of 50 mm, both tensile strain and vertical strain are less than the allowable strain. Hence for all these sections a functional overlay of 50 mm is sufficient except section starts from 0.100 km and ends at 0.600 km which requires 75 mm overlay thickness. Summary of proposed overlay is given in Table 14.

Table 14 : Proposed Overlay Thickness

Section no.	From Km	To Km	Proposed Overlay Thickness (mm)
1	0.100	0.600	75
2	2.230	2.970	50
3	3.830	3.940	50
4	3.941	4.990	50
5	4.991	5.954	50
6	5.955	6.991	50
7	6.992	7.370	50
8	8.060	9.000	50
9	9.700	10.060	50
10	11.200	12.270	50
11	14.000	14.980	50
12	15.900	16.350	50

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