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Comparative study for strengthening of existing flexible pavement using falling weight deflectometer and benkelman beam deflection techniques

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Abstract— **The failures of different categories of roads are pre-dominant in huge developing countries like India. As a result of improved connectivity the traffic is increasing on existing roads, so need of evaluation arises to provide a safe and smooth riding. "Falling weight deflectometer" (FWD) and "Benkelman beam deflection" (BBD) are prominent techniques in India for strengthening and evaluation of existing pavement. FWD is non-destructive testing for evaluation using "Dynamic Loading" seems more accurate than BBD method which have static loading pattern. But in India later one is used quite dominantly than first one. So this paper deals with difference in overlay thickness required for strengthening by these two techniques, cost reduction by Providing Optimized overlay thickness.**

For this study 3 homogeneous sections on Existing Bituminous Stretch of NH-102 in state of Bihar were selected .Traffic survey, Evaluation of existing subgrade, Pavement Condition Survey ,Different laboratory tests needed were performed. Deflections by FWD with guidelines of IRC-115 and By Benkelman beam with guidelines of IRC-81 were measured on selected sections. Remaining fatigue and rutting life after and before overlay were also checked By IIT-PAVE Software.

There was a significant difference in Overlay Thickness required for both the methods. FWD technique is more closer to optimized overlay thickness than BBD.

Keywords*— Falling weight Deflectometer; overlay ;Subgade; Benkelmean Beam *(key words)

I. *Introduction*

Pavement evaluation is done using CBR method, plate bearing methods which are destructive and Benkelman beam deflection(BBD),Falling weight deflectometer (FWD) and Light weight deflectometer (LWD) are the non-destructive techniques. Comparative study of BBD and FWD techniques signifies the importance of static and dynamic load patterns on the road, as FWD works on dynamic loading pattern and BBD works on Static loading pattern.

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Murillo Feo C.A. and Bjarano Urrego L.E., research on correlation between deflections measurement on flexible pavements under static and dynamic loads also shows the need of this comparative study. IRC-115 (2014), states about the benefits of advancing from BBD to FWD technique. "discussion on FWD & BBD " by Deming Zhang, China also concludes with the benefits of FWD technique. A research by Olle Tholen, Jay Sharma and Ronald L. Terrel states that FWD provides a force pulse shape that tends to simulate moving wheel load better than the other devices. Different studies of FWD by Swift [1973], Ullidtz [1987], Badu et al [1989], Ameri M.et. Al. [2009] and IRC-81[1997], IRC-37[2012] also emphasized the need of comparative study to evaluate the overlay thickness using FWD and BBD techniques.

After detailed study about FWD and BBD techniques we focused our mind to do a comparative study on need of overlay thickness requirement of existing flexible pavement by both the techniques. So deflections measured by both FWD and BBD on the same stretch , need of overlay is determined and thickness for overlay design was also determined with both the techniques.

II. *Scope and Objectives*

In India Traffic is increasing rapidly , so the appropriate evaluation of the existing pavement is essential need of Highway Engineers to provide a smooth and safe ride. For this best suitable method should be opted from the available options . FWD and BBD are prominent non- destructive methods of pavement evaluation and strengthening, so this study tried to find out best suited method from them. According to IRC-81, BBD gives the characteristic deflection of the pavement wherever FWD gives the complete deflection bowl on the pavement so it seems more realistic. So to justify the adequacy of FWD technique over BBD technique comparative study for evaluating overlay thickness is carried out on a identified section of National highway in India. The objectives for this study are as under :

(i) Pavement condition survey by visual method on selected stretch.

(ii) Structural details of existing pavement.

(iii) Deflection measurement on road by FWD and BBD in accordance with IRC- 115 and IRC-81 respectively.

(iv) Existing Subgrade details and sample for different laboratory tests needed for overlay thickness determination.

(v) Calculation of overlay thickness by both the methods on same stretch as per specifications.

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III. Methodology

A stretch of Two and half kilometres from chainage 19.000 to 21.500 on NH-102 in the state of Bihar was selected for comparative study of BBD and FWD testing . this was two lane road with paved shoulder and traffic data was collected from Toll plaza and design traffic of 90 MSA was considered for this study. Samples were taken out from a pit for Physical characteristics of existing subgrade soil sample such as Plasticity index, liquid limit, soil classification, moisture content and CBR value of subgrade. Laboratory tests on sample was performed and physical characteristics of subgrade were find out. Existing Crust of road was figured out by a sample pit.

Following methodology was opted for this comparative study between FWD and BBD methods of Pavement Evaluation-

A. FWD Technique

FWD is an impulse loading device in which a transient load is applied to the pavement and deflected shape of pavement surface is measured. The target peak load of 40 KN is to be applied on the bituminous surface , which corresponds to the load on one dual wheel set of a 80 KN standard axle load by adjusting the height of fall accordingly.

Pavement condition survey on given stretch by just Visual method was done and in accordance with IRC stretch is to be classified as Good , fair and poor. Selected stretch was classified as good. After visual survey the FWD test was performed in accordance with IRC-115(2014) and deflection testing points on the given stretch were selected at 500m interval as per specifications . FWD tests were done on the edge of the road because maximum load comes on wheel path and chances of pavement deterioration are maximum there. Deflection were measured on LHS and RHS on the road in staggered pattern. Nine sensors were used for measuring deflection values at distance of 0mm, 200mm,300mm,450mm,600mm,900mm,1100mm 13000mm and 1600mm. After measuring the deflections KGPBACK software were used for calculating the BACK Moduli of individual layers. Corrections for temperature were applied as per IRC-115 and final values were obtained.

After these modulus values IIT-PAVE was used for calculating overlay thickness by satisfying Rutting and Fatigue Criteria.

B. BBD Technique

According to IRC-81 pavement performance is related top elastic deflection that the pavement undergoes when it is subjected to standard load. In BBD technique static or creep loading is used.

Rebound deflection of flexible pavement were measured with the help of dial gauge when a standard truck load according to IRC-81moved forward. Deflections were taken at 50m interval on the selected stretch. After calculating rebound deflection for each point , appropriate corrections were applied according to IRC-81.Characteristic deflection were figured out and overlay thickness according to this was provided with the help of IRC-81.

IV. Data Analysis & Results

A. Physical characteristics of existing Subgrade :

Three samples were collected so that physical properties of subgrade can be assessed properly. Soil was classified as 'CL'. Soaked CBR value at 10, 30 and 65 blows were calculated and finally at 97% compaction it is given in the table 1.

TABLE 1 : THE RESULTS OF PHYSICAL PROPERTIES OF EXISTING SUBGRADE

Chainage	Sieve analysis (% passing weight)				Atterberg imits		FSI (%)	Lab compaction		CBR at 97% compaction	Moisture content
	4.75mm	*2mm*	*425*	*75*	*LL%*	*PI (%)*		*OMC (%)*	*MDD (gm/cc)*		
19+100	99.8	98.8	95.6	89.5	31	8.79	13.6	10.5	1.985	10.9	14.70
20+150	99.3	97.3	92.6	86.9	31	8.05	9.5	10.3	1.980	9.70	16.05
21+180	99.3	97.4	93.8	89.3	30	8.13	10	11.0	1.915	9.75	15.20

The existing crust composition was 100mm Bituminous and 400mm granular for first 2 kms and 100mm Bituminous and 445mm Bituminous for third sample.

B. Abbreviations:

The following abbreviations are used in this paper-

FWD Falling weight deflectometer

BBD Benkelman beam deflection

IRC Indian road congress

CBR California bearing ratio

CL Clay

FSI Free swelling index

LL Liquid limit

PI Plasticity index

OMC Optimum moisture content

MDD Maximum dry density

C. FWD Data :

The surveys were carried out in accordance with the codal provisions of IRC-115 (2014).Deflection measured at 500m interval is showed in the tables. Pavement temperatures were also recorded for pertinent temperature corrections required for subsequent analysis. No seasonal correction is applied as the data are collected during the monsoon season. All the deflections were corrected at 40 KN load that is the

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load on a dual wheel assembly in standard axle (80KN). Field data are included in table 2

TABLE 2 : DEFLECTION VALUES ON STRETCH USING FWD TECHNIQUE

Chainage	Corrected deflections(mm) at 40 KN								
	D1	*D2*	*D3*	*D4*	*D5*	*D6*	*D7*	*D8*	*D9*
19.0(R)	.353	.246	.168	.104	.069	.041	.034	.026	.107
19.5(L)	.370	.281	.139	.099	.067	.057	.031	.029	.021
20.0 (R)	.339	.299	.140	.098	.061	.053	.029	.027	.019
20.5 (L)	.471	.289	.156	.075	.047	.030	.026	.021	.015
21.0 (R)	.559	.338	.222	.130	.078	.043	.033	.027	.019
21.5 (L)	.413	.339	.198	.107	.070	.040	.033	.027	.019

D. *Back calculation of Layer Moduli (KGPBACK):*

KGPBACK, which is a specific version of BACKGA program developed by IIT, Kharagpur is recommended in IRC-115 (2014) for back calculation.

Inputs required:-

- The corrected deflections at 40KN load.
- Tyre contact pressure (adopted as 0.56 MPa as per IRC-115).
- Geophone positions
- Poisson's ratio (adopted 0.5 for bituminous, 0.4 for granular and subgrade layer)
- Range of moduli (adopted 750 to 1000 for existing bituminous surfacing, 100 to 500 for granular layer and 20 to 100 for subgrade).

TABLE 3 : BACK CALCULATED MODULUS FOR DIFFERENT LAYERS

Chainage (Km)	Back calculated modulus (MPa)		
	Bituminous	*Granular*	*Subgrade*
19.000	1451.6	499.2	100
19.500	1491.9	494.5	100
20.000	1496.3	495.3	100
20.500	1470.7	488.3	100
21.000	1439.9	161.0	100
21.500	1489.0	392.1	100

The back calculated moduli values are included in table. Temperature was 38°C so modulus is corrected for temperature as per IRC-115 (2014) and corrected modulus of individual layers are included in graph. Here modulus is given in MPa on horizontal axis.

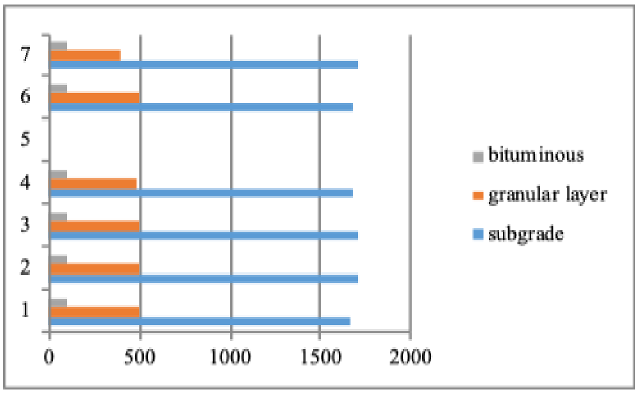

Figure 1. Comparative graph of corrected modulus for different layers

According to IRC-115(2014) 15% moduli values are selected for the stretch which are 1677.1 MPa for Bituminous layer, 464.25 MPa for granular layer and 100 MPa for subgrade layer. Now from IITPAVE software this is to be checked for rutting and fatigue criteria according to IRC-37 (2012).

$$N\phi = 0.711 * 10^{-04} * [1/\sum\tau]^{3.89} * [1/MP]^{0.854} \qquad (1)$$

Where,
$N\phi$ = fatigue life in standard axles,
$\sum\tau$ = Maximum Tensile strain at the bottom of the bituminous layer,
MP = Resilient modulus of the bituminous layer.

$$N\rho = 1.41 * 10^{-8} * [1/\sum v]^{4.5337} \qquad (2)$$

Where,
$N\rho$ = Rutting life in standard axles
$\sum v$ = Vertical strain in the subgrade

TABLE 4 : REMAINING LIFE CALCULATION FOR EXISTING PAVEMENT

Parameters	Bituminous	Granular	Subgrade
Elastic moduli(MPa)	1677	448	100
Poisson's ratio	0.5	0.4	0.4
Thickness (mm)	100	400	
Remaining Fatigue life	45.4 MSA		
Remaining Rutting life	185.4 MSA		

Trial Overlay thickness = 40 mm

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TABLE 5 : REMAINING LIFE CALCULATION AFTER PROVIDING OVERLAY THICKNESS

Parameters	New Bituminous layer	Bituminous	Granular	Subgrade
Elastic moduli(MPa)	3000	1677	448	100
Poisson's ratio	0.5	0.5	0.4	0.4
Thickness (mm)	40	100	400	
Remaining Fatigue life	107.33 MSA			
Remaining Rutting life	474.22 MSA			

So Overlay requirement for given stretch using FWD Technique is **40mm.**

E. *BBD Data :*

The surveys were carried out in accordance with the codal provisions of IRC-81 (1997). Deflection measured at 40m interval is showed in graphs. The subgrade soil is of clayey type. PI and field moisture were taken from above table .Rebound deflections were calculated as per IRC-81(1997) and included in Graphs shown below. Pavement temperatures were also recorded for pertinent temperature corrections required for subsequent analysis. Seasonal correction is also applied as per codal provisions. Rebound Deflections (in mm) with chainages (in km) are presented in graphs.

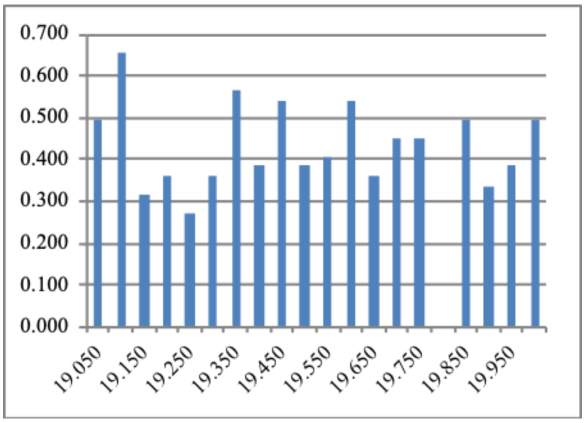

Figure 2. Comparative graph of rebound deflections (mm) with changes(km) using BBD method

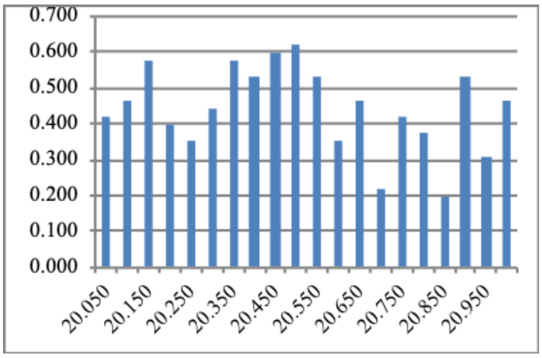

Figure 3. Comparative graph of rebound deflections (mm) with chainages using BBD technique

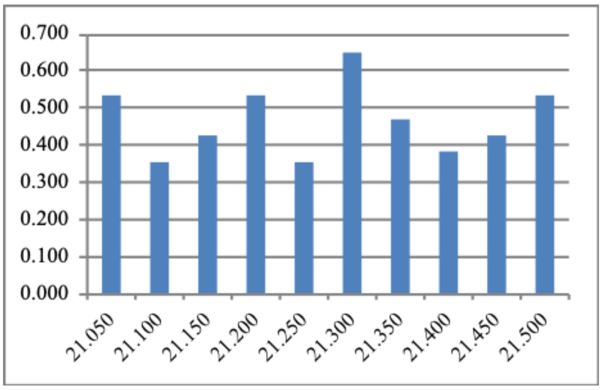

Figure 4. Comparative graph of rebound deflections (mm) with chainages (km) using BBD technique

After applying appropriate corrections according to IRC-81(1998) the characteristics deflection Km Wise road according to design chart in IRC-81 for 90 MSA the overlay thickness are included in table .Comparison with FWD technique is also included in table 6.

TABLE 6 : OVERLAY THICKNESS REQUIREMENT BY BBD AND FWD TECHNIQUES

Chainage (KM)	Characteristics defection(mm)	Overlay thickness(mm)		Overlay thickness (mm) using FWD technique
		In terms of BM	*DBM/BC*	
19.00 to 20.00	0.628	65	46	40
20.00 to 21.00	0.675	80	56	40
21.00 to 21.50	0.649	70	49	40

V. *Conclusions*

1. There is significant difference in Overlay thickness for existing pavement by BBD Technique and FWD Technique. If we provide same thickness for complete stretch it will be on higher side By BBD method than FWD method.
2. Using both the techniques in field for deflection measurement, FWD loading pattern resembles more to practical traffic situation on road whereas in BBD only part of this situation is considered.
3. In FWD technique individual layer moduli can be estimated by KGPBACK so we can have a Idea about individual layer strength whereas in BBD technique we cannot comment on inner layer strength.
4. In FWD Technique as we have the individual layer strength so overlay thickness requirement proved to be more deterministic than BBD method.
5. In BBD method only overlay thickness is only remedy of Road however it is possible that inner

layers may not be as per requirement. So evaluation of pavement is more close to reality in FWD than BBD method of evaluation.

6. Falling weight deflectometer is a High cost apparatus than Benkelman Beam but it gives some material saving as overlay thickness is overestimated in case of BBD technique however a detailed cost analysis should be done for significance of FWD in Low Volume Roads.

VI. Acknowledgement

Authors are very thankful to Ms Atashi Das and Mr. Yash Pandey for their help in conducting filed tests and collecting data.

VII. References

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