Comparison of Overlay Design in Between Lightweight Deflectometer and Benkelman Beam Deflection Test Results: A Case Study in India

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Abstract. Strengthening is an essential aspect of the operation, maintenance and management of low volume roads. In India, maintenance of other districts roads and village roads is a very significant task. Benkelman Beam Deflection (BBD) method is laborious and time-consuming because of the state of practice. However, the state-of-art Lightweight Deflectometer (LWD) method was employed to overlay the thickness design of low volume roads (LVR), utilizing a rationale that accounts for the determination of dynamic deflections of thin paved surfaces. This paper aimed to look into the behavior of in-service low-volume roads at a project level and develop a simplified method of designing overlay thickness for low-volume roads using two NDT methods. The results were compared and correlated for low volume roads (LVR). In this paper, responsive stress and strain of thin asphalt pavement beneath layers were analyzed using KENPAVE software. The overlay thickness for different sections ranges from 27.00 mm to 184.39 mm by LWD and BBD. The correlation for deflection values between LWD and BBD was R2 (0.741), while the overlay thickness designed by LWD and BBD showed a high correlation with R2 value of 0.994. This paper also serves to assess the capability of LWD to serve as a substitute to traditional BBD on low volume roads (LVR). The practical limitation of BBD test procedure and analysis may be overcome by conducting more test points using LWD on Indian thin asphalt low volume roads.

Keywords: LVR · LWD · BBD · Overlay thickness

1 Introduction

Lightweight Deflectometer (LWD) was investigated as a tool to aid in determining when to rehabilitate low-volume roads (LVR) by the overlay [1]. LWD directly measures the stiffness of pavement systems and a compacted layer needed for mechanistic pavement

H.-H. Zhu et al. (Eds.): BRWSG 2021, LNCE 230, pp. 175–182, 2022.
https://doi.org/10.1007/978-981-16-9963-4_14

design [2]. LWD has been used over thin, flexible pavements over the past decades [3–18]. India has adopted the Benkelman Beam deflection (BBD) technique for overlay thickness design [19]. Strengthening existing pavement may provide additional thickness in one or more layers over the existing thin asphalt layer [20]. An analytical method of overlay design has a few advantages, such as considering the variation of loading types, which will give more exact and accurate results. The purpose of this study is to make an attempt to analyze the existing pavement structural condition and to calculate the residual life and determination of overlay thickness required based on the pavement deflection measurements using LWD lateral geophones. The deflection bowl was analyzed by Method of Equivalent Thickness (MET), firstly proposed by Sharif and Mustaffa [21], and the results were obtained as elastic modulus in each layer. Determining the pavement structural condition by considering the factors of fatigue and rutting life of a pavement and estimating the residual life of the pavement and the overlay thickness needed were obtained. The results of Resilient Moduli signify in such a way that the lesser the resilient moduli value, the lesser the strength of the pavement. The estimation of residual life for each section was carried out, and the results show that the residual life of pavement sections between 0–1 year needs immediate overlay and the residual life of pavement sections more than 20 years is strong enough with no need for pavement sections overlay.

The LWD and BBD test was performed on a given LVR section, and elastic properties and overlay thickness were correlated. The stress and strain were also estimated of each layer to understand the performance of each layer under dynamic wheel load using KENPAVE software.

2 Methodology

A Test section was selected based on the reconnaissance survey; subsequently, a traffic survey was carried out on the test section for the duration of eight months from June 2011 to March 2012 and the commercial vehicles per day (CVPD) was 398, which are less than 450 CVPD which satisfies the criteria of low volume road to determine overlay thickness [22]. The length of the test section was 550.00 m and was divided into 11 sub-sections, i.e. 50 m each [19].

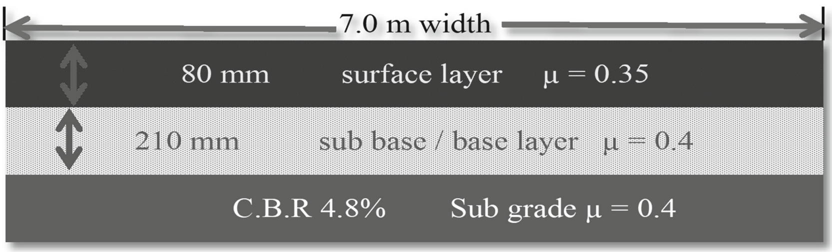

Fig. 1. Crust thickness of the test Sect. 0.0 to 550.00 m

The cross-section details of the pavement, which notifies the thickness, Poisson's ratio of various layers and subgrade CBR, is shown in Fig. 1. Further, a Pavement condition survey was carried out, and it was found that functional distress over existing pavement was more than 40 to 60%. KENLAYER is a sub-program of KENPAVE and it is used to determine the vehicle wheel load responses in terms of stresses, strains, and displacements in flexible pavement structures. Main reason for selecting this software is having an advantage of considering different axle load configurations such as, single, dual, tandem and tridem etc. Eventually, flexibility in selecting different material properties of pavement behavior models like linear elastic, nonlinear elastic and viscoelastic. The primary failure criteria of flexible pavements are fatigue cracking and permanent deformation or rutting. In this paper, based on the estimated stress and strain values, the allowable number of load repetitions was estimated.

2.1 LWD and BBD Experiments

The LWD test was conducted on the selected test location per ASTM standards with a sand pad on the wheel path [2, 23–2]. This LWD study 150 mm diameter plate was considered for the surface course, and 300 mm diameter plate was used over sub-base and subgrade layers. The deflections observed from LWD are recorded in Personal Digital

Fig. 2. (a). LWD tests points, **(b).** Testing of LWD, **(c).** BBD test on the study location.

Assistant (PDA) of Trimble make, and a mass of 20 kg produce approximate impact load values of 16 kN, and test procedure was shown in Fig. 2 (a) and (b). Similarly, the BBD test was conducted on the test points of LWD, as shown in Fig. 2 (c).

3 Results and Discussion

Total eleven sections were selected for LWD and BBD test. LVR is 2 lane (7.00 m) two way traffic Road. Tests were conducted on the wheel path of both directions in staggered manner. LWD data was collected at the same location where BBD was conducted at every 50.0 m section. LWD observed the maximum deflection values at Chainage 150.0–200.0 m, and the maximum deflection was observed at 150.00 – 250.00 m by BBD, as shown in comparisons of LWD and BBD deflections is shown in Fig. 3. LWD and BBD data were correlated and was found with R2 (0.740), as shown in Fig. 4. The modulus of sub-grade and sub-base elasticity was estimated, i.e. 48 MPa and 108 MPa, respectively [25].

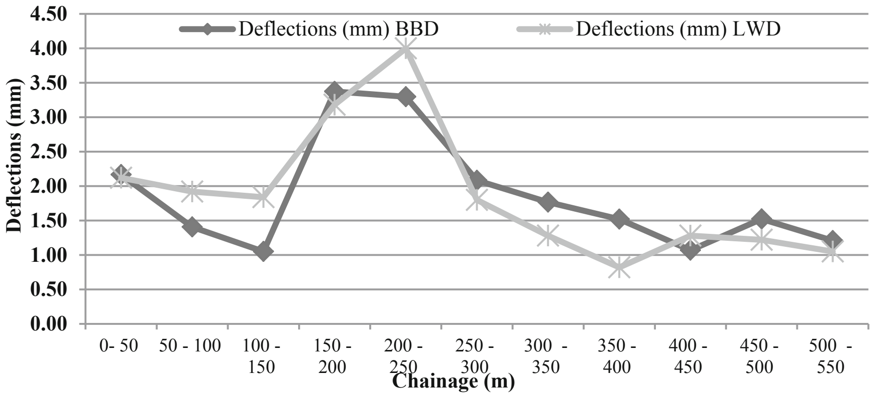

Fig. 3. Deflections by LWD & BBD

The modulus of elasticity for the surface layer was estimated through back-calculation by LWD mod software, as shown in Table 1 [26]. Results illustrate that the higher modulus of elasticity value, the higher the stiffness and structural property of the pavement. The maximum modulus of elasticity value was observed at 400.00–450.00 m indicates that the existing pavement condition is good. Bituminous Macadam was considered for overlay, and hence the thickness of overlay was estimated for distinct surface moduli 500, 550, 600, 650, 680, 700 and 760 MPa [25].

The in-situ moisture content and the plasticity index were 20.8% and 28%. The recorded annual rainfall is more than 1300, and the same was considered while designing the overlay thickness for 0.5 msa, 1.0 msa, 2.0 msa, 5.0 msa, 10.0 msa, 20.0 msa and 100.0 msa. The overlay thickness estimated from BBD analysis for 0.5, 1.0, 2.0, 5.0, 10.0, 20.0 and 100.0 msa [25] and overlay thickness estimated from the LWD analysis for the required elastic modulus for an overlay material of 500, 550, 600, 650, 680,

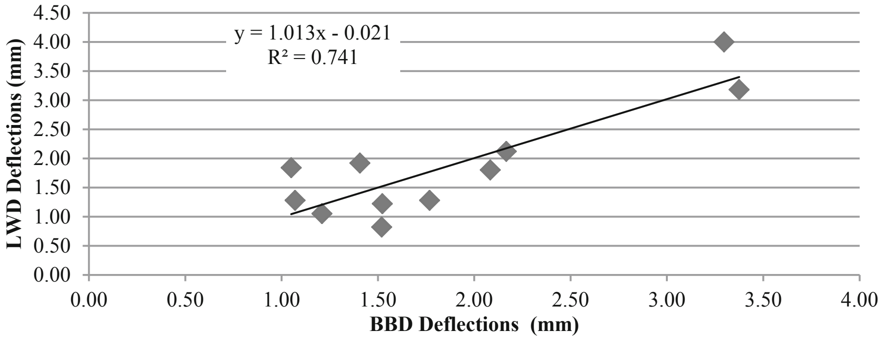

Fig. 4. Correlation between LWD and BBD deflections

Table 1. Modulus of elasticity values.

Sl. no.	Chainage (m)	Modulus of elasticity (MPa) asphalt layer
1	0–50	1381.7
2	50–100	3862.6
3	100–150	4590.0
4	150–200	494.7
5	200–250	2968.4
6	250–300	4621.5
7	300–350	7832.2
8	350–400	7366.0
9	400–450	9611.4
10	450–500	6531.9
11	500–550	3597.5

Table 2. Overlay thickness by BBD and LWD

Sl. no.	BBD (MSA)	LWD (MPa)	Overlay thickness (mm)	
			BBD	LWD
1	0.5	500	24.36	27.00
2	1.0	550	34.43	42.90
3	2.0	600	56.00	67.20
4	5.0	650	87.02	106.30
5	10	680	105.30	131.10
6	20	700	119.19	153.80
7	100	760	171.60	202.10

700 and 760 MPa by using LWD mod software is shown in Table 2. The correlation of overlay thickness obtained from the LWD and BBD was found suitable (R2 = 0.994). Henceforth, the corresponding equivalent values for the BBD and LWD in terms of MSA and MPa for estimating the overlay thickness were summarized in Table 2.

3.1 Estimation of Stress and Strain Analysis

Based on the modulus of elasticity, Poisson's ratio and thickness of each layer, the stress and strains at different sections were estimated using KENPAVE software [27]. This also estimates the allowable load repetitions, as shown in Table 3.

Table 3. Example analysis of structural evaluation at Chainage 400.00–450.00 m.

Chainage (m)	point	Vertical Coordinate (cm)	Vertical Displacement (cm)	Vertical Stain	Vertical Stress (kPa)	Tensile Strain	Tensile Stress (kPa)
		0	0.09105	-7.549E -05	549.170	6.773E -05	8136.647
		8	0.09141	8.835E -05	53.959	-9.535E -05	-8472.126
	1	8.1	0.09138	3.470E -04	53.861	-9.617E -05	21.153
		29	0.08343	4.249E -04	35.411	-2.220E -04	-10.832
		29.1	0.08336	6.126E -04	35.359	-2.218E -04	7.585
		0	0.09341	-8.231E -05	0.000	7.257E -05	8793.888
		8	0.09373	9.053E -05	56.490	-1.028E -04	-8402.559
400-450		8.1	0.09369	3.608E -04	56.387	-1.035E -04	24.125
		29	0.08526	4.539E -04	37.354	-2.322E -04	-12.295
	2	29.1	0.08519	6.519E -04	37.297	-2.321E -04	8.028

The maximum tensile strain and vertical compressive strain values observed on the bitumen layer were −1.028E-04 and 6.519E-04. Based on the tensile strain value, allowable load repetitions to prevent fatigue failure were estimated, i.e. 50.24 msa and based on the vertical compressive strain values, allowable load repetitions for rutting criteria were estimated, i.e. 11.50 msa [25]. NDT and assessment of deflection behavior of flexible pavements for low volume roads concerning the in-situ material properties is a promising procedure for evaluating the structural capacity of pavements.

4 Conclusions

In this paper, the overlay thickness of LVR was studied with conventional BBD and LWD techniques. The study was conducted on a 550 m stretch of 2-lane undivided road of 7.00 m carriageway width. The data was collected at every 50.0 m interval at both sides of the wheel path pavement. The deflections by BBD and LWD were correlated and found in poor relation with R2 (0.741). However, the correlation between overlay thickness estimated by LWD and BBD is good (R2 = 0.994). The elasticity modulus of the surface layer was estimated by LWD mod software.

Further, the equivalency values of MSA of BBD and MPa of LWD is obtained. Analysis of stress and strain analysis was estimated using KENPAVE software. The allowable load repetitions for fatigue and rutting failure criteria were estimated. The allowable load repetitions were estimated for fatigue and rutting criteria based on the estimated layer elastic properties. Finally, it was concluded that more data points are required to get the reliable correlation between LWD and BBD for overlay thickness design. However, this study proves that LWD may substitute conventional BBD in estimating the overlay thickness for low volume roads.

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