

Flexible Pavement Overlay Design Using Cumulative Difference Approach of Homogeneous Section

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Abstract—The large amount of data commonly used to characterize the pavement surface and structural conditions. Road measured data become useful information only if treated in order to match each section with statistically meaningful values. While a large number of observations along the length of a road allow a better quantification of the expected value and variance of a parameter, basing a design on an average parameter along the project length will typically be uneconomical and less reliable. Therefore, pavement surface and structural condition data along a project length needs to be delineated into uniform sections. The main objectives of this paper are to analyse the FWD test results of flexible pavement (NH-8 starts from Kamrej 0.000 Km and ends at Chalthan 16.350 Km) and 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. Cumulative difference approach (CDA) for identification of homogeneous sections suggested in the AASHTO Guide for Design of Pavement Structures were incorporated to address delineate homogeneous sections, on the basis of surface curvature index. These surface deflections basins are later used to evaluate the structural capacity of the existing pavement. KGPBACK was used for back-calculation.

Keywords— Falling Weight Deflectometer, Structural Evaluation, Cumulative Difference Approach, KGPBACK Software, IITPAVE Software.

I. INTRODUCTION

The identification of sections of uniform performance was done primarily to select an appropriate sample size for conducting deflection testing. Since the assessment of the remaining life of existing pavement and the strengthening requirement in terms of bituminous overlay will be done on the basis of the backcalculated moduli of in-service pavement layers, it is prudent to identify homogeneous sections for the purpose of structural design primarily based on deflection bowl parameters and other relevant information. Identification of homogeneous sections is generally done on the basis of the following parameters: - peak deflections or peak deflection bowl parameters, subgrade strength, design traffic, layer thicknesses and extent and severity of distress, backcalculated surface modulus of the total bituminous layers, remaining life of pavement and overlay thickness requirement. In this paper the deflection bowl parameters, Surface Curvature Index (SCI) calculated as the difference between D_0 and D_{300} where D_0 , and D_{300} are the peak deflections (mm) measured at the centre of loading plate and at a radial distance of 300 mm is a bowl shape parameter, which reflects the contribution of upper layers, along with other parameters, for identification of homogeneous sections. SCI is expressed in mm here whereas the parameter is used in inches or mils in many empirical expressions available in literature for empirically estimating moduli of layers.

A statistical technique popularly used for identification of homogeneous sections is the "Cumulative Difference" approach in IRC:115-2014 and AASTHO- Guide for Design of Pavement Structures (1993). This approach is already being used extensively in India in many highway projects. In this approach, the sequence of actual cumulative sums in a measurement series is compared with the sums that would have resulted from adding averages. The difference between these values is termed as cumulative difference. The series of cumulative differences (z_k) for the measured sequence of a given variable 'x' (SCI, subgrade strength, etc.) can be obtained using the following expressions.

$$Z_k = \sum_{i=1}^{i=k} (xi - k\bar{x}) \dots \dots \dots (1)$$

For all $k = 1, 2, 3, \dots \dots \dots n$

$$\bar{x} = \left(\frac{1}{n}\right) \sum_{i=1}^{i=n} xi \dots \dots \dots (2)$$

Wherever the trend changes from positive to negative and vice-versa in the plot of cumulative difference VS distance (or number of test location), that should be considered as a possible delineator for identifying homogeneous sections. However, judgment has to be applied for considering a particular change in trend to be significant enough to suggest the presence of a delineator there

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.

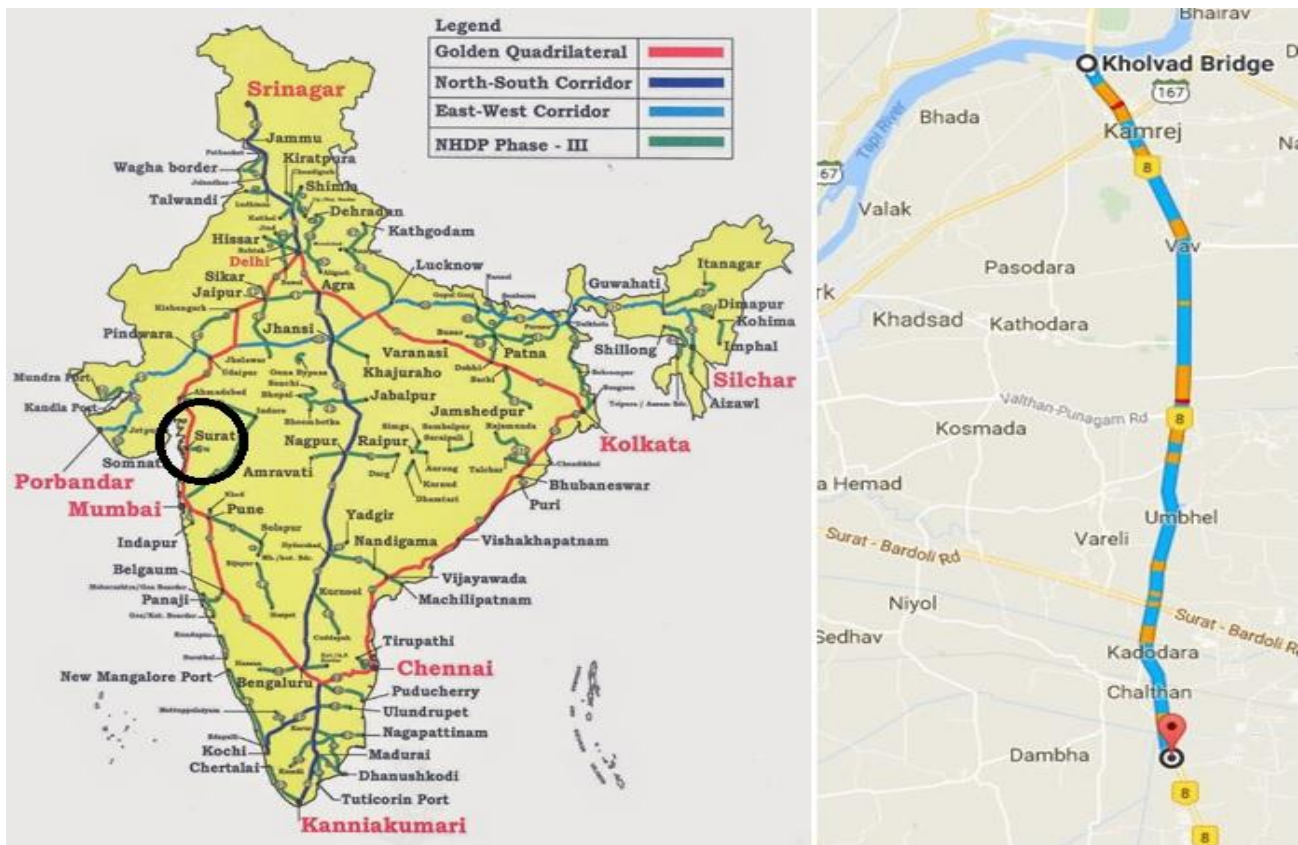


Figure 1(a) Major NH in India with Golden Quadrilateral

(b) Study Stretch Kamrej To Chalthan

III. DATA COLLECTION

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

1. Pavement Condition Survey
2. Falling Weight Deflectometer (FWD) Survey
3. Pavement Layer Types and Thickness Composition
4. Classified Volume Counts

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 the pavement is in good condition.

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 to increase the reliability of the data collection it was assumed that pavement is in fair condition as per IRC:115-2014 mentioned in Table 2. The area under study is four lane divided 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 : Deflection Measurement Scheme (IRC:115-2014)

Type of Carriageway	Recommended Measurement Scheme	Maximum Spacing (m) for Test points along selected wheel path for pavements of different classification		
		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

Table 4 : Spacing (m) between two test points along outer wheel paths

Shoulder Lane	Outer Lane	Inner Lane
260	65	130

FWD tests were conducted at above mentioned intervals. The Deflection was measured in mm at standard configuration of geophones placed radially at 0 mm (D₁), 200 mm (D₂), 300 mm (D₃), 450 mm (D₄), 600 mm (D₅), 900 mm (D₆), 1200 mm (D₇), 1500 mm (D₈), and 1800 mm (D₉) 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.

Table 5 : FWD Survey Data

Chainage in Kilometre	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	D ₈	D ₉	Pavement Temperature in °C
	0 mm	200 mm	300 mm	450 mm	600 mm	900 mm	1200 mm	1500 mm	1800 mm	
1.011	0.344	0.295	0.254	0.206	0.164	0.109	0.075	0.054	0.042	35
1.013	0.331	0.265	0.223	0.178	0.145	0.104	0.078	0.061	0.051	35
1.078	0.288	0.247	0.213	0.173	0.137	0.091	0.062	0.045	0.035	35
1.143	0.448	0.382	0.326	0.262	0.207	0.136	0.093	0.067	0.052	35
1.145	0.358	0.315	0.276	0.231	0.187	0.126	0.088	0.065	0.050	35

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. Figure 2 shows the data of test pits. There is wide variation in layer thickness along the length of road. The total thickness almost uniform.

D. Classified volume count

The commercial vehicle per day obtained 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.

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

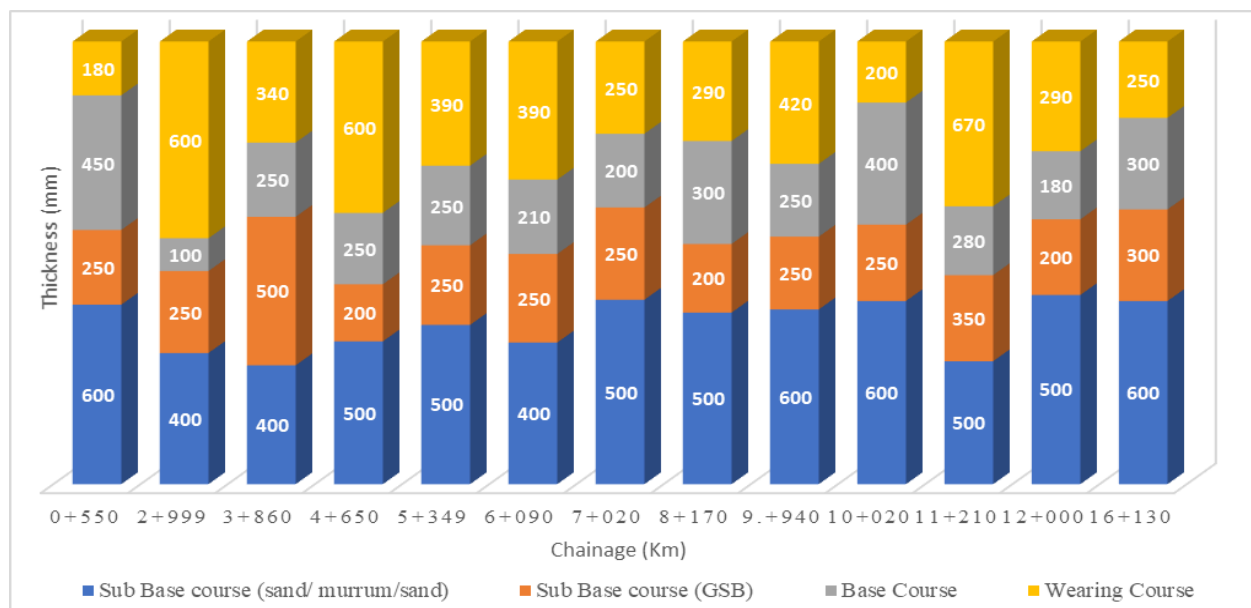


Figure 2 : Test Pit Data

IV. DATA ANALYSIS

According to IRC:115-2014, 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 for Bitumen, Granular and Subgrade. 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
1.011	754.4	102.7	99.6
1.013	750.0	109.0	100.0
1.078	758.8	341.6	99.8
1.143	752.2	101.2	92.1
1.145	772.0	100.0	99.5

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, homogeneous section is identified on the basis of Cumulative Difference Approach (CDA) method using Surface Curvature Index (SCI) Firstly, the SCI value for each deflection point is to be calculated by the equation 3 Sample of the calculation is given in Table 8 for some deflection point.

$$SCI = D_0 - D_{300} \dots\dots\dots (3)$$

Table 8 : SCI Value Calculation

Chainage in meter	0 mm (D ₀)	300 mm (D ₃₀₀)	SCI value
1.011	0.344	0.254	0.090
1.013	0.331	0.223	0.108
1.078	0.288	0.213	0.057
1.143	0.448	0.326	0.122
1.145	0.358	0.276	0.082

In the Cumulative Difference Approach (CDA) method,

$$Z_X = \sum_{i=1}^n a_i - \frac{\sum_{i=1}^n a_i}{L_p} \sum_{i=1}^n x_i \dots\dots\dots (4)$$

$$a_i = \frac{(r_{i-1} + r_i) * x_i}{2} \dots\dots\dots (5)$$

$$a_i = \bar{r}_i * x_i \dots\dots\dots (6)$$

Where,

n= nth pavement response measurement,

n_t = Total number of pavement response measurement taken in consideration,

r_i = Pavement response value of the ith measurement,

$\bar{r}_i$ = Average of the pavement response values between the (i-1) and ith tests,

L_p = Total project length.

The Z_x is calculated on the basis of the Equation 4,5 and 6 and procedure given in AASHTO's Guide (1993) appendix – j “Analysis Unit Delineation by Cumulative Differences”. The formula and equations are shown in Figure 3 and the sample format of the calculation is given in Table 9.

Col. (1) Station (Distance)	Col. (2) Pavement Response Value (r_i)	Col. (3) Interval Number (n)	Col. (4) Interval Distance (Δx_i)	Col. (5) Cumulative Interval Distance ($\Sigma \Delta x_i$)	Col. (6) Average Interval Response ($\bar{r}_i$)	Col. (7) Actual Interval Area (a_i)	Col. (8) Cumulative Area Σa_i	Col. (9) Z_x Value $Z_x =$ Col. (8) – $F^* \text{ Col. (5)}$
1	r_1	1	Δx_1	Δx_1	$\bar{r}_1 = r_1$	$a_1 = \bar{r}_1 \Delta x_1$	a_1	$Z_{x_1} = a_1 - F^* \Delta x_1$
2	r_2	2	Δx_2	$(\Delta x_1 + \Delta x_2)$	$\bar{r}_2 = \frac{(r_1 + r_2)}{2}$	$a_2 = \bar{r}_2 \Delta x_2$	a	$Z_{x_2} = (a_1 + a_2) - F^*(\Delta x_1 + \Delta x_2)$
3	r_3	3	Δx_3	$(\Delta x_1 + \Delta x_2 + \Delta x_3)$	$\bar{r}_3 = \frac{(r_2 + r_3)}{2}$	$a_3 = \bar{r}_3 \Delta x_3$	$a_1 + a_2 + a_3$	
L_p	r_n	N_t	Δx_{nt}	$(\Delta x_1 + \dots + \Delta x_{nt})$	$\bar{r}_{nt} = \frac{(r_{n-1} + r_n)}{2}$	$a_{nt} = \bar{r}_{nt} \Delta x_{nt}$	$a_1 + \dots + a_{nt}$	$Z_{x_{nt}} = (a_1 + \dots + a_{nt}) - F^*(\Delta x_1 + \dots + \Delta x_{nt})$

$$A_t = \sum_{i=1}^{h_t} a_i$$

$$F^* = \frac{A_t}{L_p}$$

Figure 3 : Tabular Solution Sequence - Cumulative Difference Approach (Source: AASTHO-1993, “Guide for Design of Pavement Structures”)

Table 9 : Z_x Value Calculation

Distance (m)	SCI (r_i)	Interval Number (n)	Interval Distance (Δx_i)	Cumulative Distance ($\Sigma \Delta x_i$)	Average Interval SCI ($\bar{r}_i$)	Actual Interval Area (a_i)	Cumulative Area (Σa_i)	Z_x Value
1011	0.108	26	65.00	509.000	0.099	6.435	71.756	45.474
1013	0.075	27	2.00	511.000	0.091	0.183	71.939	45.553
1078	0.122	28	65.00	576.000	0.098	6.402	78.342	48.600
1143	0.082	29	65.00	641.000	0.102	6.630	84.972	51.873
1145	0.084	30	2.00	643.000	0.083	0.166	85.138	51.936
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
16156	0.031	333	60.00	15654.000	0.030	1.830	808.298	0.0000

The Z_x values are plotted versus distance along the road length and the points where the slope of the Z_x curve changes its algebraic sign are taken as the border line between the consecutive homogeneous sections (AASHTO, 1993). These points have been described as change-points (Brodsky and Darkhovsky, 1993) and are referred to as such in the rest of the paper. According AASTHO Appendix -j a section is said to be homogeneous section when the graph plotted against Z_x value and distance, whenever the slope of the Z_x function changes from negative to positive or vice-versa this concept is used for identification of homogeneous section. Homogeneous section is classified from the Figure 4 is mentioned in Table 10.

Table 10 : Homogeneous Sections

Section No	From (m)	To (m)	Length (m)
1	100	2035	1935
2	2036	5431	3395
3	5432	6155	723
4	6156	6666	510
5	6667	12450	5783
6	12451	14260	1809
7	14261	15246	985

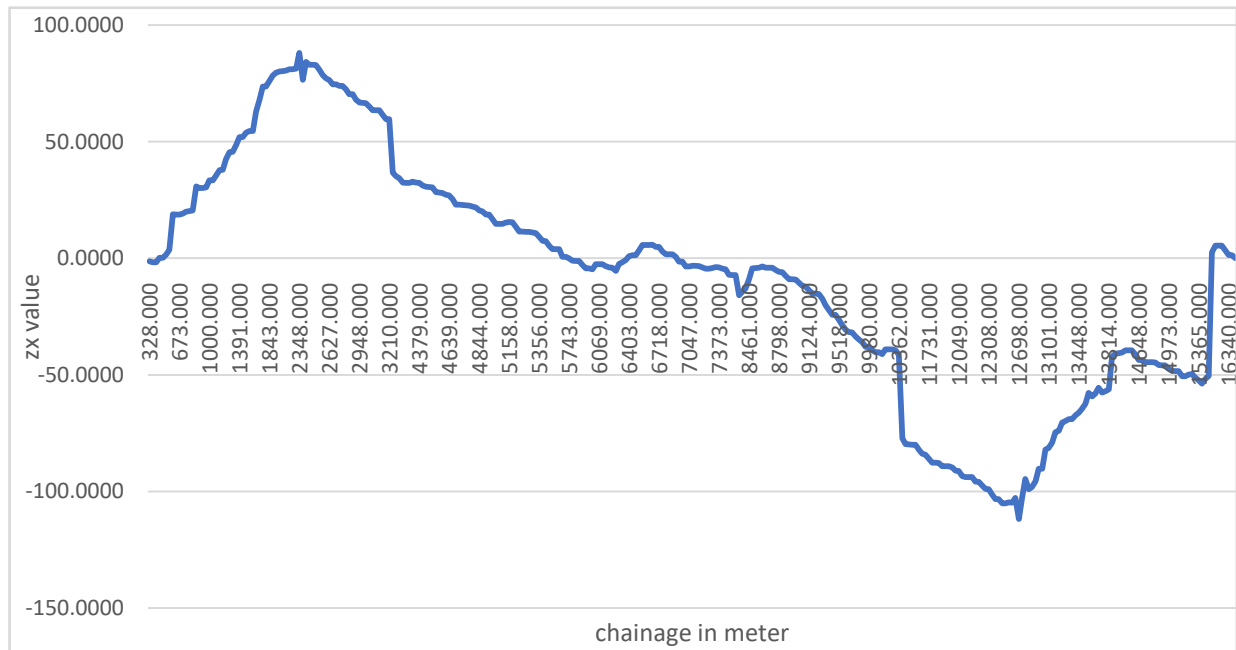


Figure 4 : Zx Value V/S Distance (m)

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 11.

Table 11 : Details of Each Homogeneous Sections

Section No.	Homogeneous section Design Chainage (m)		Length (m)	Bituminous Thickness (mm)	Granular Thickness (mm)	E1 (MPa) Bituminous	E2(MPa) Granular	E3 (MPa) Subgrade
	From (m)	To (m)						
1	100	2035	1935	180.000	450.000	752.200	106.755	99.115
2	2036	5431	3395	340.000	450.000	1500.000	457.000	99.800
3	5432	6155	723	390.000	500.000	934.847	276.540	99.800
4	6156	6666	510	390.000	460.000	973.032	185.200	99.895
5	6667	12450	5783	200.000	450.000	1500.000	489.100	99.800
6	12451	14260	1809	250.000	380.000	1122.000	397.380	99.800
7	14261	15246	985	250.000	600.000	1500.000	360.420	99.800

B. Remaining life of pavement

The residual life of pavement is calculated using the rutting and fatigue model. Certain parameters being used are 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 12.

Table 12 : 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	752.200	417.60	264.90	3.47	1217.744
2	1500	70.42	102.80	1958.62	197574.344
3	934.847	92.09	106.50	1032.93	1421363.638
4	973.032	106.80	118.60	560.88	1909406.338
5	1500	124.40	153.10	214.11	381790.254
6	1045.458	224.20	196.80	29.47	19058.342
7	1500	97.57	61.59	550.87	129069.411

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 8 are considered as per IRC:37-2012 guidelines for road under study.

Table 13 : 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

$$N = \frac{365 * [(1+r)^n - 1]}{r} * A * D * F \dots\dots\dots (8)$$

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 6 fails in fatigue life. Those section which are failed in either rutting or fatigue needs to be strengthened overlay of suitable thickness.

C. Overlay design

The allowable strain is to be calculated. Tensile strain at the bituminous layer bottom is given by Equation 9 and the compressive subgrade strain on the subgrade top is given by Equation 10 are considered as important parameters for pavement design to limit fatigue and rutting in the bituminous layers and non-bituminous layers respectively. The Table 14 shows the computed strain using Equation 9 and 10.

$$N_f = 0.711 * 10^{-04} * [1/\epsilon_t]^{3.89} * [1/M_R]^{0.854} \dots\dots\dots (9)$$

$$N = 1.41 * 10^{-08} * [1/\epsilon_v]^{4.5337} \dots\dots\dots (10)$$

Table 14 : Calculation of Allowable Strain

Section no.	Design msa	M _R	Fatigue in micron	Rutting in micron
1	100	752.200	176.045	318.997
2	100	1500.000	151.292	318.997
3	100	934.847	167.841	318.997
4	100	973.032	166.373	318.997
5	100	1500.000	151.292	318.997
6	100	1045.458	163.771	318.997
7	100	1500.000	151.292	318.997

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(ϵ_t) at the bottom of bituminous layer and the compressive subgrade strain(ϵ_v) 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 15 shows the comparison of allowable strain and computed strain from IITPAVE software at critical location.

Table 15 : Comparison of Allowable and Computed Strain

Section no.	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
1	0.100	0.600	291.50	176.04	193.60	318.9	Unsafe	Safe
2	2.230	2.970	55.11	151.29	55.50	318.9	Safe	Safe
3	3.830	3.940	71.87	167.84	62.74	318.9	Safe	Safe
4	3.941	4.990	84.07	166.37	76.23	318.9	Safe	Safe
5	4.991	5.954	93.55	151.29	124.60	318.9	Safe	Safe
6	5.955	6.991	166.00	163.77	148.50	318.9	Unsafe	Safe
7	6.992	7.370	73.52	151.29	52.16	318.9	Safe	Safe

The section from 0.100 Km to 0.600 Km and section 5.955 Km to 6.991 Km 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 55 mm, 60mm and so on till allowable strain is greater than calculated strain. Table 16 shows the comparison of allowable and computed strain for section 1 and 6.

Table 16 : Comparison of Allowable and Computed Strain for Section 1 and 6

Section no.	From km	To km	Overlay thickness (mm)	Fatigue Strain from IITPAVE in micron	Allowable Fatigue Strain in micron	Rutting Strain from IITPAVE in micron	Allowable Rutting Strain in micron	Fatigue	Rutting
1	0.100	0.600	125	170.20	760.45	139.20	318.99	Safe	Safe
6	5.955	6.991	55	161.30	163.77	145.20	318.99	Safe	Safe

V. 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. Cumulative difference approach is used for identification of the homogeneous section a subsequent overlay design of that sections. 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 and section starts at 5.955 km and ends at 6.991 km which requires 125 mm and 55 mm overlay thickness respectively. Summary of proposed overlay is given in Table 17.

Table 17 : Proposed Overlay Thickness

Section no.	From Km	To Km	Proposed Overlay Thickness (mm)
1	0.100	0.600	125
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	55
7	6.992	7.370	50

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