SSRG International Journal of Civil Engineering
ISSN: 2348 – 8352 /doi:10.14445/23488352/IJCE-V7I7P110

Volume 7 Issue 7, 73-82, July 2020
©2020 Seventh Sense Research Group®

Feasibility of Lightweight Deflectometer Measured Surface Deflection on Flexible Pavement for Quality Assessment

Vishal Kumar Narnoli[#1], Sanjeev Kumar Suman[*2]

[# 1]*Ph.D. student, Department of Civil Engineering, National Institute of Technology Patna, Patna, Bihar, India, Pin-800005*

[*2]*Assistant Professor, Department of Civil Engineering, National Institute of Technology Patna, Patna, Bihar, India, Pin-800005*

Received Date: 04 June 2020
Revised Date: 12 July 2020
Accepted Date: 17 July 2020

Abstract

In this study, a lightweight deflectometer (LWD) is used to measure the surface deflection of the flexible pavement in Bihar; India. An LWD field-testing program was undertaken on 30 test locations of all four roads for relative condition assessment. The surface deflection obtained by using a 150 mm diameter plate was found to be 1.5 - 1.8 times higher than the surface deflection obtained by using 300 mm diameter plates. The coefficient of variation (COV) of the surface deflection ranges from 9 to 15% and 7 to 27% in the case of 300 mm and 150mm diameter plate respectively. The result shows all the deflection datasets are normal. The control chart shows the uniformity of data except for a few sections of roads. The LWD device was found to provide quick test results and simple to operate on any pavement, and hence the frequency of deflection tests can be increased, leading to an improvement in the overall quality of pavement and, thus, pavement performance.

Keywords — *LWD, surface deflection, flexible pavement, descriptive statistics, normality check, uniformity check*

I. INTRODUCTION

The pavement is a fundamental transportation infrastructure system to sustain both moving vehicles and people. The pavement deteriorates under the action of traffic loading and prevailing environmental effect. To ensure adequate serviceability of pavement, the performance of pavement is timely measured. The responses in terms of strain, stress, and deflection are used in pavement structural evaluation. In developing countries, the Benkelman beam (BB) test has been widely used for structural evaluation and strengthening of existing flexible pavement. This test is simple and relatively inexpensive with another deflection test. The pavement deflection is measured due to the static loading caused by the dual wheel of a loaded truck. The overlay design by BB test is based on the rebound deflection which is a measure of pavement performance [11]. The main drawback of BB test is its time-consuming nature, the requirement of the lane closure, and limited data set for analysis. To cope with this deficiency many organizations are using other NDT devices such as Falling Weight Deflectometer (FWD) and Light Weight Deflectometer (LWD) testing to evaluate the structural performance of the pavement. The routine assessment of pavement structural behavior helps in the adaptation of better pavement design and rehabilitation strategies. The LWD is a portable device conventionally used for quality control (QC) and quality assurance (QA) of compacted soil and granular layers. For measuring the stiffness of the thin asphalt pavement layer, it gives a quick estimate of stiffness characteristics (surface modulus) of the material. Since low amplitude peak load is generated from LWD so its use for thick asphalt pavement layer is very seldom. Several factors such as the stiffness of the surface layer, stress magnitude, and its stress distribution and diameter of the testing plate affect the depth of influence of each test [17]. The main limitation of the LWD devices is their limited depth of influence, i.e. about 1.5 – 2 times the plate diameter [1, 7-10, 12-13, 18-19].

The LWD device with a single geophone at the center of the plate cannot back-calculate the surface modulus of the multilayer pavement structure. Since the depth of influence of LWD testing extends to more than one layer of pavement, the measured modulus represents the composite modulus[15,19]. LWD test conducted on the pavement layer having a thickness less than the depth of influence yields composite modulus of pavement [2]. The composite modulus is calculated using the Boussinesq theory for uniform stress distribution under the circular plate. The positions of the additional geophones do not affect the surface modulus of the surface layer[12-13].

The LWD being a plate load test gives a direct estimate of the composite modulus of pavement. Due to this, the device gained tremendous popularity among various stakeholders of pavement engineering for QC/QA. The device has been extensively used in various developed nations by their respective transportation agencies. Quality assurance (QA) is defined as all the planned and systematic activities implemented within the quality system and demonstrated as needed, to provide adequate confidence that an entity will fulfill the requirements.

The use of LWD for the evaluation of thin surface flexible pavement has been discussed and reported a good correlation between LWD and FWD data [8-9]. The LWD testing was also performed on a paved surface and **a** comparison has been made for the composite modulus data obtained from FWD and LWD [14]. An attempt has been made to evaluate the potential use of LWD for measuring the in-situ stiffness pavement materials [12-13]. The LWD and FWD testing were conducted on asphalt concrete road with layer thickness varying from 20-35 cm. The surface modulus value was found to increase linearly with an increase in drop weight. The LWD was found to be an effective and economically viable tool for the evaluation of local asphalt surface pavements [6].

Regular monitoring and assessment of pavement are necessary to ensure the serviceability of flexible pavement. The pavement surface deflection under standard load and the distresses are important parameters for pavement quality assurance. This paper strives to develop a quality assurance (QA) procedure for preventive and periodic maintenance of flexible pavement. The LWD offers a faster, low cost, direct, and reliable estimation of surface deflection of flexible pavement.

II. LIGHTWEIGHT DEFLECTOMETER(LWD)

In this paper, the Dynatest LWD 3031 is used for pavement evaluation (Fig.1). Testing was performed using ASTM E 2583[3] specification. Generally, a single person can be sufficient for handling LWD and it takes about 3 - 4 minutes for testing at each test point. The surface deflection is measured with a central geophone located at the center of LWD. Using peak force applied and resulting deflection in equation 1, the composite modulus (E_o) is computed [19].

$$E_O = \frac{k(1-\upsilon^2)\sigma \mathrm{R}}{\delta_c} \quad (1)$$

where k = π/2 for rigid plate or 2 for flexible plates respectively, δc = centre deflection; σ = applied stress in kPa; and R = radius of the plate in mm, υ = Poisson's ratio taken as 0.35 for bituminous layers [5].

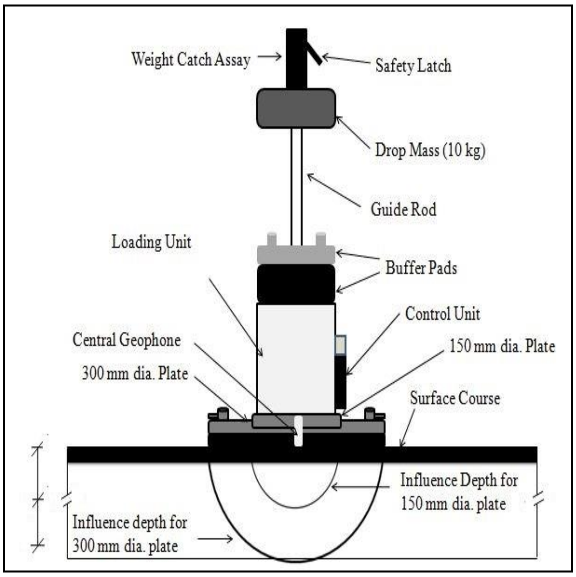


Fig 1: Description of Light Weight Deflectometer

III. TESTING PROGRAMME AND ANALYSIS

A. Study Area

The study was carried out on four flexible pavements situated in the proximity of Patna, Bihar, India. The flexible pavements under study are that caters daily commercial vehicles per day ranges from 1000 to 2500. Table-I shows the details of the road section under consideration and their structural composition obtained from the detailed project report (DPR) of the department of road construction.

B. Testing Procedure

It is customary to conduct the pavement evaluation just after the monsoon season. The LWD testing was performed after the monsoon season in August and September to simulate the worst condition. The ambient air temperature on the day of testing ranges from 32 °C to 43 °C. The LWD testing was performed on the surface of the pavement along the wheel path of the vehicle at an interval of 250 m as shown in Fig.2 using plate diameter namely 150 mm and 300 mm. The calibration of the device is necessary for the validity and reliability of the test result. The LWD testing device was calibrated and verified as per the guidelines of ASTM E2835 [4].

Before conducting the test at a point, a thin layer of fine-grained sand having a thickness of less than 20 mm is placed. The rubber pad is placed over the sand layer, over which the steel plate and LWD are mounted.

TABLE I

Detail of the Road Sections for the Survey

Road No.	Designation w.r.t. plate size(300mm &150mm)	Latitude / Longitude		Length (Km)	CBR of Subgrade (%)	Design thickness of layers(mm)		
		Testing start point	Testing Endpoint			Bituminous Layer	Base Course	Sub-base course
1	R1-300,R1-150	25°25'38.8"N 85°18'24.9"E	25°23'49.1"N 85°20'41.8"E	5.5	8	100	250	200
2	R2-300,R2-150	25°16'30.1"N 85°00'37.7"E	25°12'51.8"N 84°59'08.9"E	7.5	6	105	250	260
3	R3-300,R3-150	25°47'44.6"N 85°16'48.2"E	25°51'21.7"N 85°17'34.5"E	7.25	8	120	250	240
4	R4-300, R4-150	25.557810N 85.257732E	25°30'07.3"N 85°16'06.2"E	7	10	140	250	200

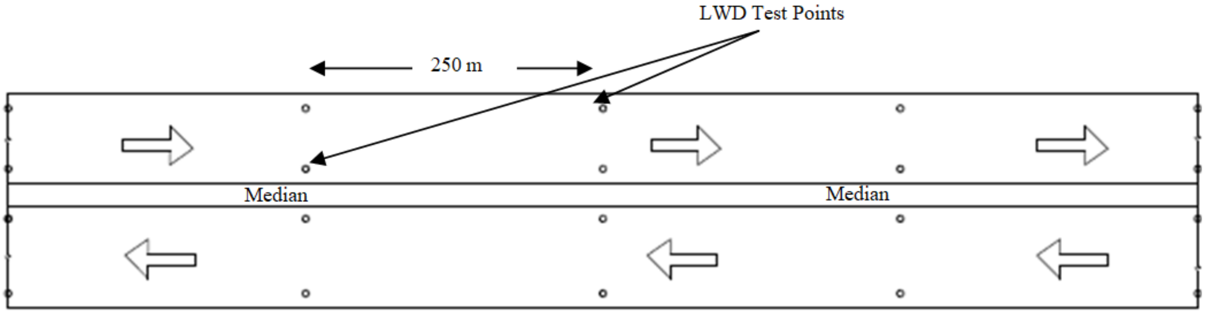


Fig 2: Typical layout of LWD testing points on the selected road stretch

It is ensured that the LWD test on level ground and that stress distribution is uniform. A drop mass of 10 kg falls freely from a height of 850 mm. The total weight of equipment is approximately 22 kg. The standard sizes of the loading plate used are 300 mm and150 mm. The peak force generated by 10 kg drop mass lies in the range of about 6.9 kN to 7.1 kN with a half-sine pulse of 15-millisecond duration. The load cell has a capacity of impact load ranging from 0-25 kN, with an accuracy of 2 % ± 2 kPa and a precision level of 0.0003 kN. A total of ten drops are performed at each test point. The first three seating drops are performed to ensure close contact. Then another seven drops were performed, and the deflection corresponding to each blow is noted. The central deflection is measured by a deflection sensor also called geophone, which is a velocity transducer having an accuracy of 2% ± 2 µm and a precision level of 0.1 µm. The dual plate system allows testing with the two-plate diameter at the same spot without the movement of the instrument.

IV. RESULT AND DISCUSSION

A. *Descriptive Statistics*

Descriptive statistics describe the characteristics of a data set. Table II-III shows the descriptive statistics of deflection data collected for different four sites using 300mm and 150mm diameter plates of LWD. The COV is a very useful comparative statistical measure. Due to its dimensionless nature, it is very suitable for structural and functional data analysis of each homogenous section for a particular pavement. The COV can help the pavement engineer to identify the pavement section needing urgent remedies. The test data with lower COV value implies that the data are less dispersed than the test data with higher COV. The first three deflection data at each test point were discarded from the dataset because the first three drops are noticed as seating drops. This procedure is adopted according to the guidelines laid in ASTM E2835 [4].

B. *Normality test for deflection data*

In statistics, *normality tests* are used to determine if a data set is well-modeled by a *normal* distribution and to compute how likely it be normally distributed. The Ryan-Joiner (RJ)[22] statistic measures, how well the data follow a normal distribution by calculating the correlation between observed data and the normal scores of observed data. This test is similar to the Shapiro-Wilk normality test [22]. If the RJ correlation coefficient is near 1, the dataset is likely to be normal.

Table II
Descriptive Statistics for 300 mm diameter plate

Description	Surface Deflection (micrometer)				Surface Modulus (MPa)			
Test Site	1	2	3	4	1	2	3	4
No. of test points	30	30	30	30	30	30	30	30
Mean	45.00	59.00	44.00	76.00	595.20	455.34	603.21	349.40
Median	46.00	58.50	44.00	75.50	572.55	450.03	598.30	348.69
Standard Deviation	6.44	9.43	3.96	7.15	87.71	71.84	56.96	33.36
COV	0.15	0.16	0.09	0.10	0.14	0.16	0.09	0.09
Minimum	34.00	43.00	36.00	62.00	446.19	351.00	516.18	299.15
Maximum	59.00	75.00	51.00	88.00	774.26	612.21	731.25	424.60
Max-Min	25.00	32.00	15.00	26.00	328.08	261.21	215.07	125.45

Table III
Descriptive Statistics for150 mm diameter plate

Description	Surface Deflection (micrometer)				Surface Modulus (MPa)			
Test Site	1	2	3	4	1	2	3	4
No. of test points	30	30	30	30	30	30	30	30
Mean	70.00	100.40	56.00	86.00	757.16	559.15	946.24	615.80
Median	69.00	94.00	55.50	87.00	763.04	560.11	948.73	605.17
Standard Deviation	4.90	26.84	4.84	6.85	52.93	140.49	79.59	49.75
COV	0.07	0.27	0.09	0.08	0.07	0.25	0.08	0.08
Minimum	61.00	57.00	48.00	75.00	666.46	327.02	797.73	548.44
Maximum	79.00	161.00	66.00	96.00	863.11	923.68	1096.88	702.00
Max-Min	18.00	104.00	18.00	21.00	196.66	596.67	299.15	153.56

This paper presents the normality test for LWD deflection measurements carried out on four different roads. If the strength of correlation falls below the appropriate critical value, the null hypothesis of population normality will be rejected. From the probability distribution plot of the normality test, it is reasonable to assume that the deflection data follows the normal distribution. Results are presented in Figures 3-6, which shows RJ value approaching one; it means to follow the normal distribution.

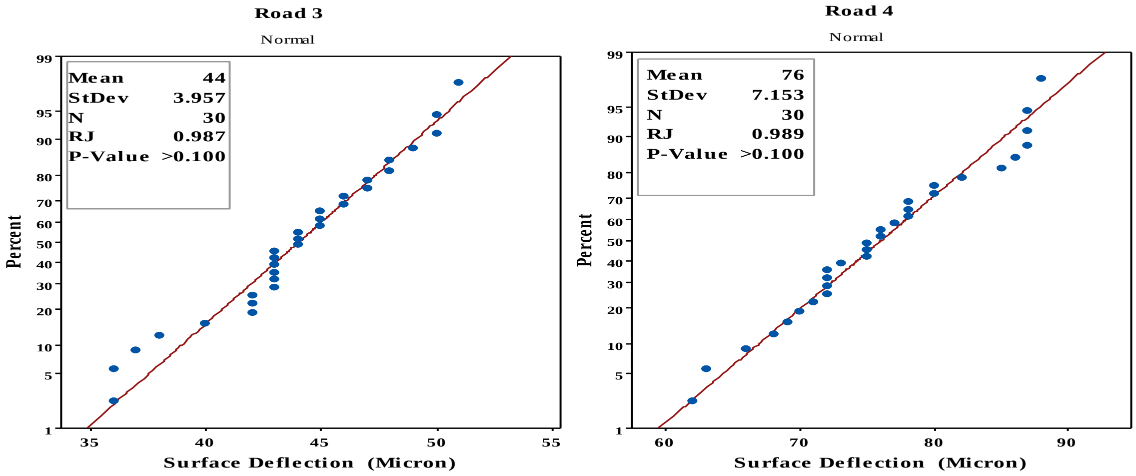


Fig 4: Normality check plot for R3-300(left) and R4-300(right)

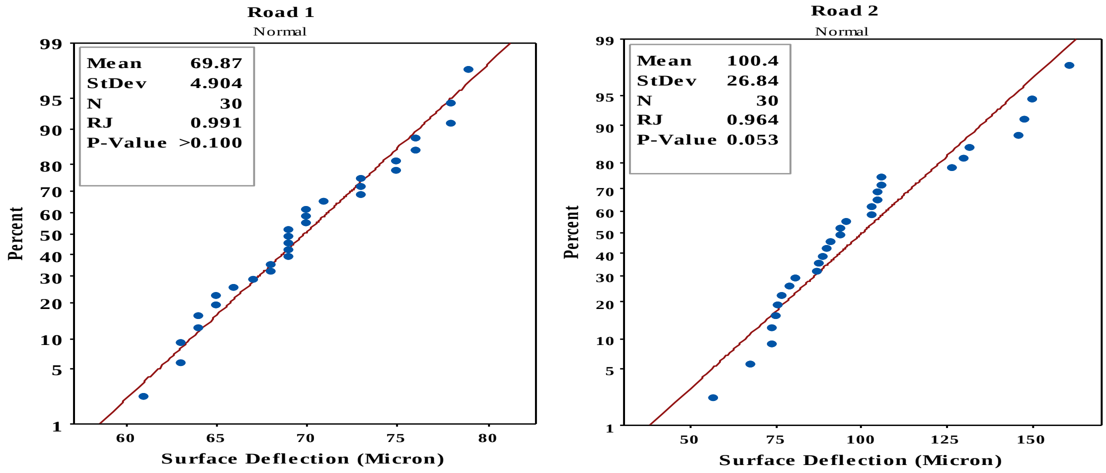


Fig 5: Normality check plot for R1-150(left) and R2-150(right)

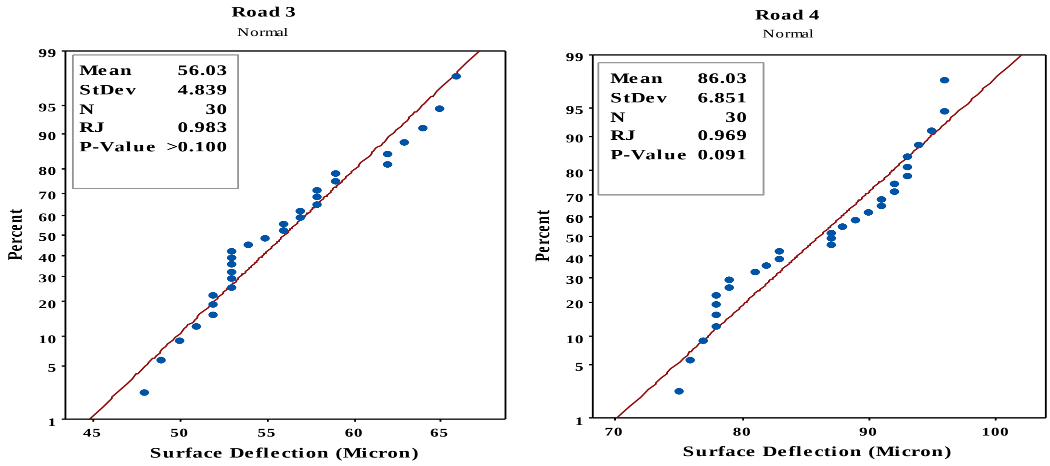


Fig 6: Normality check plot for R3-150(left) and R4-150(right)

C. Deflection data Uniformity Test

The deflection data uniformity test is used to determine the degree of homogeneity of variance test data, which is performed by using the control chart in Minitab software. The control chat can show the deviation of data (out of control) of the average value. Individual Moving Range (I-MR) chart technique is used for observation of individual data. The formulation of the upper control limit (UCL), the centerline (CL), and lower control limit (LCL) for individual control chart are as follows:

$$CL = \bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (2)$$

$$UCL = \bar{x} + 3\frac{\overline{MR}}{d_2} \quad (3)$$

$$LCL = \bar{x} - 3\frac{\overline{MR}}{d_2} \quad (4)$$

Where the value of d_2 is obtained from Table factor for constructing variable control chart. Said to be uniform if the observation plots of all the data are between the upper control limit (UCL) and lower control limit (LCL) [16]. Nonuniformity of road section data may be due to instrumental error, personal error or testing site is not favorable. Hence, it requires a thorough investigation. The deflection data uniformity test results are shown in Figure 7-14.

Deflection data uniformity test result shows that all the values of deflection data are uniform in the roads R2-300, R4-300, R1-150, and R4-150.Whereas, the values of deflection data of 3.34%,13.34%,16.67% and 6.67% are non-uniform in the roads R1-300,R3-300,R2-150 and R3-150 respectively.

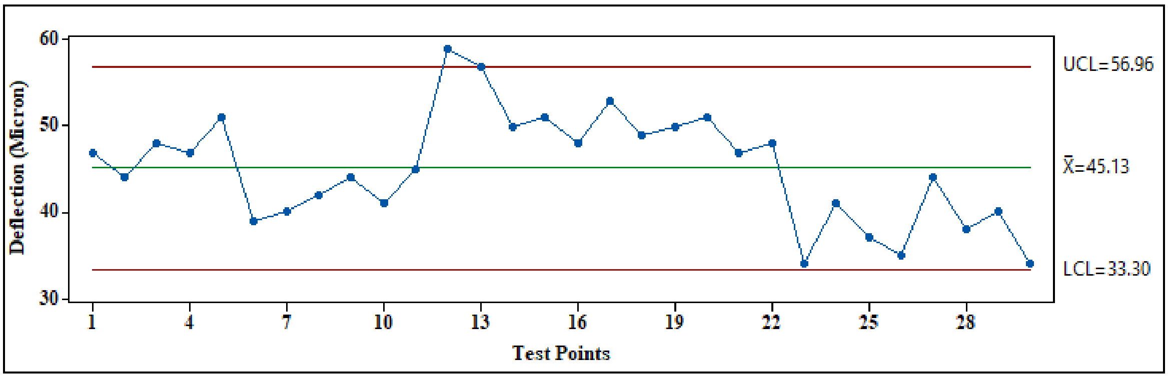


Fig 7: Control chart for R1-300

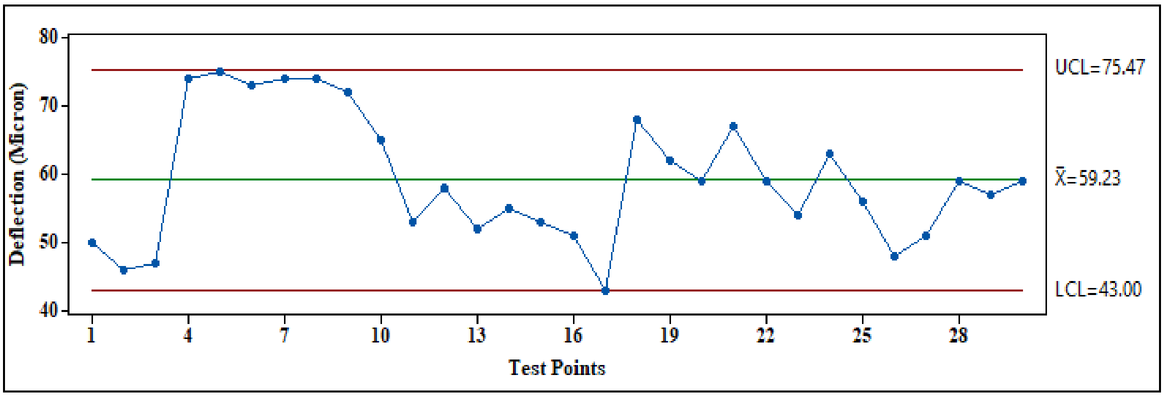


Fig 8: Control chart R2-300

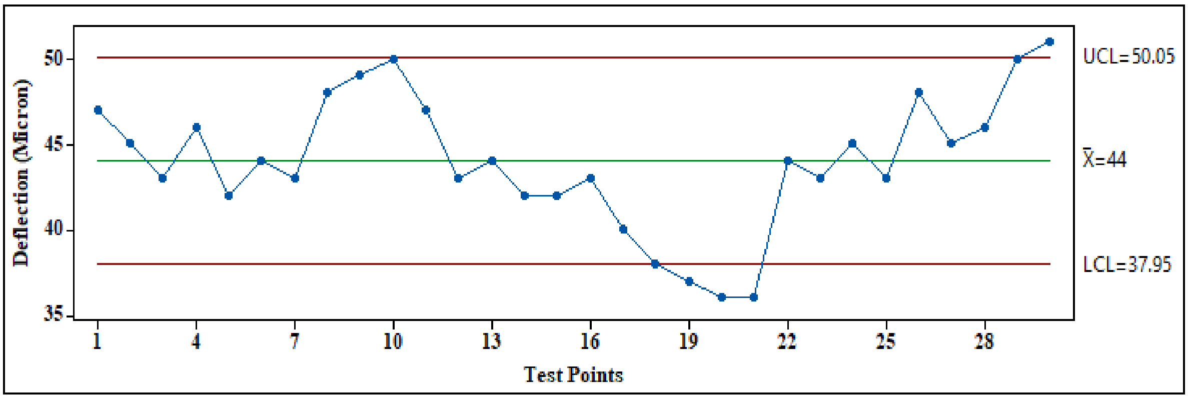


Fig 9: Control chart R3-300

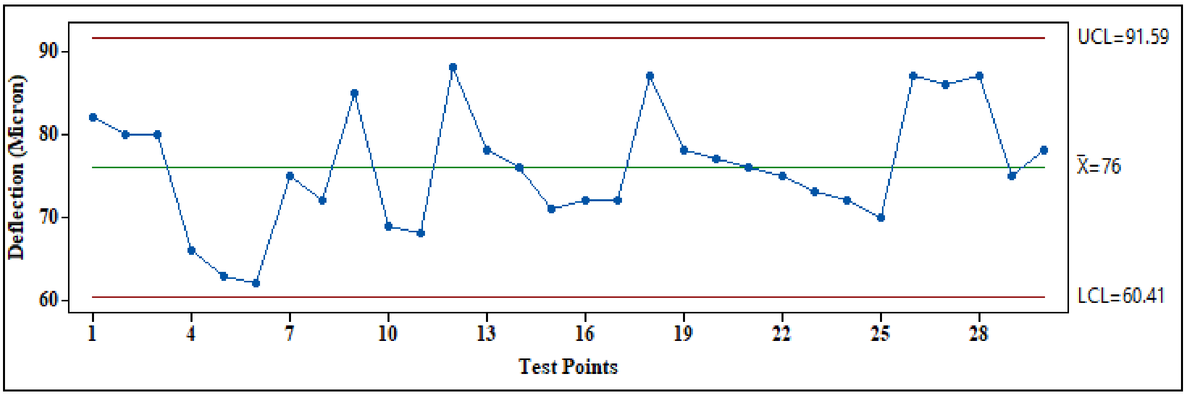


Fig 10: Control chart R4-300

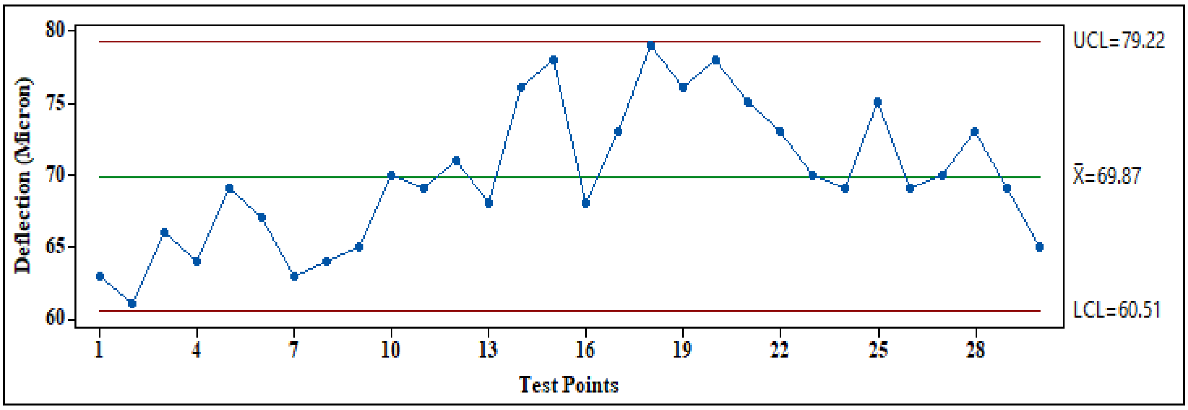


Fig 11: Control chart R1-150

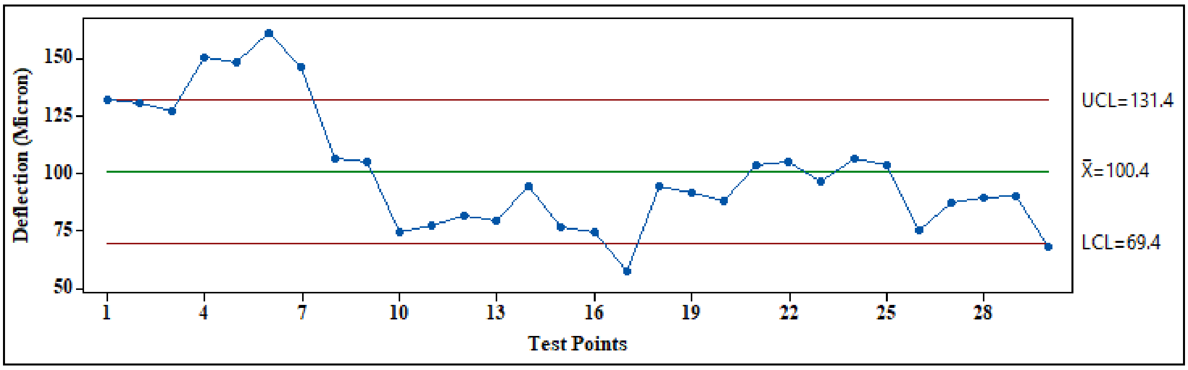


Fig 12: Control chart R2-150

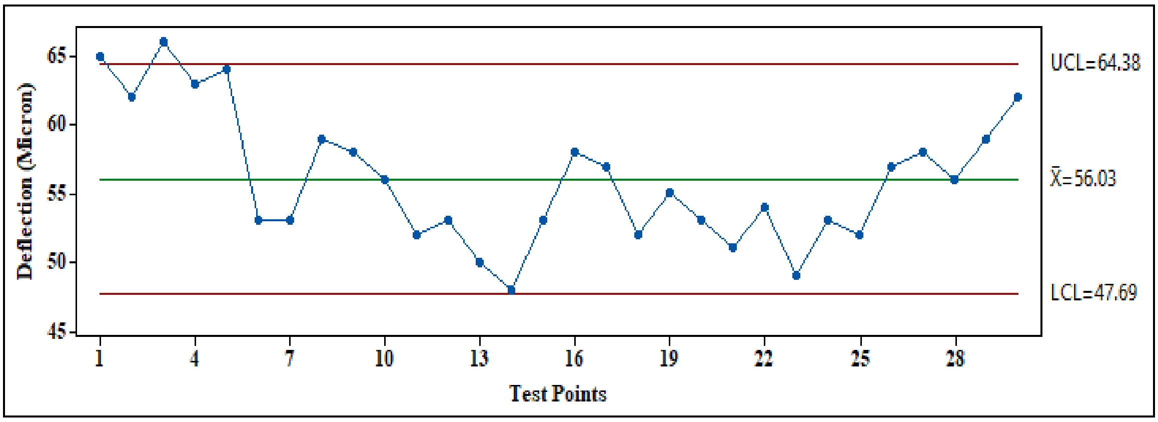


Fig 13: Control chart R3-150

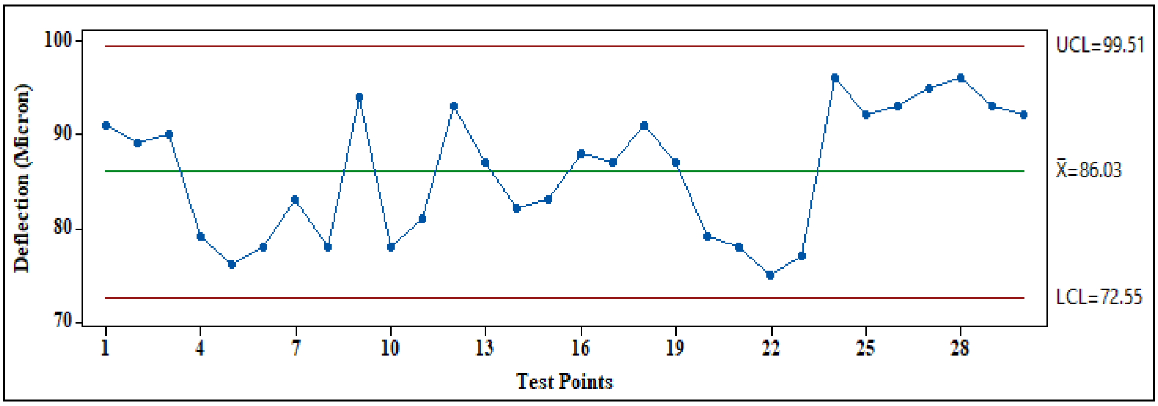
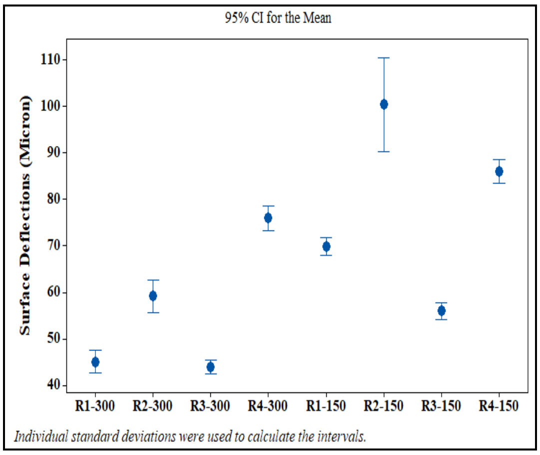


Fig 14: Control chart R4-150

D. Interval Plot

The interval plot of LWD testing conducted with varying plate sizes for the selected roads is shown in Fig.15 From the interval plot of LWD deflections it was observed that with an increase in age of the pavement, the variability of LWD deflection at its different homogenous section increases.


95% CI for the Mean

Individual standard deviations were used to calculate the intervals.

Fig 15: Interval plot for deflection data

The variability in LWD obtained deflections were found to be relatively low for newly constructed pavements. The road-1 and 2, which were in service for two and three, years respectively showed higher variability for deflections in the case of 150 and 300 mm diameter plates. For road 2, the deflections values obtained using 150 mm diameter were found to vary relatively very high as compared to other test locations. This variability can be due to the roughness of the test surface.

V. SUMMARY AND CONCLUSIONS

In-situ LWD tests were performed on four numbers of flexible pavement roads to assess the feasibility of using LWDs for condition assessment of pavements. The testing program included LWD testing at 30 locations on surface layers for each road. The results of the study yield the following conclusions:

- LWD is a non-destructive instrument and it is gaining popularity due to its portability, single-person handling, time-saving, and quick result displaying. For fully deteriorated pavement sections, LWD testing with150 mm and 300 mm diameter plate showed no appreciable difference in deflection.

- Composite modulus or surface modulus obtained from the LWD test was found to be dependent on pavement layer thickness. The surface layer thickness showed a considerable influence on composite modulus.
- For the sections with no cracking and/or from low to medium cracking the surface deflection obtained by using 150 mm diameter plate was found to be 1.5 - 1.8 times higher than the surface deflection obtained by using 300 mm diameter plates.
- The coefficient of variation (COV) of the surface deflection ranges from 9 to 15% and 7 to 27%in cases of 300 mm and 150mm diameter plate respectively. A little bit higher value of COV needs to be checked for uniformity.
- Before uniformity check for deflection dataset, it needs to be performing normality test. The Ryan-Joiner (RJ) statistic measure for normality test was used. The result indicates that all the deflection datasets are normal. The control chart for uniformity check shows the LWD test measurements on the pavement surface can be considered uniform except for a few sections of roads.
- Since the LWD deflection measurement is a relative measure, hence it can be utilized for pavement condition assessment at the project level in the pavement management system.
- Therefore, more study is needed before recommending LWD as a device for structural health monitoring and pavement maintenance management.

Funding - Not applicable.

Acknowledgment

The authors are grateful to the Road Construction Department, Bihar for allowing conducting the testing on in-service roads. The authors are also grateful to Prof. Ramakar Jha, Head, Department of Civil Engineering, NIT Patna, and Dr. Ranja, Prof In-charge Transportation Lab, Department of Civil Engineering, NIT Patna for providing us the equipment and continuous support during this work.

VI. REFERENCES

[1] Alshibli K. A., Abu-farsakh M., and Seyman E., Laboratory Evaluation of the Geogauge and Light Falling Weight Deflectometer as Construction Control Tools, Journal of Materials in Civil Engineering, ASCE, 17(5) (2005) 560–569.

[2] Apeagyei A. K., and Hossain M. S., Stiffness-Based Evaluation of Base and Subgrade Quality Using Three Portable Devices, 88th Transp. Res. Board Annual Meet, (2010) 10–1721.

[3] ASTM Standard E2583, Standard Test Method for Measuring Deflections with a Light Weight Deflectometer (LWD)", Annual Book of Standards, ASTM International, West Conshohocken, PA. (2007).

[4] ASTM Standard E2835, Standard Test Method for Measuring Deflections using a Portable Impulse Plate Load Test Device, Annual Book of Standards, ASTM International, West Conshohocken, PA. (2011).

[5] Bilodeau J. P. and Doré G., Stress distribution experienced under a portable light-weight deflectometer loading plate, International Journal of Pavement Engineering, Taylor & Francis, 15(6)(2014) 564-575.

[6] Burhani A., Correlation study on the falling weight deflectometer and lightweight deflectometer for the local pavement system, MS Thesis, Russ College of Engineering and Technology of Ohio University, (2016).

[7] Commuri S., Zaman M., Beainy F., Singh D., Nazari M., Imran S., Barman M., Pavement Evaluation Using a Portable Lightweight Deflectometer, Technical report, Oklahoma Transportation Center, Midwest City, Oklahoma,2012; accessed from https://rosap.ntl.bts.gov on 04.01.2020.

[8] Fleming P. R., Frost M. W., Lambert J. P., Review of Lightweight Deflectometer for Routine in Situ Assessment of Pavement Material Stiffness, Journal of Transportation Research Board, Transportation Research Record, 2004(1) (2008) 80–87.

[9] Fleming P. R., Frost M. W., Rogers C. D. F., A comparison of devices for measuring stiffness in situ, Proc. Fifth Int. Symp. Unbound Aggregates Roads, UNBAR 5, Nottingham, United Kingdom, (2000) 193–200.

[10] Hoffmann O. J. M., Guzina B. B., Drescher A., Stiffness Estimates Using Portable Deflectometers, Transportation Research Record, Journal of Transportation Research Board, 1869(1)(2007) 59–66.

[11] IRC: 81, Guidelines for the strengthening of flexible road pavements using Benkelman beam deflection technique, Indian Road Congress, New Delhi, India, (1997).

[12] Kavussi A., Yasrobi S., Evaluation of FWD as Potential Quality Control Tool of Pavement Layers, Journal of Civil Engineering and Management, 16(1)(2010) 123–129.

[13] Kavussi A., Rafiei K., Yasrobi S., Evaluation of PFWD as potential quality control tool of pavement layers, Journal of Civil Engineering and Management, 16(1)(2010) 123–129.

[14] Khosravifar S. Standardizing lightweight deflectometer modulus measurements for compaction quality assurance, Maryland department of transportation state flexible pavement administration research report, University of Maryland,(2017).

[15] Lin Y.C., Chen A., Chou C. P., Lin Y.C., Chen A., Temperature Adjustment for Light Weight Deflectometer Application of Evaluating Asphalt Pavement Structural Bearing Capacity, Transportation Research Record, Journal of Transportation Research Board, 2641(1)(2017) 1–16.

[16] Montgomery, Douglas C., Introduction to Statistical Quality Control, Sixth Edition, United States of America,(2009).

[17] Nazzal M. D., Abu-Farsakh M. Y., Alshibli K., Mohammad L., Evaluating the light falling weight deflectometer device for in-situ measurements of elastic modulus of pavement

layers, Transportation research record, Transportation research board, National research council, Washington, DC,(2007) 13-22.

[18] Park S. S., Bobet A., Nantung T. E., Correlation between Resilient Modulus (MR) of Soil, Light Weight Deflectometer (LWD), and Falling Weight Deflectometer (FWD), Report No. FHWA/IN/JTRP-2018/08, Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, DOI: 10.5703/1288284316651.

[19] Senseney C., Mooney M., Characterization of Two-Layer Soil System Using a Lightweight Deflectometer with Radial Sensors, Transportation Research Record, Journal of Transportation Research Board, 2186(2186) (2010) 21–28.

[20] Steinert, B. C., Humphery, D. N., Kestler, M. A., Portable falling weight deflectometer study, New England Transportation Consortium, Univ. of Maine, Orono, ME, (2005); Accessed from www.semanticsscholar.org on 20.01.2020.

[21] Sulewska M. J., Bartnik G., Application of the Light Falling Weight Deflectometer (LFWD) to Test Aggregate Layers on Geosynthetic Base, Procedia Eng. 189(5) 221–226.

[22] Ukponmwan H.N., Ajibade F.B., Evaluation of Techniques for Univariate Normality test using Monte Carlo Simulation, American Journal of Theoretical and Applied Sciences,(2017)6(5-1),51-61.

[23] Vennapusa P. K. R., White D. J., Comparison of lightweight deflectometer measurements for pavement foundation materials, Geotech. Test Journal,.32(3)(2007) 239–25.

[24] AE. Prakash Kumar Makwana, Dr. Rakesh Kumar Correlative Study of LWD, DCP and CBR for sub-grade"International Journal of Engineering Trends and Technology 67(9)(2019) 89-98.