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Pavement Overlay Design using Falling Weight Deflectometer

Swetha G, Chandana I, Rakesh M

Abstract: ***Pavement evaluation is a technique of assessing the condition of a pavement, both structurally and surface characteristics. Pavements which have been subjected to traffic, deform elastically under load which depends on type subgrade soil and its compaction level, pavement thickness and its composition, drainage conditions, pavement surface temperature and wheel load. There are number of different types of pavement deflection testing equipment which are being used all over the world. The most common types are Benkelman Beam Deflection (BBD), Falling Weight Deflectometer (FWD) and Dynamic Cone Penetrometer. BBD test widely used method in which rebound deflection is measured on static loading and there by evaluating strength of the pavement. However with limitations and practical difficulties of BBD, FWD was chosen for the study. The deflections of the pavement are recorded due to the dynamic loading and studied for further strength determination. A 4-lane National Highway has been selected and tested for residual strength and it is designed for overlay as per IRC:115-2014 & IRC:37-2012 using FWD equipment and with the assistance of KGPBACK and IIT PAVE software's. An overlay of 50 mm on one direction and 100 mm on opposite direction was recommended to meet the functional and structural requirement respectively.***

Keywords ***: Falling Weight Deflectometer (FWD), Pavement overlay, KGPBACK, IIT PAVE, IRC:115-2014 and IRC:37-2012.***

I. INTRODUCTION

The objective of the study is to evolve structural condition of the pavement using Falling Weight Deflectometer and subsequent analysis is carried out to ascertain the relative performance of the pavement in the perspective of evaluating residual life. The load-deflection data from the FWD was inferred through the analytical techniques by back calculation to estimate the elastic moduli of the pavement layers. Thus calculated moduli was therefore used for the strength evaluation of different layers of pavement and the estimation of strength requirement of pavement. The procedures for the test and evaluation of structural condition of pavements is detailed in IRC- 115:2014.

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* Correspondence Author

Swetha G*, Civil Engineering department, Gokaraju Rangaraju Institute of Engineering Technology, Affiliated to JNTUH, Hyderabad.

Chandana I, Civil Engineering department, Gokaraju Rangaraju Institute of Engineering Technology, Affiliated to JNTUH, Hyderabad.

Rakesh M, Civil Engineering department, Gokaraju Rangaraju Institute of Engineering Technology, Affiliated to JNTUH, Hyderabad.

II. DESIGN METHODOLOGY

Performance of flexible pavements can be evaluated by subjecting the pavement to external loads such that it simulate the traffic loading and recording the response of pavement to such loading by measuring the elastic deflection under such loads. For the reason, the Falling Weight Deflectometer was chosen as per the guidelines in IRC:115_2014. Falling Weight Deflectometer, which is closely simulates the duration and amplitude of the load pulses produced by moving wheel loads. The basic working principle of the impulse loading equipment is to drop a mass on the pavement to produce an impulse load and measure the surface deflections. The mass is dropped on a spring system, which in turn transmits the load to the pavement through a loading plate. The resulting bowl characteristics are observed and used in the back-calculation of pavement material properties.

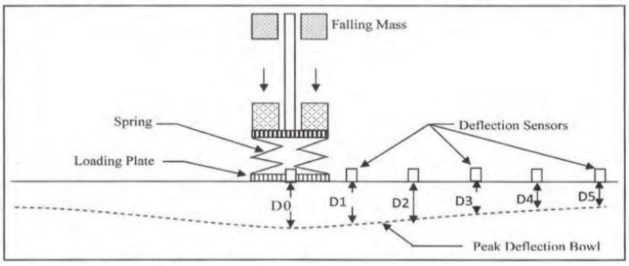

Fig. 1. Working Principle of FWD

The FWD test data was collected from different load drops at each test point primarily consisted of peak load, peak deflections at different radial locations. Unrealistic deflection values and obviously enormous data are removed.

The target peak load was applied on bituminous pavement is 40kN (+/- 4kN), which corresponds to the load on one dual wheel set of an 80kN standard axle load. But in practice applied peak load always may not be exactly 40kN, hence the deflection values measured by geophones should be normalized to equivalent 40kN loading. The normalization of deflections are done linearly. KGPBACK is the Back calculation technique used to calculate the elastic moduli of existing pavement layers. Normalized surface deflections, along with other inputs such as radial distances at which deflections are measured, layer thicknesses, Poison's ratio values of different layers, target load and loading plate radius, are used to back-calculate the elastic moduli of different layers of the existing pavement.

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Elasticity moduli values were corrected for temperature and seasonal variation which is further used for the estimation of the design Elastic Moduli (E) values. As per IRC guidelines 15th percentile of E values are considered for the project study. For areas in India having a tropical climate, the temperature corrections has to be applied for the temperatures more than the standard pavement temperature which is 350C. The temperature corrections are applied for the back calculated modulus obtained from of bituminous layer using below mentioned equation.

$$E_{T1} = \lambda E_{T2} \quad (1)$$

Where,

λ is temperature correction factor, is given as

$$(1\text{-}0.238\ln T1)/(1\text{-}0.238\ln T2)$$

E_{T1} is back-calculated modulus (MPa) at temperature T1 (^{0}C)
E_{T2} is back-calculated modulus (MPa) at temperature T2 (^{0}C)
Seasonal corrections for subgrade and granular moduli were also applied using the following relationships developed for different seasons (winter/ summer/ monsoon) as per IRC: 115-2014.

$$E_{sub\ mon} = 3.351 * (E_{sub\_win}) * 0.7688 - 28.9 \quad (2)$$

$$E_{sub\ mon} = 0.8554 * (E_{sub\_sum}) * 0.7688 - 8.461 \quad (3)$$

$$E_{granu\_mon} = -0.0003 * (E_{granu\_Sum})2 + 0.9584 * (E_{granu\_Sum}) - 32.989 \quad (4)$$

$$E_{granu\_mon} = 10.5523 * (E_{granu\_win}) * 0.624\text{-}113 \quad (5)$$

The results from the above analysis along the physical and load characteristics of the pavement were given as inputs to the IIT PAVE software to obtain the peak strains at critical locations of the pavement. These strains are later used to find residual fatigue and rutting strengths of the pavement. The layer moduli were used to analyze the pavement for critical strains which are indicators of pavement performance in terms of rutting and fatigue cracking as suggested by IRC. A diagram with different layers of flexible pavement and critical strain locations is shown in following Fig. 3.

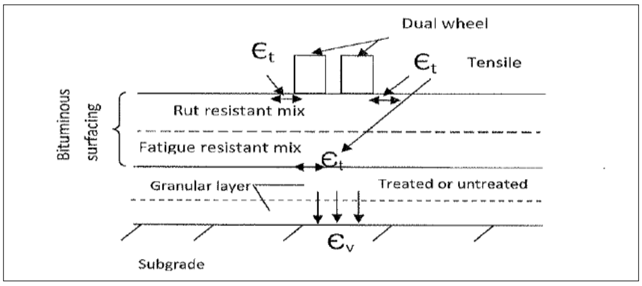

Fig. 2. Different layers of flexible pavement & Critical Strain locations

The fatigue (or fracture) life in Million Standard Axles (MSA) of the bituminous layer and the number of load repetitions in terms of standard axles that cause fatigue denotes the fatigue life of the pavement. The fatigue model for 90 percent reliability is given in following equation.

$$N_f = 0.711 * 10\text{-}0.4 * [1/\varepsilon_t]\ 3.89 * [1/M_R]\ 0.854 \quad (6)$$

Where,

N_f is Fatigue life in number of standard axles
ε_t is Maximum tensile strain at the bottom of bituminous layer
M_R is resilient modulus of the bituminous layer.

Rutting life in Million Standard Axles (MSA) is the permanent deformation in pavement usually occurring longitudinally along the wheel path. Rutting model for 90 percent reliability level was given in following equation.

$$N = 1.41*10\text{-}8 * [1/\varepsilon_v]\ 4.5337 \quad (7)$$

Where,

N is Number of cumulative standard axles
εv is Vertical strain in the subgrade

Thus the obtained fatigue and rutting life of the pavements are compared with the design strength to arrive the design thickness of the pavement overlay.

III. PAVEMENT CHARACTERISTICS AND DEFLECTION MEASUREMENT SCHEME

In this study, the pavement of interest is four lane dual carriageway from NH5. The project stretch from Km. 951.500 to Km 1022.500 both on LHS and RHS at 250m spacing on outer wheel path of outer lane and at 500 m spacing on outer wheel path of inner lane. Deflections obtained on each side of the carriageway has been normalized to correspond standard target load of 40kN as per guidelines. Pavement layer thicknesses are essential inputs to the process of back-calculation of layer moduli and, in turn, to the estimation of remaining life and overlay requirements of the in-service pavement. A pit of size 0.6m x 0.6m was excavated at an interval of 10km as the records suggest the uniformity of the pavement composition. The total crust thicknesses of the pavement measured along the chainage varies 660 mm to 890 mm with bituminous layer of varying thickness from 200 to 360 mm and a granular layer of thickness 450 mm to 690 mm.

IV. RESULT ANALYSIS

The FWD test is calibrated to ensure the deflection values given by the sensors are reliable. The mean and standard deviation of deflections are calculated for twelve drops for each geophone separately. As per IRC:115-2014, the standard deviation of the peak load should be less than 5 percent of the mean value of the peak load.The measured load deflection data was normalized by removing the erroneous output and processed by applying all temperature and seasonal corrections to arrive at representative moduli of each layer by back calculation through KGPBACK. The representative moduli of bituminous, granular and subgrade layers of LHS and RHS with all corrections applied are shown graphically in the below Fig. 3.

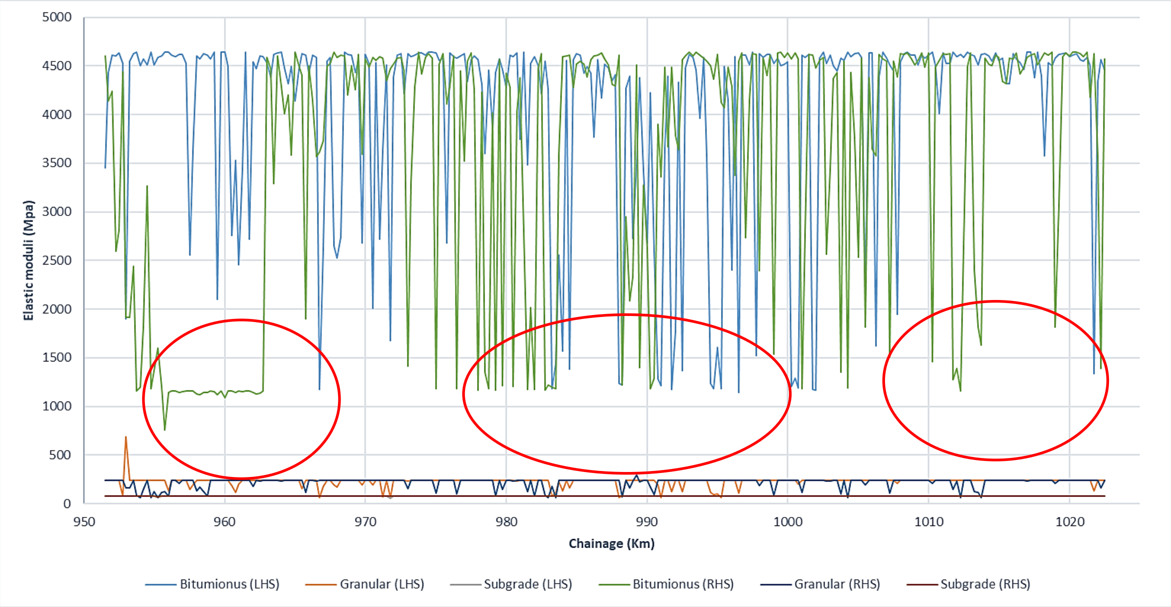

Fig. 3. Elastic moduli of different layers of pavemen

It is clear from the above graphical representation, the RHS bituminous layer has very low values of moduli. Selection of 15th percentile modulus values (15% of the values will be less than this value) of each of the three layers considered for analysis. The design 15th percentile values are mentioned below Table I.

Table I: 15th Percentile Back Calculated Modulus Values on LHS and RHS Side

Side	15th Percentile of Moduli for the design		
	Bituminous (MPa)	Granular (MPa)	Subgrade (MPa)
LHS	2562.15	223.2669	77
RHS	1198.46	161.65	77

With the above elastic modulus, physical and load characteristics of the pavement, the critical strain values of the pavement were obtained from the IITPAVE and those strain results were used to calculate the fatigue and rutting life of the bitumen layer as shown in the below Table II.

Table II: Residual Life of pavement on RHS Side

Side	Analysis of pavement using IITPAVE		Remaining Life of Pavement	
	Horz. Tensile Strain (microns)	Vert. Comp. Strain (microns)	Fatigue (MSA)	Rutting (MSA)
LHS	114.40	163.20	187.78	2087.42
RHS	195.00	198.80	20.61	853.27

As the residual strength of the pavement is more than the required design strength there is no requirement for structural overlay on the LHS. However an overlay of 50mm is suggested for functional requirement which covers surface defects like cracks, potholes, roughness, etc. Along RHS, the residual strength of the pavement is 20.61 MSA which is much less than the design requirement of the pavement. A structural overlay is to be designed to meet the design strength. A trial of 100mm overlay is used on IITPAVE software along with other properties as input. Based on the design life of pavement, the residual life of the pavement is re-calculated as shown in below Table III.

Table III: Residual & Design life of pavement

Side	Design strength (MSA)	Residual strength (MSA)	Design overlay strength (MSA)	Overlay Thickness (mm)	Strength after overlay (MSA)
LHS	170	187.78	Not required	50	188
RHS	150	20.61	130	100	159.18

V. CONCLUSION

The results discussed above indicates that the drop in elastic moduli and residual life of the pavement and requires overlay to meet design strength and foundational requirement of the pavement. To conclude, a thickness of 50mm of functional overlay on LHS side and a thickness of 100 structural overlay on RHS side was arrived to meet design strength and foundational requirement of the pavement.

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AUTHORS PROFILE

Swetha G, Assistant Professor, Civil Engineering department, Gokaraju Rangaraju Institute of Engineering Technology, Affiliated to JNTUH, Hyderabad.

Chandana I, Assistant Professor, Civil Engineering department, Gokaraju Rangaraju Institute of Engineering Technology, Affiliated to JNTUH, Hyderabad**.**

Rakesh M, Assistant Professor, Civil Engineering department, Gokaraju Rangaraju Institute of Engineering Technology, Affiliated to JNTUH, Hyderabad**.**