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ANALYSIS OF THE FLEXIBLE PAVEMENT USING FALLING WEIGHT DEFLECTOMETER FOR INDIAN NATIONAL HIGHWAY ROAD NETWORK

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Abstract

The foremost requirement for developing efficient pavement maintenance and management strategies is to ascertain the properties of the pavement material and its structural capacity. This can be done by studying the response of the pavement to the applied load. In this study, the Falling Weight Deflectometer (FWD) and KGPBACK were used to evaluate the performance of a road section of the National Highway in the state of Haryana in India by studying the deflection in response to the load applied at selected points on the highway. FWD was used to put a dynamic load on existing pavement and the response of the pavement to the load was measured. The deflection values thus obtained were used in the KGPBACK software to determine the elastic moduli of the modelled layers of the pavement. The in-situ elastic moduli obtained were further used in IITPAVE software for overlay design of the pavement. Data obtained from the study was also used as the input parameter in the HDM-4 model to predict the deterioration of the pavement with time due to the prolonged application of traffic loads. The HDM-4 model was also used to check the effect of bituminous overlay maintenance on the distress models and all four distress (cracking, ravelling, rutting and roughness) were found to decrease. Therefore, the study provided in this paper presents a guideline methodology that could be used by administrators in order to estimate when and how much of funding would require to preserve and maintain the Indian Highway road network.

Keywords: pavement, maintenance, deflection, FWD, KGPBACK, HDM-4.

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1. Introduction

Indian government considers road network as critical to the country’s economic and social growth. Due to this, heavy investments have been made in past few years to speed up the development of the road networks in India and today, the Indian road network is one of the largest around the world (Singh and Chopra 2018a). At the same time, it

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is important to note that equal amounts of time and money need to be invested in maintaining, rehabilitating and preventing the deterioration of the existing pavement networks which in turn requires analysis of the pavement structure, performance and capacity(Singh and Chopra 2018b). The most widely used technique of evaluating the pavement performance of Indian roads is the static deflection technique (Reddy and Veeraragavan 1997). However, this empirical approach does not simulate the loads applied by the fast-moving traffic and no measurements of the entire deflection profile is done with this method(Solanki et al. 2015). To overcome the limitations of this method, non-destructive test device such as Falling Weight Deflectometer (FWD) can be used (Chen et al. 1999). FWD is an impulse loading device in which a transient impulse load is applied to the pavement surface and the deflection shape of the pavement is measured by a series of geophones located at different radial distances. This method provides a better characterization of the pavement layers structure condition. The surface deflections obtained from the FWD testing were used to backcalculate in situ material properties using an appropriate analysis technique or software (Kim et al. 2002). One such software is KGPBACK based on the salient features of the genetic algorithm used for back calculation of layer moduli of each pavement layer from the measured deflection basins. In KGPBACK, an iterative technique is used in which deflection value calculated for certain assumed elastic moduli values are compared with the observed deflection values. The estimated deflection values are then adjusted by altering the elastic moduli and the iteration continues until the calculated and observed deflection values match closely. In this manner, the accurate elastic moduli are determined. The elastic moduli of a pavement serve as an important parameter to predict the right overlay design using the IITPAVE software. Further, the data obtained from the study can also be used for predicting the deterioration of the pavement with time due to prolonged application of traffic loads. This can be done using Highway Development and Maintenance (HDM-4), a software developed by the world bank. HDM-4 attempts to build a regression model for the complex interaction between the traffic loading, pavement structure and the environmental conditions for predicting the various types of distress developed in pavement over time(Jain et al. 2005, Deori et al. 2016). As these distresses initiates, develops and progresses in different rates in the different climatic conditions the HDM-4 model needs to be calibrated as per the local conditions(Bannour et al. 2017). This calibrated HDM-4 model can be used by the highway administrators and engineers for developing optimum maintenance and rehabilitation strategies of the pavements.

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2. Test Section Description

The pavement that has been evaluated in this study is a part of the in-service section of National Highway in the state of Haryana, India. This section consists of a two-lane single carriageway flexible pavement of width 7m with a paved/earthen shoulder of 1.5m. Test pits of size (1.0m x 0.6m x 0.6m) were made at the selected points on the highway for determining the thickness of the pavement structure and the pavement was found to comprised of three layers: 200mm bituminous surface, 325mm base/sub-base and sub-grade. The historical data of the pavement rehabilitation measure, traffic etc. were provided by the local government in state of Haryana. The data was taken for identifying the reasons for different modes of distress developed in pavement over time and distress caused due to deficiency in design, poor material selection and improper construction. The pavement was classified into three sections based on the pavement condition described in IRC 115 (2014). The pavements were assigned section ID as H-1, H-2 and H-3 and the inventory details of the sections are shown in Table 1.

Table 1. Inventory details of the selected pavement sections.

Section Name	Length of section(km)	Carriageway width(m)	Pavement Condition	Drainage condition
H-1	3.30	7	Poor	Poor
H-2	3.12	7	Fair	Fair
H-3	5.0	7	Good	Good

Traffic volume count was found out to be 12,541 in terms of Annual Average Daily Traffic (AADT) and the traffic composition were found out to be 39.35% for cars, 0.69% for mini bus, 3.91% for bus, 8.71% for light commercial vehicles, 19.85 for 2-axle trucks, 14.36% for 3-axle trucks, 12.94 % for Multi Axle truck and 0.19% for others (crane, jcb etc.) respectively. Axle load survey was conducted and based on that the design traffic was found out to be 70 msa for construction period of 15 years.

3. Methodology

In our study, rebound deflections were measured using the Falling Weight Deflectometer (FWD) to evaluate the structural properties of the pavement. The deflections calculated were further used in KGPBACK software for iteratively back calculating and determining the elastic moduli for each of the pavement layer. The calculated elastic moduli were finally used for designing the overlay thickness of the pavement using IITPAVE software. The HDM-4 model was then run to predict the deterioration of the pavement with traffic over time.

3.1. Falling Weight Deflectometer

Falling Weight Deflectometer (FWD) is a fully automatic impulse loading device in which transient load is applied on the pavement and the deflected shape of the pavement surface is measured at different radial distances. In this way, FWD simulates the effect of actual traffic induced loads. The principle behind the FWD is that it measures the deflection in a pavement structure under the impact of the vertical load. A weight is dropped onto a set of springs mounted on a 300 mm diameter plate that rests on the pavement surface. The characteristics of the springs are such that the load pulse generated by the falling weight is like the loading of a moving wheel. A load cell that is mounted directly on top of the loading plate measures the load applied on the pavement surface. The deformation of the pavement surface due to the applied load is measured at nine locations by the geophones which are placed at a maximum radius of 2.5m, on the surface of the pavement. The geophones measure the velocity of the pavement during deflection and the deflections are obtained by integration of the recorded signal. The electronic equipment carries out this latter process automatically so that the magnitude of the deflections is recorded directly. A representation of FWD and the deflection basin is shown in Figure 1 and Figure 2 respectively.

Figure 1. Representation of FWD for evaluation of pavement

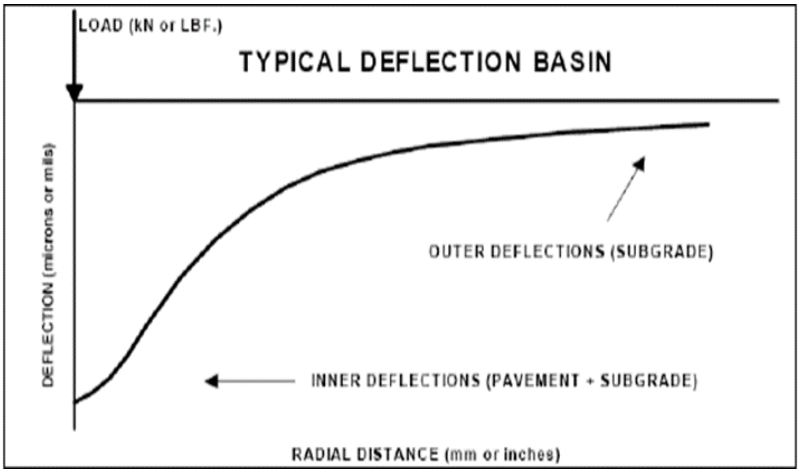

Figure 2. Typical Deflection basin on the selected pavement surface

The deflections measured at 9 geo-phonic sensors are located at 0, 300,450, 600, 900, 1200, 1500, 1800, 2100 µm radial distances, respectively, at the flexible pavement section. The peak load applied on pavement is 40 KN (+/- KN) which corresponds to the loads on one dual wheel sets of 80 KN standard axle load. The FWD was found out to be calibrated for producing accurate and reproducible results as per the guidelines given in IRC 115- 2014. The guidelines for selection of the deflection point along the three homogenous sections were selected based upon the pavement condition data. For H1 section the maximum distance was selected as 60m, whereas for H2 section and H3 section it was 130m, and 500m respectively. It was further ensured that the position of the wheel path was 1.0 m away from the outer edge of the outer lane of the carriageway.

3.1. Analysis of the FWD Data

All test points have been included in a detailed back-analysis procedure to determine the effective stiffness of the various pavement layers. A pavement structure can be satisfactory modelled as a (non-)linear elastic multi-layered structure. This model enables the different pavement layers to be analysed. The sub-grade model allows for a non-linear variation in material stiffness with depth. In addition, the model searches for a depth to a stiff layer below which there is no influence on the measured surface deflections.

3.1.1. Back Calculation Process

KGPBACK which is a specific version of BACKGA program developed by the transportation engineering section at IIT Kharagpur is used for the back-analysis procedure for calculation of the elastic moduli of the pavement surface using the deflection measurements calculated from FWD. This is important for analyzing the structural condition of the in-service pavement. The back-calculation process is primarily used to find out the in situ elastic moduli of different layers of pavement. In this process, the elastic moduli values are assumed to lie within the entered elastic moduli ranges for which deflection values are calculated. These calculated values are compared with the observed deflections, and accordingly the assumed elastic moduli values are further adjusted to a more accurate value for the next iteration and these iterations continues until the calculated and observed deflection values difference becomes predominantly smaller. The process of back calculation is shown explained in the Figure 2. The in situ elastic moduli of individual layer were back calculated along with inputs such as the measured surface deflections, tyre contact pressure, Geophone positions, Poisson’s ratio and range of moduli for each layer as shown in Table 2.

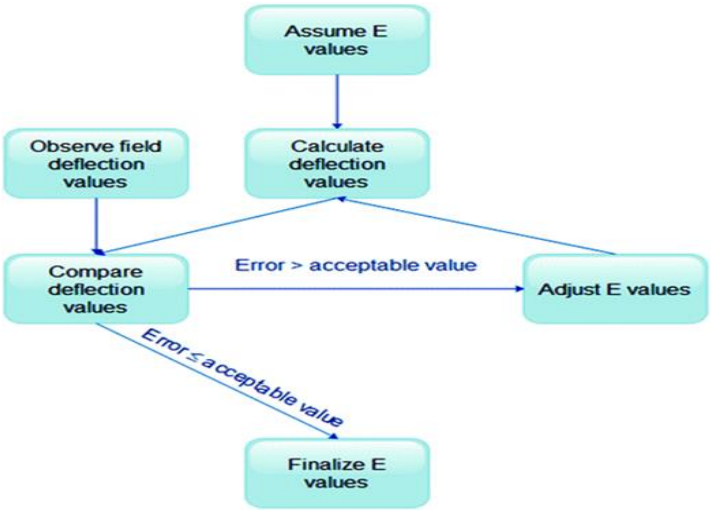

Figure 3. Back calculation process

Table 2. Input Parameters in KGPBACK software

Parameters	Values	
Single Wheel Load (N)	40000	
Contact Pressure (MPa)	0.56 (As per IRC: 115-2014 and IRC 37-2012)	
Number of Deflection Measuring Sensors	9	
Radial distance (mm)	0 300 450 600 900 1200 1500 1800 2100	
Measured Deflection (mm)	Normalized deflection obtained after normalization of field dat.	
Poisson's ratio values	0.5 0.4 0.4 (Bituminous layer, Granular layers & Subgrade as per IRC 115-2014)	
Moduli range of layers	Granular layers (combined)	100 to 500 MPa
	BT Layer-thick layer without much cracking	750 to 3000 MPa
	BT layer in distressed condition (Fair to Poor)	400 to 1500 MPa

The range of the subgrade moduli range is selected by the following equation for the carrying out the back calculation.

Lower Range - 20Mpa
Upper Range –

$$E = 357.87\ x\ DCP^{-0.857} \tag{1}$$

where E_subgrade = backcalculated modulus of subgrade (MPa),
DCP = Dynamic Cone Penetrometer value (mm/blow)

3.2. Application of the FWD Results

Back calculation of FWD data provided quick information on the in situ elastic moduli values of individual layers. These in situ moduli values were further corrected by applying temperature and seasonal corrections to make-up for errors due to variation in climatic conditions as per IRC 115 (2014). The corrected in situ elastic moduli values indicate the deterioration of pavement over a period and this data was further used to design the overlay thickness of the pavement using the IITPAVE software. After determining the corrected moduli 15th percentile value for each of the section were calculated which was used as the input parameter in IIT PAVE.

3.2.1. IITPAVE

IITPAVE is the mechanistic empirical pavement design software which is used for analyzing the pavement responses. It aims at determining the total thickness of the pavement structure as well as the thickness of the individual structural components required for carrying the estimated traffic loading under the prevailing climatic conditions with satisfactory pavement performance. The IITPAVE software was used to compute the stress/strain values due to traffic loading and temperature variation at critical locations assuming flexible pavement as a four-layer system (overlay layer, existing surface, existing base/sub-base and existing sub-grade layers). Thickness of the layers and corrected in situ elastic moduli were used as the input values in the software as shown in Table 3 while assuming a trial thickness for overlay. The thickness of overlay assumed must be such that the developed stresses/strains are below the allowable stress/strain values which was computed using linear layered elastic model in IRC-37(2012).

Table 3. Input Parameters in IIT PAVE software

Parameters	**Typical Values**
Number of layers (n)	3
Elastic modulus (E), in MPa	3000
Poisson’s Ratio (μ)	0.5, 0.4,0.4
Single Wheel Load (N), Tyre Pressure (MPa)	20000, 0.56

3.2.2 Remaining service life of Pavement

The remaining service life of the pavement is calculated in terms of rutting and fatigue life of the pavement.
For determining the fatigue life, the allowable tensile strains are calculated using the fatigue criteria mentioned in Clause 6.2.2 of IRC 37 (2012) whereas for determining the rutting life the allowable vertical compressive strains were calculated using the rutting criteria as mentioned in Clause 6.3 of IRC 37 (2012)

3.3. HDM-4

In order to run HDM-4, extensive field work was conducted to collect the required data for all the three road sections H1, H2 and H3. The field work included the collection of inventory data such as the geometry of the road section, structure evaluation data (to check load carrying ability of the structure) and the functional evaluation data (for checking pavement condition, etc.), climate, temperature and the thickness of the pavement. The measured distress for all the three sections for the year 2016 are shown in the Table 4. The maintenance strategy adopted was the base alternative (no maintenance) and the thick overlay of bituminous course over the existing pavement. The next step included the calibration of the HDM-4 model in order to predict the distress as per the local conditions. Calibration factors were adopted from the study conducted by Deori et al. (2016) and Jain et al. (2005) for all distress (cracking, ravelling, rutting and roughness) as shown in the Table 5.

All these parameters were used as the input parameter in the calibrated HDM-4 pavement deterioration model to predict the distress developed over the coming years.

Table 4. Measured distress for all the three selected section

Homogenous sections	Cracking (%)	Ravelling (%)	Rutting (mm)	Roughness (IRI m/Km)
H-1	27.86	25	6.7	4.7
H-2	10.5	7.5	3.4	3.10
H-3	3.8	4.1	2.1	2.5

Table 5. Calibrated Factors

Model	Calibrated factors
Cracking initiation	0.45
Cracking progression	1.25
Ravelling initiation	0.37
Ravelling progression	0.52
Rutting progression	0.77
Roughness progression	0.85

4. Results and Discussions

- The elastic modulus of each layer obtained from the KGPBACK software were corrected by applying the seasonal and temperature corrections and the 15th percentile modulus values were selected for all the three sections. The elastic modulus for the bituminous layer was found out to be highest for H-3 section and lowest for H-1 section as shown in the Table 6. It can be inferred that the elastic modulus values of existing layers plays an important role to comment on the pavement condition.

Table 6. 15th percentile elastic modulus values for all the selected sections

Section Name	Bituminous layer moduli (E_1) (MPa)	Granular Base moduli (E_2) (MPa)	Subgrade moduli (E_3) (MPa)
H-1	335.9	60.2	77.0
H-2	703.9	64.7	77.0
H-3	1124.8	150.4	76.8

- The existing condition of the pavement for all the three sections were found using the IIT PAVE software and the remaining rutting and fatigue life were found out to be increasing with the pavement condition from poor to good as depicted in the Table 7.

Table 7. Remaining life of the existing pavement sections.

Homogenous sections	Thickness (mm)		15th percentile corrected E values for temperature and seasonal (MPa)			Horizontal tensile strain at the bottom of bituminous layer calculated using IITPAVE software	Vertical compressive strain at the top of subgrade layer calculated using IITPAVE software	Remaining life(msa)	
	Bituminous layer	Granular Base/sub-base layer	E_1	E_2	E_3			Fatigue life	Rutting life
H-1	200	325	335.9	60.2	77.0	0.5504E-03	0.3523E-03	2.4	6.5
H-2	200	325	703.9	64.7	77.0	0.3301E-03	0.2707E-03	9.2	21.6
H-3	200	325	1124.8	150.4	76.8	0.1888E-03	0.2088E-03	54.0	70.2

- After providing the overlay of bituminous course over the existing pavement, the horizontal tensile strain as well as the vertical compressive strain for all the three sections was found out to be lower than the critical strains. It was found out that an optimum overlay of 125 mm if provided to section H-1, would result in an increase in fatigue and rutting life from 2.4 to 71.2 and 6.5 to 328.7 msa respectively. Similarly, providing a 90mm and 40 mm thick overlay to section H-2 and H-3, respectively, would increase their rutting and fatigue life to 70.2 and 530.8 msa respectively for H-2 section, 80.9 and 893.6 msa for H-3 section. This indicated the importance of the overlay maintenance strategy adopted on the selected pavement sections.

Table 8. Predicted overlay summary for the selected pavement sections

Homogenous sections	E value of overlay of VG-40 (MPa)	Design Overlay Thickness (mm)	Required life (MSA)	Critical strains calculated using IRC 37-2012 equations		Horizontal tensile strain at the bottom of bituminous layer calculated using IITPAVE software	Vertical compressive strain at the top of subgrade layer calculated using IITPAVE software	Remaining life (msa)	
				Horizontal strain	Vertical strain			Fatigue life	Rutting life
H-1	3000	125	70	0.1424E-03	0.3471E-03	0.1418E-03	0.1486E-03	71.2	328.7
H-2	3000	90	70	0.1424E-03	0.3471E-03	0.1423E-03	0.1337E-03	70.2	530.8
H-3	3000	40	70	0.1424E-03	0.3471E-03	0.1372E-03	0.1192E-03	80.9	893.6

- The calibrated HDM-4 model compared the distress developed with and without application of maintenance strategy applied during the year 2017. The change in the percentage values for the cracking and ravelling distress was found out to decrease to 0% for all the three sections after applying the maintenance strategy whereas rutting was found to decrease upto 85% for all the three sections as shown in the Table 9,10 and 11. Further, roughness distress was found to decrease upto 72.05% for the section H-1, whereas for sections H-2 and H-3, the roughness distress decreased upto 57.75 and 17.76 % respectively. The average roughness graph for all the three sections are depicted in Figure 4,5 and 6. The decrease in the distress values ensured the accountability of the bituminous overlay thickness provided on the selected pavement sections.

Table 8. Comparison of distresses developed before and after applying maintenance strategy for section H-1.

Distress Parameters	No maintenance	Maintenance (dense graded bituminous overlay)	Percentage change (%)
Cracking (%)	46.75	0	100
Ravelling (%)	47.56	0	100
Rutting (mm)	6.92	1.04	84.97
Roughness (m/km)	5.01	1.40	72.05

Table 9. Comparison of distresses developed before and after applying maintenance strategy for section H-2.

Distress Parameters	No maintenance	Maintenance (dense graded bituminous overlay)	Percentage change (%)
Cracking (%)	22.24 %	0	100
Ravelling (%)	26.66 %	0	100
Rutting (mm)	3.57	0.54	84.87
Roughness (m/km)	3.29	1.39	57.75

Table 10. Comparison of distresses developed before and after applying maintenance strategy for section H-3.

Distress Parameters	No Maintenance	Maintenance (dense graded bituminous overlay)	Percentage change (%)
Cracking (%)	8.83	0	100
Ravelling (%)	14.22	0	100
Rutting (mm)	2.22	0.33	85.13
Roughness (m/km)	2.59	2.13	17.76

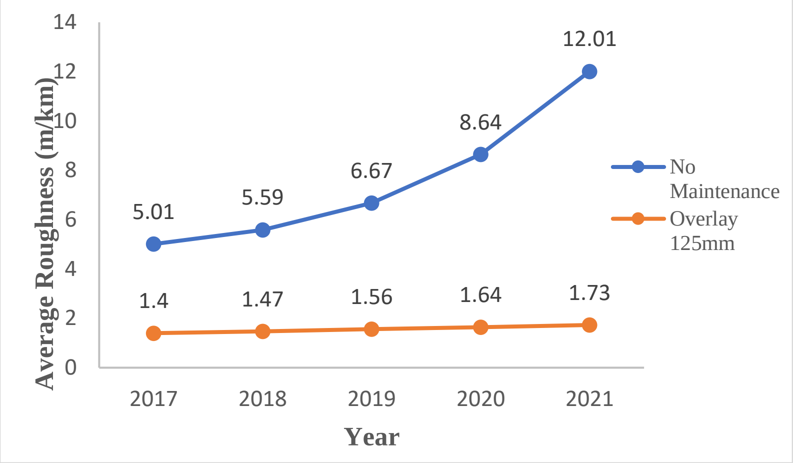

Figure 4. Comparison for average roughness for section H-1

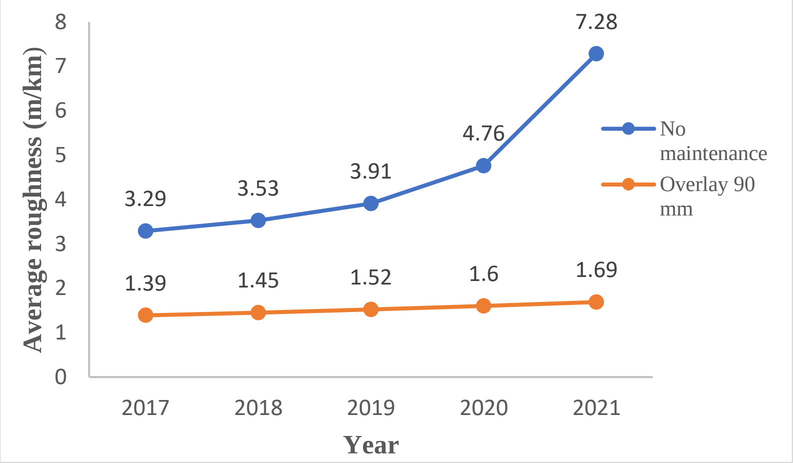

Figure 5. Comparison for average roughness for section H-2

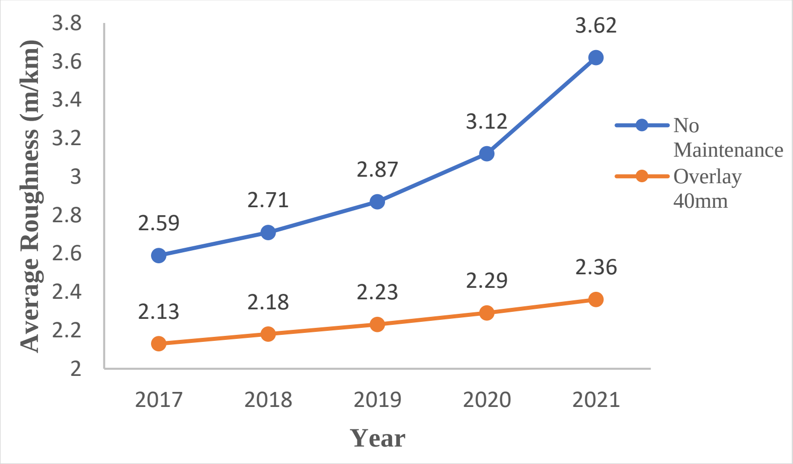

Figure 6. Comparison for average roughness for section H-3

5. Conclusion

This paper deals with the prediction, comparison and analysis of the overlay to be provided over the existing pavement of the National highway in the state of Haryana, India using the salient features of KGPBACK, IITPAVE and HDM-4. In this study, deflection measurements were carried out on the pavement using the established FWD system on the three selected sections classified as H-1, H-2 and H-3 based upon the pavement condition. The deflection measurements were used for obtaining the elastic moduli of each layer through KGPBACK software. The elastic moduli of the H-3 was found out to be the highest whereas for section H-1, it was found out to be the lowest which tells the effect of the pavement condition on the elastic modulus. Prediction of the overlay was done with the help of IIT PAVE software and the overlay thickness was found to be varying depending upon the elastic modulus of the existing pavement. The accountability of the provided overlay thickness was ensured by the HDM-4 software as it depicted a clear decrease in the cracking, ravelling, rutting and roughness distress values. The improvement in conditions of all pavement sections on modelling the bituminous overlay maintenance strategy suggested that if such strategies are applied on the Indian roads it would increase the lifetime of the Indian Highway Roads.

6. References

Bannour, A., El Omari, M., Lakhal, E. K., Afechkar, M., Benamar, A., and Joubert, P. (2017). “Optimization of the maintenance strategies of roads in Morocco: calibration study of the degradations models of the highway development and management (HDM-4) for flexible pavements.” *International Journal of Pavement Engineering*, Taylor & Francis, 8436(October), 1–10.

Chen, J., Hossain, M., & Latorella, T. M. (1999). Use of Falling Weight Deflectometer and Dynamic Cone Penetrometer in Pavement Evaluation. *Transportation Research Record*, *1655*(1), 145–151. https://doi.org/10.3141/1655-19

IRC (Indian Roads Congress). (2012). “Guidelines for the design offlexible pavements.” IRC:37-2012, New Delhi, India, 12–18

Deori, S., Choudhary, R., Tiwari, D., and Gangopadhyay, S. (2016). “Calibration of HDM-4 models for Indian conditions of flexible pavement having modified bitumen in wearing course.” *International Journal of Pavement Engineering*, Taylor & Francis, 8436(October 2017), 1–14.

IRC 115. (2014). *Guidelines For Structural Evaluation And Strengthening Of Flexible Road Pavements Using Falling Weight Deflectometer (Fwd) Technique*. New Delhi.

Jain, S. S., Aggarwal, S., and Parida, M. (2005). “HDM-4 Pavement Deterioration Models for Indian National Highway Network.” (August), 623–631.

Kim, Y. R., Ph, D., Park, H., and Ph, D. (2002). *Use Of Falling W Eight D Eflectometer Multi-Load Data For Pavement Strength Estimation*.

Reddy, B. B., and Veeraragavan, A. (1997). “Structural Performance of Inservice Flexible Pavements.” *Journal of Transportation Engineering*, 123(2), 156–167.

Singh, A., and Chopra, T. (2018a). “Development of Pavement Maintenance Management System For The Urban Road Network by Calibrating the HDM-4 Distress Models.” 1–8. New Delhi: CSIR- CRRI, pp.239-248. ISBN: 978-93-88237-20-8

Singh, A., and Chopra, T. (2018b). “Calibration Of Rutting And Roughness Distress Models Of Hdm-4 For Developing Pavement Maintenance Management.” 1–6., *Streamlining Information Transfer between Construction and Structural Engineering*. [online] Fargo, USA: ISEC Press. Available at: https://www.isec-society.org/ISEC_PRESS/ASEA_SEC_04/html/INF-02.xml

Solanki, U., Solanki, U. J., Gundalia, P. J., and Barasara, M. D. (2015). “A Review on Structural Evaluation of Flexible Pavements using Falling Weight Deflectometer Structural Evaluation of Flexible Pavement using Falling Weight Deflectometer View project A Study of interface bond between Prime coat over granular base , prime c.” *Ttea*, (January 2014), 1–10.