Development Correlation between Benkelman Beam Deflection and Falling Weight Deflectometer for Conventional Whitetopping Overly

D. R. Jundhare[1], Dr. K. C. Khare[2]; and Dr. R. K. Jain[3]

[1]Research Scholar, Civil Engineering Department, Sinhgad College of   Engineering, Vadgaon (Bk.), Pune-411041. M. S. India. University of Pune
[2]Professor, Civil Engineering Department, Sinhgad College of   Engineering, Vadgaon (Bk.), Pune-411041.M. S. India
[3]Professor, Pad. Dr. D.Y. Patil Institute of Engineering and Technology, Pimpri, Pune - 411018. M. S. India

ABSTRACT

India has one of the largest highway and road networks on the planet, third only to the road network of the United States and China. The road network has expanded from 0.4 million km in 1951 to about 3.32 million kilometers presently, a sevenfold increase, but traffic has increased 120 times (Department of Road Transport and Highways, Govt. of India). This leads to the deterioration of the surface of the asphalt pavements and a need to rehabilitate them before further damage could occur. Since the use of a concrete overlay, called as whitetopping, is a relatively new concept in Hot Mix Asphalt (HMA) pavement rehabilitation in India, there is a need to evaluate its performance for Indian traffic and climatic conditions by conducting Falling Weight Deflectometer (FWD) and Benkelman Beam Deflection (BBD) test on conventional whitetopping overlays constructed in Pune city (India). This paper presents the linear, exponential and logarithmic relationship between Benkelman Beam and FWD deflections for the edge and corner loading positions of conventional whitetopping overly by using computer.
Keywords: Benkelman Beam Deflection, Falling Weight Deflectometer, Conventional Whitetopping

INTRODUCTION

Whitetopping is the Portland Cement Concrete (PCC) overlay constructed on the top of an existing bituminous pavement. Rutting of bituminous pavement is a real problem in hot climate like India, with heavy truck loads, operating under frequent start/ stop conditions. Whitetopping is applied where rutting of bituminous pavement is a recurring problem. Whitetopping is classified into three types according to the PCC slab thickness as follows (IRC: SP: 76 – 2008):

Conventional Whitetopping: It consists of a PCC overlay of thickness 200 mm or more which is designed and constructed like a new rigid pavement without assuming any composite action. It is constructed without consideration of any bond between the concrete overlay and underlying bituminous layer.

Thin Whitetopping (TWT): It consists of a PCC overlay of thickness greater than100 mm and less than 200mm. The bond between the overlaid PCC and underlying bituminous layer is often considered but it is not mandatory. High strength concrete with fibres is commonly used.

Ultra- Thin Whitetopping (UTW): PCC overlay of thickness equal to or less than 100 mm is classified as Ultra-Thin Whitetopping (UTW). Bonding between PCC overlay and underlying bituminous layer is mandatory in case of UTW. The UTW requires a good bond with the underlying HMA layer to perform well as indicated by the literature (Cole 1997; Rasmussen et al. 2002; Lin and Wang 2005).

Pavement surface deflection measurements are the primary means of evaluating a flexible pavement structure and rigid pavement load transfer. Although other measurements can be made that reflect (to some degree) a pavement's structural condition, surface deflection is an important pavement evaluation method because the magnitude and shape of pavement deflection is a function of traffic (type and volume), pavement structural section, temperature affecting the pavement structure and moisture affecting the pavement structure. Deflection measurements can be used in back calculation methods to determine pavement structural layer stiffness and the subgrade resilient modulus. Thus, many characteristics of a flexible pavement can be determined by measuring its deflection in response to load. Furthermore, pavement deflection measurements are non-destructive. Pavement surface deflection can be measured using Benkelman Beam or Falling Weight Deflectometer.

Corresponding Author: D. R. Jundhare, Research Scholar, Civil Engineering Department, Sinhgad College of   Engineering, Vadgaon (Bk.), Pune-411041. M. S. India. University of Pune. E mail: djundhare@yahoo.com

Use of Falling Weight Deflectometer (FWD) for the evaluation of pavements is gaining popularity in many countries, as it is possible to simulate the magnitude and duration of load applied by a fast moving vehicle on highways using this equipment. However, the use of FWD in India has been very limited so far because of its high cost and difficulties encountered in maintaining the equipment. Therefore, a need has been aroused to identify an alternative to FWD test, which can be cost effective and easily available. Benkelman Beam test is one the static load deflection equipment which measures the maximum deflection response of a pavement to static or slowly applied loads. Advantages of the Benkelman Beam include ease to use, low equipment cost, and large database can be created about performance of the pavement over the years. But, the guidelines given by IRC: 81-1997 for conducting Benkelman Beam Test are applicable only for flexible pavements. In this study attempt has been made to conduct this test on the top of conventional whitetopping. Hence, Benkelman Beam test as per IRC: 81-1997 and FWD test have been carried out to find deflection on top 320 mm thick conventional whitetopping overlay constructed in Pune city, India. The deflections on the surface of slab were measured at corner and edge loading positions. Relationship is drawn between deflections readings measured by Benkelman Beam on X axis and deflections readings obtained by FWD on Y axis. Thus the paper discusses about the linear, exponential and logarithmic relationship between Benkelman beam deflection and Falling Weight Deflectometer for the edge and corner loading positions of conventional whitetopping overly. The data of study area has been given in Table 1 (Jundhare D.R. et al., 2008)

BENKELMAN BEAM DEFLECTION (BBD) TEST

Static load deflection equipment measures the maximum deflection response of a pavement to static or slowly applied loads. The most commonly used static deflection device is the Benkelman Beam. Surface deflection data from 320 mm thick conventional whitetopping overlay test sections at Pune City, India was obtained using nondestructive test of Benkelman Beam. This test has been carried out on top surface of existing conventional whitetopping to obtain the deflection measurements at edge and corner of each slab as shown in Figures 1 and 2. The vehicle used to carry out BBD test was having 81.70kN rear axle weight as per guidelines given in IRC: 81-1997. The pavement temperature was measured after every one hour interval during the deflection measurements using a digital thermometer as shown in Figure 3. The cross section of conventional whitetopping is shown in Figure 4. The deflection data was analyzed and characteristic deflection calculated after incorporating necessary corrections for temperature and seasonal variations. The deflections were worked out as per guidelines given in IRC: 81-1997. The observations and results are given in Table 2 and 3.

Table 1: Details of Study Area Data and Analysis

Sr. No.	Description	Value Adopted
1	Type of pavement	Conventional Whitetopping
2	Length of road	9.00 km
3	Compressive Strength of Concrete (F_{ck})	40 MPa
4	Flexural Strength of Concrete = $0.7 \sqrt{F_{ck}}$	4.43 MPa
5	Elastic Modules of Concrete (E) (Cl.4.7.2 –IRC:58)	31625 MPa
6	Poisson's Ratio (μ) (Cl.4.7.2 –IRC:58)	0.15
7	Coefficient of Thermal Expansion of Concrete (α) (Cl.4.7.3 –IRC-58)	$1.0E\text{-}05/^{O}C$
8	Tyre pressure (q) (Cl.4.2 – IRC-58)	0.8 MPa
9	Rate of Increase of Traffic (r)	3%
10	Spacing of Contraction Joints (L)	4500 mm
11	Width of Slab (B)	3650 mm
12	Present Traffic Volume	21233 ESAL/Day
13	Design Life of Pavement	20 Years
14	Number of Lanes / Carriageway	2
15	Dual Carriageway (Y/N)	Yes
16	Type of Subgrade (R for Rocky & S for Soil)	S
17	If Soil Subgrade, CBR of Subgrade (%)	8
18	Temperature Differential (t) (Table –1-IRC: 58)	21° C
19	Modulus of subgrade reaction	0.12 MPa/mm
20	Panel size	3650 mm x 4500 mm

Fig.1: BBD Test in Progress

Fig.2: Enlarged View at Corner Loading

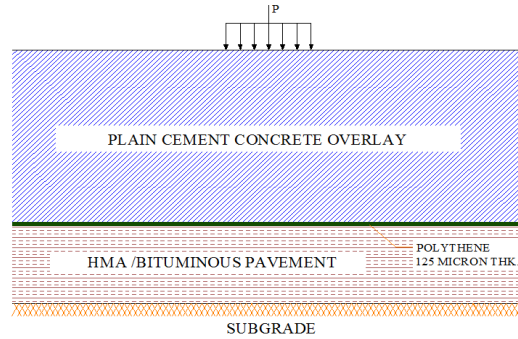**Fig.3:** Measuring Pavement Temperature (Inside)

Fig.4: Cross Section of whitetopping

Table 2: BBD Test Analysis for Edge Wheel Loading on Surface of Conventional Whitetopping

Panel / Slab No.	Dial Gauge Reading (mm)			Deflection in mm	Pavement Temp. (0C)	Temperature correction	Seasonal Correction Factor	Corrected Deflection (D)
	Initial	Intermediate	Final					
1	100	94	93.5	0.13	37.5	-0.025	1.05	0.11025
2	99	94	93	0.12	36.5	-0.015	1.05	0.11025
3	34	29	28	0.12	36.5	-0.015	1.05	0.11025
4	88	83	82	0.12	36.5	-0.015	1.05	0.11025
5	76	71	70.5	0.11	36.5	-0.015	1.05	0.09975
6	77	73	72	0.10	34.5	0.005	1.05	0.11025
7	81	77	76	0.10	34.5	0.005	1.05	0.11025

Table 3: BBD Test Analysis for Corner Wheel Loading on Surface of Conventional Whitetopping

Panel / Slab No.	Dial Gauge Reading (mm)			Deflection in mm	Pavement Temp. (0C)	Temperature correction	Seasonal Correction Factor	Corrected Deflection (D)
	Initial	Intermediate	Final					
1	44	40	39.5	0.09	37.5	-0.025	1.05	0.06825
2	98	95	94	0.08	36.5	-0.015	1.05	0.06825
3	88	85	84	0.08	36.5	-0.015	1.05	0.06825
4	69	63	62	0.08	36.5	-0.015	1.05	0.06825
5	54	51	50.5	0.07	36	-0.01	1.05	0.06300
6	78	76	75	0.06	34.5	0.005	1.05	0.06825
7	81	79	78	0.06	34.5	0.005	1.05	0.06825

FALLING WEIGHT DEFLECTOMETER (FWD) TEST

Impact deflection testing by FWD for pavement nondestructive evaluation (NDE) is widely used testing devices among many nondestructive testing technologies available for pavement condition evaluation (Hudson et al., 1987).

The FWD device applies an impact load on a steel loading plate and measures peak deflections on the pavement surface using seismic velocity transducers at the center and at the several locations away from the loading plate.
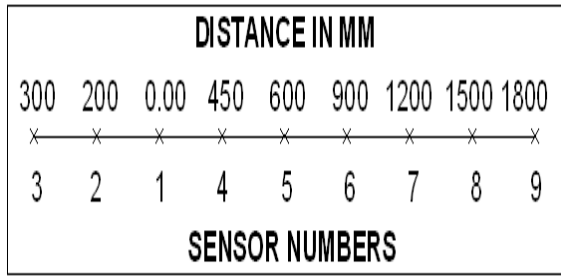

Fig.5: Schematic of FWD Deflection Sensors   **Fig. 6:** FWD Test Carried on Study Road

Use of FWD for evaluation of pavements is gaining popularity in many countries, as it is possible to simulate the magnitude and duration of load applied by a fast moving vehicle on highways using this equipment. In order to determine the applicability of utilizing the finite element method to analyze the unbonded conventional whitetopping, non-destructive field testing of pavement using FWD was performed on existing conventional whitetopping overlay under study. In this study, Dynatest 8000 FWD model with 150 mm diameter load plate and nine displacement measuring sensors, was used which is trailer mounted and have the capability to apply load of 50 kN and 100 kN. For details of the testing procedure, construction report (Cable et al. 2003, Foxworthy, P.T., and Darter M. I., 1986) is referred. One transducer is located at the center of the load plate and remaining transducers are placed at varying intervals from the plate. Figure 5 shows schematic showing the arrangement of the sensors of FWD test equipment used in this study. The Figure 6 shows the FWD test carried out on surface of conventional whitetopping overlay and test data given in Table 4and 5.

Table 4: FWD Stresses and Deflections Data at Edge of Overlay Slab

Sr. No.	Stress In MPa	DEFLECTION IN MM AT DISTANCE IN MM FROM LOAD POINT									Test Load (kN)
(Series)		0	-200	-300	450	600	900	1200	1500	1800	
1	0.814	0.1223	0.1004	0.0902	0.0857	0.0778	0.0652	0.0585	0.0414	0.0392	51.53
2	0.912	0.1214	0.1002	0.0921	0.0899	0.0781	0.0609	0.0552	0.0463	0.0384	54.46
3	0.757	0.1229	0.1018	0.0982	0.0878	0.0794	0.0696	0.0518	0.0475	0.0368	50.51
4	0.811	0.1187	0.1004	0.0808	0.0715	0.0701	0.0622	0.0566	0.0450	0.0343	51.32
5	0.821	0.1115	0.0934	0.0827	0.0728	0.0690	0.0628	0.0586	0.0399	0.0294	53.02
6	0.798	0.1195	0.0995	0.0875	0.0724	0.0699	0.0655	0.0546	0.0399	0.0293	51.40
7	0.785	0.1183	0.0981	0.0851	0.0786	0.0695	0.0599	0.0502	0.0384	0.0297	51.48

Table 5: FWD Stresses and Deflections Data at Corner of Overlay Slab

Sr. No.	Stress In MPa	DEFLECTION IN MM AT DISTANCE IN MM FROM LOAD POINT									Test Load (kN)
(Series)		0	-200	-300	450	600	900	1200	1500	1800	
1	0.749	0.0861	0.0792	0.0674	0.0611	0.0595	0.0541	0.0485	0.0373	0.0287	52.93
2	0.761	0.0879	0.0710	0.0689	0.0605	0.0593	0.0548	0.0459	0.0350	0.0341	53.78
3	0.725	0.0893	0.0796	0.0686	0.0615	0.0570	0.0588	0.0455	0.0346	0.0365	51.24
4	0.781	0.0896	0.0761	0.0699	0.0581	0.0551	0.0544	0.0438	0.0333	0.0294	51.20
5	0.773	0.0791	0.0699	0.0649	0.0615	0.0557	0.0521	0.0405	0.0378	0.0295	54.63
6	0.812	0.0872	0.0798	0.0667	0.0619	0.0569	0.0498	0.0398	0.0391	0.0273	51.39
7	**0.742**	**0.0832**	**0.0794**	**0.0618**	**0.0616**	**0.0561**	**0.0502**	**0.0399**	**0.0298**	**0.0236**	**52.44**

CONCEPT OF LINEAR, EXPONENTIAL, LOGARITHMIC FUNCTIONS AND R- SQUARED VALUE

The **Linear functions** are functions that have x as the input variable, and x has an exponent of only 1. Such functions look like the ones in the graphic to the left. Notice that x has an exponent of 1 in each equation. Functions such as these yield graphs that are straight lines, and, thus, the name linear. A very common way to express a linear function is named the *'slope-intercept form'* of a linear function. When drawn on a common (x, y) graph it is usually expressed as: $y = mx + c$. Or, in a formal function definition: $f(x) = mx + c$. This function basically

describes a set, or locus, of (x, y) points, and these points all lie along a straight line. The variable *m* holds the slope of this line. The variable *c* holds the y-coordinate for the spot where the line crosses the y-axis. This point is called the *'y-intercept'*.

The **exponential function** is the function e^x, where *e* is such that the function e^x is its own derivative. The exponential function is used to model a relationship in which a constant change in the independent variable gives the same proportional change (i.e. percentage increase or decrease) in the dependent variable. The function is often written as exp (*x*), especially when it is impractical to write the independent variable as a superscript.

The **logarithmic function** is defined as the inverse of the exponential function. For B > 0 and B not equal to 1,

y = Log Bx   is equivalent to   x = B y.

Note: The logarithm to the base e is written ln(x).

In statistics, the coefficient of **determination R^2** is the proportion of variability in a data set that is accounted for by a statistical model. In this definition, the term "variability" is defined as the sum of squares. There are equivalent expressions for R^2 based on analysis of variance decomposition. R^2 is a statistic that will give some information about the goodness of fit of a model. In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. An R^2 of 1.0 indicates that the regression line perfectly fits the data.

The linear, exponential and logarithmic relationship has been developed using FWD and Benkelman Beam deflection values on conventional whitetopping overlays and equations and   R-squared values have been given in Table 6. The Figure 7,8,9,10,11 and 12 shows the graphs of linear, exponential and logarithmic relationship for BBD and FWD deflection values.

Table 6: Summary of Relationship and equations for Edge and Corner Lading Positions

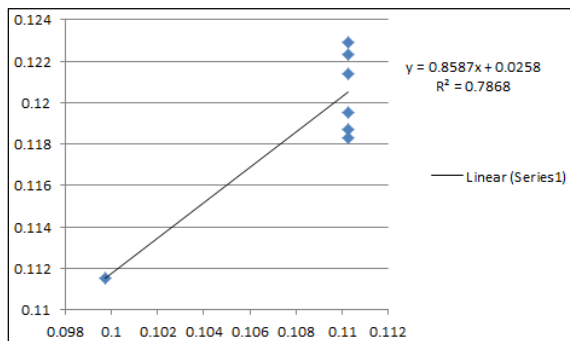| Sr. No.	Relationship	Edge Loading	Corner Loading
1	Linear	Y= 0.8587x + 0.0258 R^2 = 0.7868	Y= 1.546 + 0.0183 R^2 = 0.6696
2	Exponential	Y= $0.0533e^{7.3957x}$ R^2 = 0.7991	Y= $0.0246e^{18.547}$ R^2 = 0.6852
3	Logarithmic	Y= 0.0901ln(x)+0.3192 R^2 = 0.7868	Y= 0.10141ln(x)+0.3594 R^2 = 0.6696

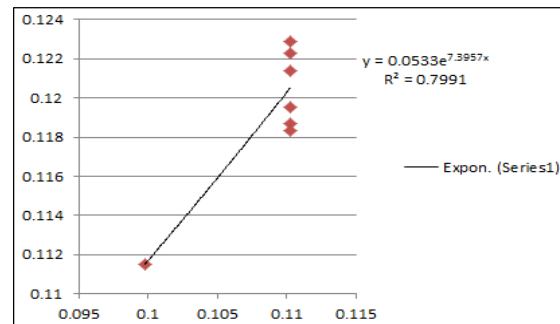**Fig. 7:** Linear Relationship at Edge Loading

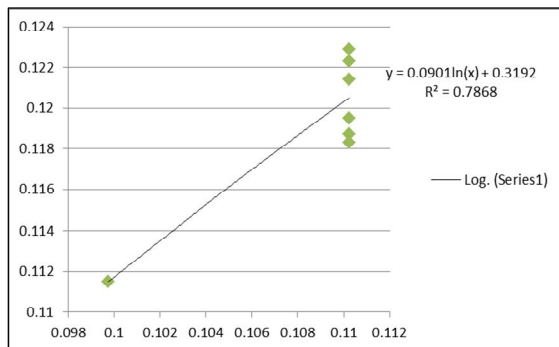**Fig. 8:** Exponential Relationship at Edge Loading

Fig. 9: Logarithmic Relationship at Edge Loading
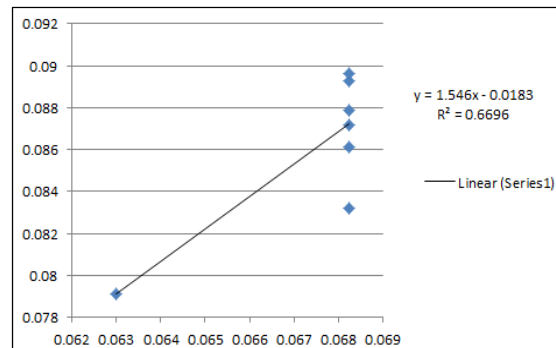

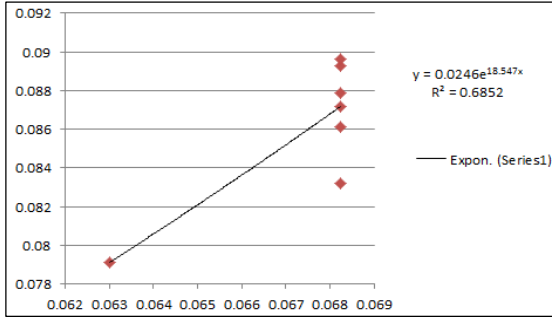**Fig.10:** Linear Relationship at Corner Loading

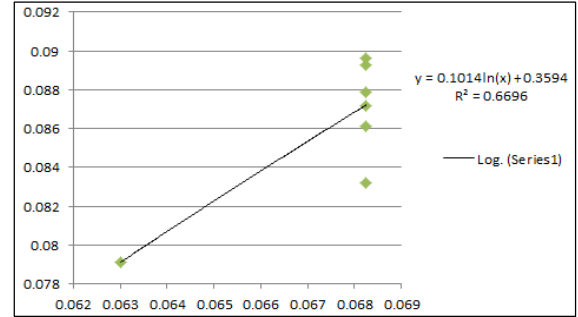**Fig. 11:** Exponential Relationship at Corner Loading

Fig. 12: Logarithmic Relationship at Corner Loading

CONCLUSION

Following conclusions are reached from the detailed study carried out using BBD as per guidelines given in IRC: 81-1997 and FWD test as NDT for determining deflection at edge and corner load positions of 320 mm thick on in-service conventional whitetopping overlay constructed in Pune city, Maharashtra State (India), for its performance evaluation and correlation development subjected to various traffic and climatic conditions relevant to Indian scenario.

- The linear, exponential and logarithmic relationship has been developed using Benkelman Beam and FWD deflection values on conventional whitetopping overlays.
- Among of the linear, exponential and logarithmic relationships; the exponential relationship gives high R^2 value.
- R^2 value of the three relationships, it is higher in edge loading position than corner loading position.
- The relationships developed are quite fair as R^2 values are in between 0.65 to 0.80 which shows the good correlation strength between the BBD and FWD deflection values.

ACKNOWLEDGEMENT

REFERENCES

1. Cable, J. K., Anthony, M. L., Fanous, F. S., and Phares, B. M. (2003). "Evaluation of Composite Pavement Unbonded Overlays: Phases 1 and 2." *Ames, IA*: Center for Portland Cement Concrete Pavement Technology.

2. Cole, L W. (1997). "Pavement Condition Surveys of Ultrathin Whitetopping Projects", *Proc., Sixth Int. Conf. on Concrete Pavements*, Purdue University, West Lafayette, Indiana, Volume 2, 175-187.

3. Foxworthy, P.T., and Darter M. I. (1986). "Preliminary Concepts for FWD Testing and Evaluation of Rigid Airfield Pavements." *Transportation Research Record*, 1070, Transportation Research Board.

4. Hudson, W.R., Elkins G.E., Uddin W., and Reilley K.T. (1987). "Evaluation of Pavement Deflection Measuring Equipment." FHWA-TS-87-208, *Federal Highway Administration.*

5. IRC: 58 – 2002 "Guidelines for the Design of Rigid Pavement for Highways." *Indian   Road Congress,* New Delhi.

6. IRC: 81 – 1997 "Guidelines for Strengthening of Flexible Road Pavements using Benkelman Bean Deflection Technique." *India Road Congress,* New Delhi.

7. IRC: SP: 76 – 2008 "Tentative Guidelines for Conventional, Thin and Ultra-Thin   Whitetopping." *Indian Road Congress,* New Delhi. 2008.

8. Jundhare D.R., Sanjay Nayak and Ugile E.P. (2008). "Case Study and Performance Evaluation of Rigid Pavement Overlay Technology on Existing Bituminous Pavement of Mumbai- Pune Road within Municipal Corporation Limit of Pimpri –Chinchwad" *Journal of the Indian Road Congress*, Vol. 69-1 New Delhi, pp 471-492.

9. Lin, D.F., and Wang H.Y. (2005). "Forensic Investigation of Ultra-Thin Whitetopping Failures in Taiwan" *ASCE journal of Performance of Constructed Facilities*, Vol. 19, No. 2.

10. Rasmussen, R.O., B.F. McCullough, J.M. Ruiz, J. Mack, and J.A. Sherwood. (2002). "Identification of Pavement Failure Mechanisms at FHWA Accelerated Loading Facility Ultrathin Whitetopping Project." *Transportation Research Record No. 1816*, pp. 148-155.