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GUIDELINES FOR THE STRUCTURAL EVALUATION OF RIGID PAVEMENT BY FALLING WEIGHT DEFLECTOMETER

INDIAN ROADS CONGRESS
2014

GUIDELINES FOR THE STRUCTURAL EVALUATION OF RIGID PAVEMENT

BY

FALLING WEIGHT DEFLECTOMETER

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GUIDELINES FOR THE STRUCTURAL EVALUATION OF RIGID PAVEMENT

BY

FALLING WEIGHT DEFLECTOMETER

1 INTRODUCTION

1.1 A large number of cement concrete pavements have been constructed in India on all categories of roads in order to have durable maintenance free roads even under adverse moisture and heavy traffic conditions. The moduli of subgrade reaction (k) are usually adopted from their correlation with CBR values recommended in Portland Cement Association (PCA) Manual of USA. A stiff subbase of DLC covered with a plastic sheet has a very high modulus of subgrade reaction not found in any international guideline. The modulus of subgrade reaction (k) over the layer recommended in IRC:58-2011 has been computed based on a theoretical approach given in AASHTO Guide for Design of pavement structures, 1993. Its validity is yet to be established. The pavement might be over designed or under designed. It is necessary to determine the actual pavement design parameters such as strength of concrete and modulus of subgrade reaction by back calculation from field tests after the construction and reassess actual life of the pavement. Properties of different layers also can be determined by using analytical tools. One of the most difficult exercises for a pavement engineer is analyzing deflection data collected with a falling weight deflectometer though FWDs have been in use for over 30 years, the methods to process the data are far from perfect. Engineers, based on the deflection, their experience and judgement, can take appropriate measures to prevent continuing damage to concrete pavements.

The draft “Guidelines for the Structural Evaluation of Rigid Pavement by Falling Weight Deflectometer” was prepared by the Sub-group comprising Shri R.K. Jain, Shri Satander Kumar, Dr. B.B. Pandey and Col. V.K. Ganju. The Committee deliberated on the draft document in a series of meetings. The H-3 Committee finally approved the draft document in its meeting held on 19th June, 2014 and authorized the Convenor, H-3 Committee to send the final draft for placing before the HSS Committee. The Highways Specifications & Standards Committee (HSS) approved the draft document in its meeting held on 9th August, 2014. The Executive Committee in its meeting held on 18th August, 2014 approved the same document for placing it before the Council. The Council in its 203rd meeting held at New Delhi on 19th August, 2014 approved the draft “Guidelines for the Structural Evaluation of Rigid Pavement by Falling Weight Deflectometer” for publishing.

The composition of the Rigid Pavement Committee (H-3) is given below:

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Das, S.N., Director General (RD), Ministry of Road Transport & Highways, New Delhi

1.2 A good number of panels of concrete pavements display cracks at corners and along longitudinal and transverse joints within five years of their construction (**Photos 1 and 2**) though the thicknesses were large enough to prevent flexural cracking caused by combined effect of stresses due to heavy axle loads and temperature gradients. A major cause of damage to a concrete pavement is due to the permanent deformation caused to granular layers and the subgrade due to the heavy vehicles operating on highways. The location of voids below the pavement caused by the settlement of the lower layers must be found out and filled up as early as possible. Conditions of dowel bars at the transverse joints and tie bars at longitudinal and shoulder joints should be evaluated from time to time to determine the load transfer efficiency of joints by FWD so that retrofitting of the dowel and tie bars can be done before the pavement slabs are damaged.

1.3 It is desirable to carry out theoretical analysis of multi layer rigid pavements by finite element method to determine pressure on the subgrade soils and estimate the extent of voids formation below the concrete pavements due to heavy loads. Since a Dry Lean Concrete cannot be treated like Winkler's foundation, a more refined method considering a concrete pavement and DLC resting on Winkler foundation is more appropriate for checking the safety of the pavement.

Photo 1 Longitudinal Cracks

Photo 2 Corner Cracks

2 SCOPE

2.1 These guidelines are meant for evaluating the structural condition of in-service rigid pavements using Falling Weight Deflectometer and for estimating the strength of the pavement concrete as well as the modulus of the subgrade reaction so that the capacity of the pavement to with stand future traffic loading i.e. balance life of the pavement, can be determined using cumulative fatigue damage principle as laid down in IRC:58-2011.

2.2 Structural evaluation exercise should include load transfer at the transverse and longitudinal joints so that necessary measures may be taken to retrofit dowel and tie bars before extensive damage occurs. The deflection data can be used to detect voids at transverse joints, longitudinal joints, interiors as well as at the corners so that actions can be taken to fill up the voids by grouting to prevent large scale damage to pavements.

2.3 Method for filling of voids detected by FWD testing or by any other means like GPR etc. by cement grouting and for retrofitting of dowel bars/tie bars has been described in **Appendix - I**.

2.4 These guidelines may require revision from time-to-time in the light of experience and developments in the field. Towards this end, it is suggested that to all the organizations using the guidelines should keep a detailed record of periodical measurements, performance, traffic, climatic condition, etc. and provide feedback to the Indian Roads Congress for further revision.

3 CONSTRUCTION HISTORY

Before the evaluation process begins, following types of data are to be collected:

i) Month and the year of construction
ii) Traffic considered in pavement design
iii) Thickness and strength of pavement concrete

iv) Thickness and strength of dry lean concrete subbase
v) CBR of subgrade
vi) Modulus of subgrade reaction considered in design
vii) Temperature differential of pavement concrete

4 TRAFFIC

Traffic data for the highway under consideration should be collected since its characteristics may change after the completion of the project.

4.1 Axle Load Survey

Pattern of commercial vehicles has undergone a sea change during the last decade. Number of tandem and tridem axles on major highways have increased considerably while share of single axle load with dual wheel has decreased. The legal axle load limits in India are fixed as 10.2, 18 and 24 tonnes for single axles, tandem axles and tridem axles respectively. Each of the axles have dual wheels on either side. A large number of axles operating on National Highways carry much higher loads than the legal limits. Data on axle load distribution of the commercial vehicles is required to compute the number of repetitions of single, tandem and tridem axles carrying different loads. Axle load survey may be conducted for 48 hours both in day as well as in night hours, covering a minimum sample size of 10 percent in both the directions as laid down in IRC:58-2011. Heavy axle loads induce very high flexural stresses in the pavement slab resulting in large consumption of fatigue resistance of concrete. They also transmit very high pressure on the subgrade and subbase causing permanent deformation in the granular and subgrade soils.

4.2 Axle Load Spectrum

Spectrum of axle load should be determined for single, tandem, tridem and multi-axle loads for the evaluation of safety of pavement from cracking and evaluation of the remaining life of a concrete pavement from the consideration of cumulative fatigue damage. The following load intervals for each class of axle load, as prescribed in Clause 5.2 of IRC:58-2011 should be as follows:

Single axle	---	10 kN
Tandem axle	---	20 kN
Tridem axle	---	30 kN

After the collection of axle load data, they may be tabulated as per the format shown in **Table 1** for the computation of fatigue damage till the time of the test and the remaining life of the pavement. Additional columns have to be added for including the fatigue damage analysis for each category of axle loads.

Table 1 Spectrum of Axle Load

Single Axle Load Interval kN	Class Mark kN	Cumulative No. of Axles	Tandem Axles Load Interval kN	Class Mark kN	Cumulative No of Axles	Tridem Axle Load Interval kN	Class Mark kN	Cumulative No of Axles
195-205	200	-	390-410	400	-	585-615	600	-
185-195	190	-	370-390	380	-	555-585	570	-
175-185	180	-	330-350	340	-	525-555	540	-
165-175	170	-	330-350	340	-	495-525	510	-
155-165	160	-	310-330	320	-	465-495	480	-
145-155	150	-	290-310	300	-	435-465	450	-

The buses and light vehicles like pickups will not contribute to fatigue damage and hence they be ignored in the analysis.

The cumulative number of repetitions of axles at the time of structural evaluation of the pavement may be computed from the following formula:

$$C = \frac{365 \times A \left\{(1+r)^{n} - 1\right\}}{r} \qquad \text{... 1}$$

Where,

C = Cumulative number of axles, for estimating fatigue damage at the time of FWD test. C can be determined for different values of n to determine the remaining life. C has to be further classified into repetitions of axle loads based on their weight as shown in **Table 1**.

A = Initial number of axles per day in the year when the road is operational.

r = Annual rate of growth of commercial traffic (expressed in decimals) from actual data collected after the construction.

n = Period in years after the construction.

Expected number of applications of different axle load groups at the time of evaluation can be estimated from the axle load spectrum.

5 FALLING WEIGHT DEFLECTOMETER

5.1 Falling Weight Deflectometer (FWD) is an impulse-loading device in which a transient load is applied to the pavement and the deflected shape of the pavement surface is measured. The working principle of a typical FWD is illustrated in **Fig. 1**. D0, D1, D2 and D3 mentioned in **Fig. 1** are surface deflections required at radial distances of 0 mm, 300 mm, 600 mm and 900 mm for determination of pavement design parameters. Impulse load is applied by means of a falling mass, which is allowed to drop vertically on a system of springs placed over a circular loading plate. The deflections are measured using displacement sensors as shown in **Fig 1**. Trailer mounted as well as vehicle mounted FWD models are available commercially. The working principle of all these FWD models is essentially the same. A mass of weights is dropped from a pre-determined height onto a series of springs/ buffers placed on top of a loading plate. The corresponding peak load and peak vertical surface deflections at different radial locations are measured and recorded.

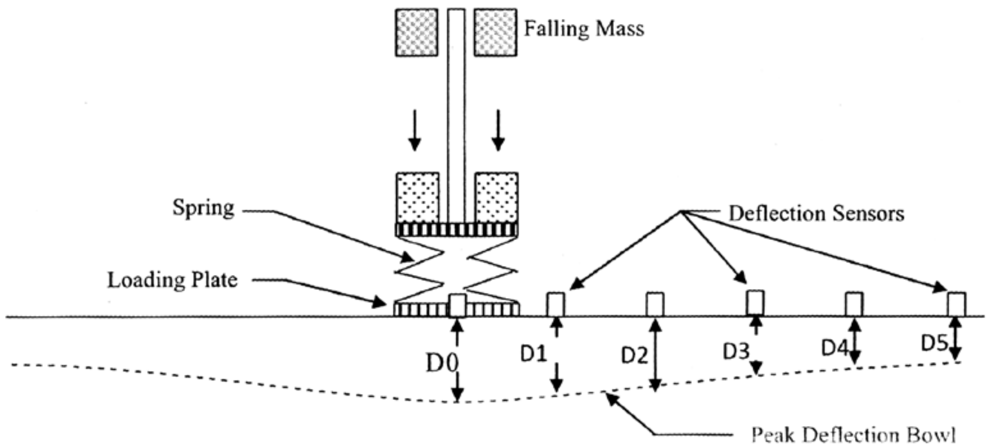

Fig. 1 Working Principle of Falling Weight Deflectometer

5.2 Different magnitudes of impulse load can be obtained by selection of a suitable mass and an appropriate height of fall. Under the application of the impulse load, the pavement deflects. Velocity transducers are placed on the pavement surface at different radial locations to measure surface deflections. Geophones or seismometers are used as displacement transducers. Load and deflection data are acquired with the help of a data acquisition system.

5.3 A typical Falling Weight Deflectometers (FWD) include a circular loading plate of 300 to 450 mm diameter. 300 mm diameter load plate is recommended in these guidelines for evaluation of rigid pavements. A rubber pad of 5 mm minimum thickness is glued to the bottom of the loading plate for uniform distribution of load.

5.4 A falling mass in the range of 50 to 350 kg is dropped from a height of fall in the range of 100 to 600 mm to produce load pulses of desired peak load and duration. Heavier models use falling mass in the range of 200 to 700 kg. The target peak load in the range of 40 kN to 60 kN or higher may be applied on concrete pavements to get a reasonable deflection of the order of 0.50 mm since pavements of major highways in India consisting of 150 mm DLC and 300 mm PQC are very stiff and a higher load may be required to get a deflection of about 0.15 mm.

5.5 Calibration of the FWD: For producing reproducible results, the FWD should be calibrated. The calibration procedure has been described in details in the IRC:115-2014.

6 PAVEMENT EVALUATION PROCESS

6.1 Pavement condition survey of the entire project length shall precede the actual deflection test by FWD. A suggested format for Pavement Condition Survey is given in

Appendix - II. It will consist of visual observations of cracking and faulting if any. Ground Penetrating Radar (GPR) may be used to determine the thickness of pavements in a short time and to locate approximately the areas where voids may have formed below the pavement slab which can be confirmed by FWD deflection tests at a later stage. FWD deflection data may be collected at interiors, corners, transverse joints and longitudinal joints in the outer lane at intervals of 500 m. Heavy loads travel mostly in outer lanes and very often greater distresses also are found in the outer lanes. If there are distresses in the inner lanes also, FWD test should be done in those lanes also. The loading positions are shown in **Fig. 2**.

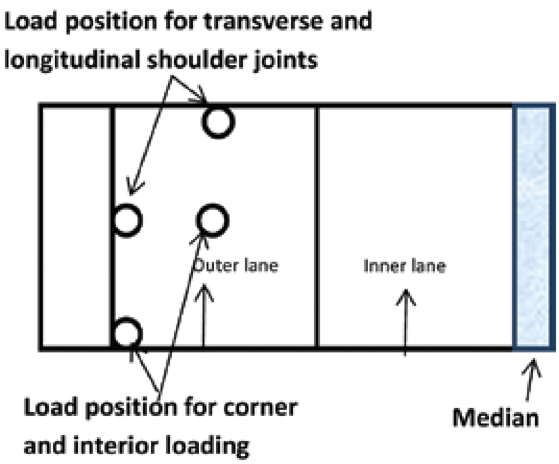

Fig. 2 Load Positions for Corner, Interior, Transverse and Longitudinal Shoulder Joints

For two way two lane roads, both lanes have to be tested for corner, edge, interior, transverse and longitudinal joint loading. Single lane roads are usually provided on low volume roads and FWD test on such pavements are not necessary. Spacing for tests can be lower depending upon the condition of pavements. For the evaluation of the modulus of subgrade reaction as well as strength of pavement concrete, it is necessary that the test be carried out at the interior when the temperature gradient is zero or negative when top surface is cooler than the bottom and the central portion of the pavement slab is in full contact with the foundation. During the day time, the surface is hotter than the bottom and the slab will curl up forming a convex surface with raised central region as shown in **Fig. 3(a)**. The test in the raised part will show high deflection. The edges will be resting on the foundation. Similarly, edges will get raised during the night and test at the edge will give large deflections as shown in **Fig. 3(b)**. These factors should be considered while carrying out the test.

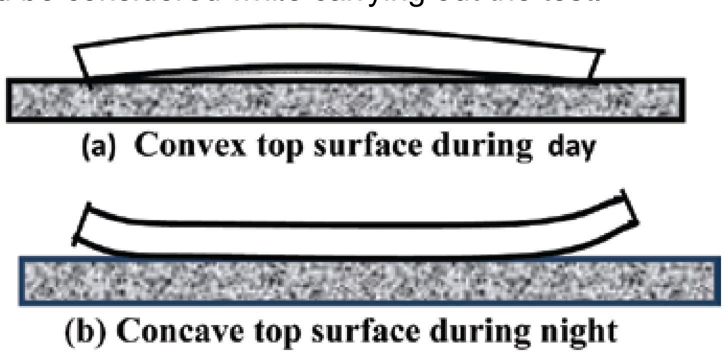

Fig. 3 Shape of Top Surfaces of a Concrete Slab During Day and Night

For two lane roads without concrete shoulder, test should be carried out at the corner, interior and edge positions. When there are no dowel bars, tests as the transverse joints should be carried out in the morning hours to determine the load transfer due to aggregate interlock when the joint opening will be higher because of contraction of slabs at lower temperatures.

6.2 Surface Temperature Measurement

Ideally, the pavement temperature will be recorded directly from temperature holes at each test location as the FWD test is being performed. While this is the preferred approach for research projects, it is not practical for production level testing (network level or maintenance and rehabilitation projects). Therefore, for production level testing the economic and practical approach is by measuring the surface temperature at each test location. This can be easily done using an infrared thermometer. The FWD can automatically measure and record the pavement surface temperature to the FWD file. If the FWD is not equipped with an Infrared thermometer, then the FWD operator can use a hand held thermometer and record the temperature to a file. By measuring and monitoring the surface temperature during testing, the FWD operator can suspend testing if the pavement becomes too hot (>40ºC).

6.3 Evaluation of Subgrade Modulus, Elastic Modulus of Concrete and Strength of Pavement Concrete

Step by step procedure:

1. FWD test should be done and deflection at 0 mm, 300 mm, 600 mm and 900 mm radial distances from the centre of loading point should be measured.
2. The area parameter of deflection basin should be calculated using following formulae-

$$A = 6\left[1+2\left(\frac{D1}{D0}\right)+2\left(\frac{D2}{D0}\right)+\left(\frac{D3}{D0}\right)\right] \qquad \text{... 2}$$

Where,

A = Area parameter of the deflection basin

D0 = Deflection at centre of the loading plate in mm

D1 = Deflection in mm at 300 mm from centre of the loading plate

D2 = Deflection in mm at 600 mm inch from centre of the loading plate

D3 = Deflection in mm at 900 mm from centre of the loading plate

The value of A is about 11.8 for a single layer elastic half space (pavement and soil has the same elastic modulus) while for an extremely rigid layer with a very high elastic modulus (D0=D1=D2=D3),the value of A is 36. For a concrete pavement, A will be less than 36.

3. From area of deflection basin, Radius of relative stiffness (l) can be evaluated from the charts given in **References 1 and 2**. The excel sheet provided with the guidelines uses the chart in equation form and it gives directly the value of l.

4. After finding the Radius of relative stiffness, normalised deflections (d_i) are calculated using various equations formed from the charts given in **References 1 and 2**. The excel sheet directly gives the values of the normalised deflections.

5. Subgrade modulus value can be found by following formulae for different normalised deflections and average of all should be taken as subgrade modulus.

$$k_i = \frac{Pd_i}{l^2 D_i} \qquad \text{... 3}$$

Where,

i = 1, 2, 3, 4

l = Radius of relative stiffness, mm

P = Load in kN

D_i = Measured deflections in mm at various radial distance

d_i = Normalised deflections in mm at various radial distances

k value for pavement design should be 50% of that determined by FWD since only static modulus of subgrade reaction is to be used for pavement design(2).

6. Elastic Modulus (MPa) of concrete can be found by using the formulae

$$E_c = \frac{12(1-\mu_c)k\, l^4}{1000h^3} \qquad \text{... 4}$$

μ_c = Poisson's Ratio of Concrete.

h = Thickness of concrete layer in mm.

l = radius of relative stiffness in mm

k = modulus of subgrade reaction in MPa/m

E = Elastic modulus of concrete, MPa

Strength of concrete can be determined from the value of E_c from the following relation

$$f_c = (E_c/5000)^{0.50} \qquad \text{... 5}$$

Flexural strength (f_{mr}) can be determined from the f_c of the concrete slab as given below

$$f_{mr} = 0.7(f_c)^{0.50} \qquad \text{... 6}$$

The entire computation process is illustrated in the programmed excel sheet attached with the guidelines. A solved example is given in **Appendix III**.

Note: *The concrete properties (E_c, f_c, f_{mr}) estimated are for the age of concrete at the time of FWD test. The strength values obtained from the computed elastic modulus are based on statistical correlation from laboratory tests and they are approximate. Exact values of strength of concrete may be determined from cores for verification.*

6.4 Fatigue Behaviour of Cement Concrete

IRC:58-2011 gives the fatigue equations (Cl 5.8.6) that should be used for the evaluation of fatigue life. Computed values for modulus of rupture and modulus of subgrade reaction are to be used in fatigue damage analysis.

The relation between fatigue life (N) and stress ratio is given as:

N = unlimited for SR < 0.45

$$N = \left[\frac{4.2577}{SR - 0.4325}\right]^{3.268} \text{ when } 0.45 \leq SR \leq 0.55 \qquad \text{... 7}$$

$$\text{Log } N = \frac{0.9718 - SR}{0.0828} \text{ for } SR > 0.55 \qquad \text{... 8}$$

Where,

SR = ratio of load stress and modulus of rupture of concrete

Cumulative Fatigue Damage (CFD) during the design period can be expressed as

$$\text{CFD} = \sum_{i=1}^{k} \frac{n_i}{N_i} \text{ (10 A.M to 4 P.M)} + \sum_{i=1}^{k} \frac{n_i}{N_i} \text{ (0 A.M to 6 A.M)} + \sum_{i=1}^{k} \frac{n_i}{N_i} \text{ (Remaining hours)} \qquad \text{... 9}$$

The computation indicates that contribution to CFD for bottom up cracking is significant only during 10 A.M to 4 P.M because of higher stresses due to simultaneous action of wheel load and positive temperature gradient. For the top down cracking, only the *CFD* during the period between 0 A.M to 6 A.M is important. Various locations may have different behaviour and designers may examine this aspect.

Stress ratio can be obtained from the ratio of axle load stress and the computed modulus of rupture from the FWD test as illustrated in the **Appendix I**. Excel Sheet format given in IRC:58-2011 can be used for the evaluation of the fatigue life consumed till the date of the test and the remaining life of the pavement can easily be estimated. Sum of the fatigue lives consumed for bottom up cracking as well as for top down cracking should be less than 1.0 to ensure that the estimation of the pavement life is more conservative since cracks appearing on the surface could have started from the top or from the bottom.

7 CAUSES OF EARLY CRACKING OF CONCRETE PAVEMENTS

7.1 Single axle loads cause higher bending stresses in pavement slabs while tandem and tridem axles carrying double and triple load of that carried out by singe axle cause lower bending stresses due to superposition of positive and negative bending moments. But vertical stresses on the granular and the subgrade soil are very large due to heavily loaded multi-axle vehicles. Tandem axles weighing as much as 400 kN (legal limit = 19 tons i.e. 186.2 kN) and tridem axles far above the legal limits are common on heavy duty corridors. The pavement slabs designed as per IRC:58-2011 are safe for cracking due to flexural tensile stresses against overloaded trucks since this is considered in the fatigue damage analysis.

Heavy axle loads, cause high vertical stresses on the granular layer and the subgrade resulting in accumulation of permanent deformation with time forming voids below the slabs. The voids can be at the corner edge, transverse and longitudinal joints or in the interior of cement concrete slab. The stresses can be very high when a part of the slab is unsupported near a void. More water can accumulate in the voids and fast moving heavy loads may cause high pressure in the confined water causing serious erosion of soil and granular material which will increase the size of the voids further. Cracks will appear in those places due to repeated bending of unsupported slab causing early damage to pavement slabs. It is necessary to detect the voids early and grout it with cement mortar to fill up the voids. If GPR is available, locations identified by GPR can be tested with FWD to confirm the existence of voids since interpretation of GPR data may not be very precise.

8 DETECTION OF VOIDS UNDERNEATH THE RIGID PAVEMENT

Detection of voids below a pavement slab can easily be done by a Falling Weight Deflectometer. Deflections are measured along the wheel path and a plot of central deflection vs distance has to be made.

The locations where the deflections are much higher (**Fig. 4**) than the normal may indicate presence of voids. Drilling and grouting with cement-mortar slurry may make the pavement safe.

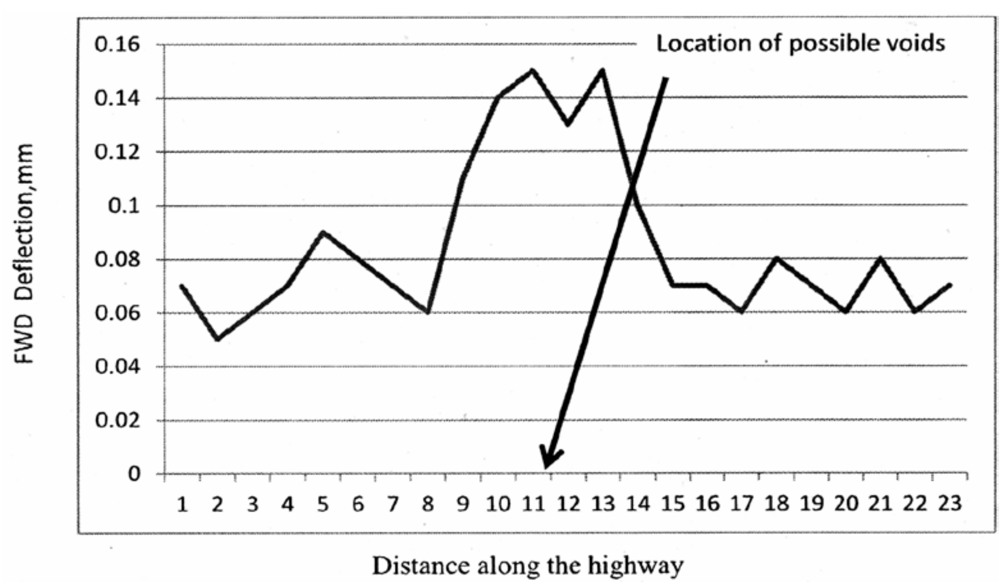

Fig. 4 Deflection Data Along a Highway

FWD Tests should be done during the period when the pavements are not in curled conditions. In winter, time available for test may be longer. Conditions in India vary markedly with geographical locations and local experience should be the guiding principle for tests. If FWD tests are done on a pavement slab over a void and a slab without any void at different load levels such as 40 kN, 50 kN, 60 kN and 70 kN or 80 kN and the results may appear as shown in **Fig. 5**. The Y-axis shows the maximum deflections under different loads. This is another way to differentiate Pavement slabs with and without voids below it.

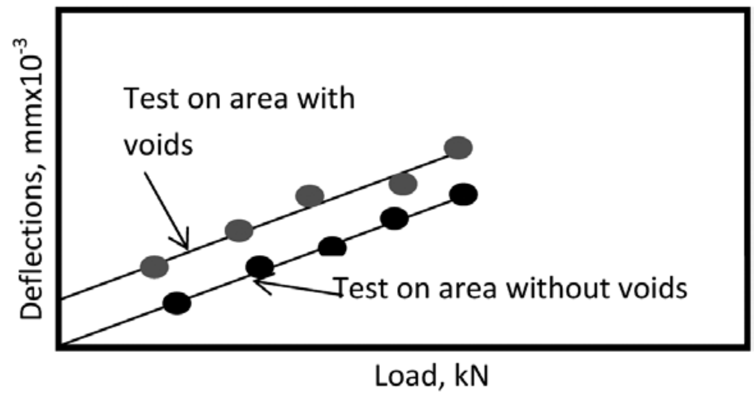

Fig. 5 FWD Test on Area with and Without Void

9 EVALUATION OF LOAD TRANSFER EFFICIENCY OF JOINTS

Transverse as well as longitudinal joints deteriorate with traffic due to continuous loading. The proper load transfer at joints has to be maintained for a good functioning of pavements. For a new pavement, the joint efficiency is nearly 100 percent since the deflections on either side of joint under a wheel load are almost equal and the ratio decreases as the joints deteriorate under repeated loading. **Photo 3** shows loading plate of an FWD stationed close to a longitudinal joint near the shoulder of a four lane highway in India.

When deflection sensors are at the either side of a joint with deflections D_1 and D_2 on the loaded and unloaded sides as shown in **Fig. 6**, the Load Transfer Efficiency (LTE) is defined as:

$$LTE = 100 (D_2/D_1) \quad \text{... 10}$$

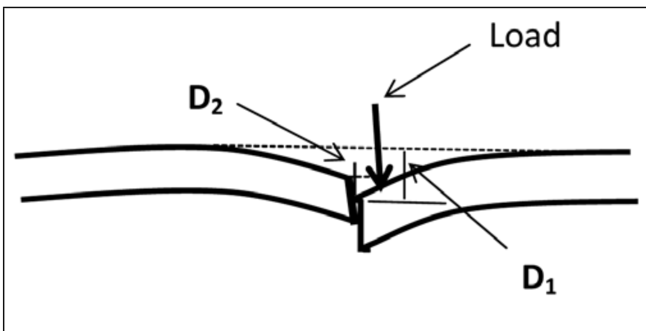

Fig. 6 Deflections on the Loaded and Unloaded Side at a Joint	Photo 3 FWD Test at a Concrete Shoulder Joint

Condition of joints

For a new pavement, $D_1 = D_2$ but D_2 becomes less and less as the joints deteriorate.

If $D_2/D_1 < 0.5$ transverse joints in critical condition

If $D_2/D_1 < 0.4$ longitudinal joints in critical condition

Where,

D_1 is the deflection on the loaded side of the slab

And D_2 is the deflection on the unloaded side of the slab

If the above conditions are reached, retrofitting of dowel and tie bars are recommended, as prescribed in IRC:SP:83. The above deflections can be measured by FWD.

If the deflection sensors are 300 mm apart during the FWD tests as shown in **Fig. 7**, the Load Transfer Efficiency is determined from equation given as:

$$LTE = 100\,B\,(D_2/D_1) \qquad \text{... 11}$$

Where,

B lies between 1.05 and 1.15. A typical value of 1.05 may be adopted (2). If the LTE values are too low, retrofitting of dowel bar and tie bars are recommended before large scale deterioration occurs. Tests should be carried out across the cracks also to examine the load transfer across them. This will help in establishing whether the cracks extended to full depth.

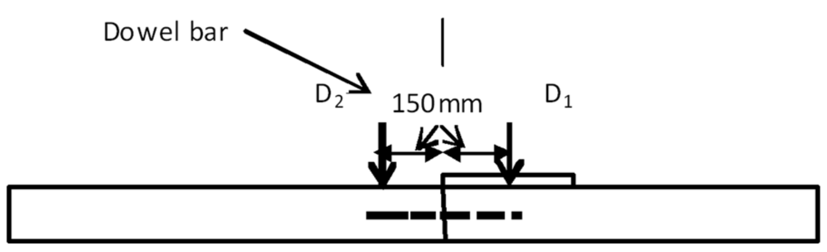

Fig. 7 Deflection Measurements at a Joint by FWD with Sensors 300 mm a part

Extract of Typical test results of FWD testing for load transfer efficiency of transverse joints conducted by Central Road Research Institute (CRRI) on NH-2 are given in **Appendix - IV**. Similar format can be used for recording data.

10 FREQUENCY OF TEST

Tests for structural evaluation should be repeated between three and five years for assessing the health of the rigid pavements so that appropriate action is taken timely to prevent distress.

Appendix - I

(Refer Clause 2.3)

1. Filling of Voids in Rigid Pavement

1.1 General: A major cause of damage to the concrete pavement is due to the permanent settlement/deformation caused to granular layers and the subgrade due to heavy vehicles operating on highways within 3 to 5 years of its construction. Although the design thickness of pavement can withstand the combined effect of stresses due to heavy axle loads and temperature gradient, but the voids created due to permanent settlement of the lower layers and curling of pavement create additional stresses causing longitudinal transverse cracking during day time and corner cracking during the night time. It is therefore recommended that detection of voids underneath the Rigid Pavement is done as described in **Section 8** on a regular interval of 3 to 5 years or when such longitudinal/transverse/corner cracks start appearing on the rigid pavement.

1.2 Grouting Process

i) Holes of 12 to 15 mm dia are drilled up to the bottom of the DLC at 1 m square interval over the whole area of voids to be filled under the slab.

ii) Compressed air is blown into the holes to remove loose debris and water etc.

iii) The holes are temporarily plugged and the slab surface is swept to clean.

iv) Grout material is injected in each hole at a pressure of 0.35 N/mm^2 until the voids accept no more grout or flow up through an adjacent hole.

v) For early and fast flow of grout and to minimise air beneath the PQC two holes are drilled, vacuum pump may be used for sucking air from second hole.

vi) Sides of injection holes are roughened and cleaned and filled with polymerized fine concrete or epoxy mortar.

vii) Traffic is opened only after minimum appropriate curing time for the grout.

2. Retrofit of Dowel/Tie Bars

This has been described in Chapter: 11. Special Technique for Rehabilitation of Rigid Pavement in IRC:SP:83-2008.

Appendix - II

(Refer Clause 6.1)

Pavement Condition Data Sheet

Road Name: **Section :**								**Weather :**						**Road No:** **Date of Survey :**			
Chainage (Km)	**Chainage**	**Panel Size**		**Shoulder**		**Riding Quality**		**Pavement Condition**						**Pavement Edge Pop out (mm)**	**Condition of Joints**	**Road Side Drain (NE/PF/F)******	**Remarks**
	Panel No.	**Length (m)**	**Width (m)**	**Composition**	**Condition (Fair/Poor/ Failed)**	**Speed (Km/Hr)**	**Quality (G/F/P/VP)**	**Transverse Cracks less than 1.5 m**	**Transverse Cracks more than 1.5 m**	**Longitudinal Cracks Full Depth**	**Pothole**	**Corner Cracks**	**Settlement**				

Note: Crack Mapping should also be done on the road plan

Surveyed by:

Appendix - III

(Refer Clause 6.3)

Example: An FWD test was conducted on a 300 mm thick concrete pavement. The radius of FWD plate is 150 mm and recorded maximum load is 50 kN. Sensors were located at 0, 300, 600 and 900 mm and corresponding deflections recorded are 0.080, 0.075, 0.065, 0.055 mm. It is assumed that concrete has Poisson's ratio of 0.15. Determine subgrade modulus and elastic modulus of concrete when subgrade is considered as liquid (Winkler) foundation.

Solution: Changing the following values in excel sheet specified for subgrade modulus calculation we can easily get the subgrade and elastic modulus of concrete:

Radius of loading plate (a), mm	= 150
Load (*P*),kN	= 50
Poisson ratio for concrete (μ_c)	= 0.15
Poisson ratio for subgrade (μ_r)	= 0.45
Thickness of the concrete slab *h* (mm)	= 300
Deflection measured at 0 mm distance from the center of the load area	= 0.08 mm
Deflection measured at 300 mm distance from the center of the load area	= 0.075 mm
Deflection measured at 600 mm distance from the center of the load area	= 0.065 mm
Deflection measured at 900 mm distance from the center of the load area	= 0.056 mm

Using excel sheet.

The modulus of Subgrade reaction = 78 MPa/m

K value for design is to be taken as 50% of 78 MPa/m as per the AASHTO 93 since only static k value is to be used or design, k = 39 MPa/m

Elastic modulus of concrete in MPa	= 32908 MPa
Compressive strength of concrete (cube)	= 43.32 MPa
Flexural strength	= 4.61 MPa

A excel sheet have been programmed for carrying out all the computations instantly

Appendix - IV

(Refer Clause 9)

Sample Data-Load Transfer Efficiency

The Load Transfer Efficiency (LTE) of transverse joints was measured by Central Road Research Institute (CRRI) on Delhi-Mathura Road (NH-2) with three different target impact loads of 5500 kg, 7600 kg and 11000 kg. The dia of loading plate of FWD was 300 mm and sensors measuring deflections of loaded and unloaded slab across the joint were 200 mm apart. The pavement layers consisted of 150 mm thick Dry Lean Concrete (DLC) over compacted subgrade and 300 mm thick Pavement Quality Concrete (PQC) of M40 Grade. The drop weights, deflection of loaded and unloaded slabs and LTE are given in **Table 2 to 4**.

Table 2 Joint Load Transfer Efficiency (Target Impact Load - 5500 kg)

Joint No.	Drop Weight, kg	Loaded Slab Deflection, µm	Unloaded Slab Deflection, µm	LTE, %
1	5634	170	167	98.23
	5559	165	161	97.57
	5575	165	161	97.57
2	5671	106	105	99.05
	5591	105	103	98.09
	5612	106	104	98.11
3	5614	163	161	98.77
	5662	163	159	97.54
	5578	162	161	99.38
		Avg. = 145 µm or 0.145 mm		Avg. = 98.25

Table 3 Joint Load Transfer Efficiency (Target Impact Load - 7600 kg)

Joint No.	Drop Weight, kg	Loaded Slab Deflection, µm	Unloaded Slab Deflection, µm	LTE, %
1	7679	218	215	98.62
	7537	213	210	98.59
	7663	216	141	99.29
2	7657	142	141	99.29
	7621	142	141	99.29
	7663	143	140	97.90
3	7599	219	214	97.71
	7607	220	213	96.81
	7603	216	212	98.14
		Avg. = 192 µm or 0.192 mm		Avg. = 98.40

Table 4 Joint Load Transfer Efficiency (Target Impact Load - 11000 kg)

Joint No.	Drop Weight, kg	Loaded Slab Deflection, μm	Unloaded Slab Deflection, μm	LTE, %
1	10924	293	285	97.26
	10971	294	286	97.27
	10921	293	285	97.26
2	10881	292	289	98.97
	10985	294	289	98.29
	10971	295	291	98.64
3	11301	214	212	99.06
	11178	210	210	100
	11082	211	210	99.52
		Avg. = 266 μm or 0.266 mm		Avg. = 98.47

Note : The load transfer efficiency of all the joints tested are very high and hence they are in good condition.

Appendix - V

(Refer Clause 6.3)

Evaluation of strength of pavement slab and modulus of subgrade reaction of foundation from FWD test

Evaluation of foundation properties as well as strength of concrete using Falling weight deflectometer both winkler as well as solid elastic foundations are considered in the analysis. the inputs are (1) defelctions at radial distances of 0, 300, 600, 900 mm (2) applied load and the radius of the loading plate (3) Thickness of the pavement slab. The poisson ratio of the slab and the foundation are taken as 0.15 and 0.45 respectively. The outputs are modulus of subgrade reation elastic modulus of the concrete slab and flexural strength of the concrete.In case of solid elastic foundation the outputs are elastic modulus of the foundation and the concrete and the flexural strength of the concrete

Inputs		
Type of foundation [Liqiud - 1 ; Solid - 2]	1	1
Radius of loading plate (**a**), mm in Col F	5.905511811	150
Load (**P**), kN in Col f	11227.5	50
Poisson ratio for concrete (μ_c)	0.15	0.15
Poisson ratio for subgrade (μ_f)	0.45	0.45
Thickness of the concrete slab **h** (mm) in Col F	11.81102362	300
Deflection measured at 0 mm distance from the center of the load area **(w_0) ,Col F**	0.003149606	0.08
Deflection measured at 300 mm distance from the center of the load area **(w_1),Col F**	0.002952756	0.075
Deflection measured at 600 mm distance from the center of the load area **(w_2),Col F**	0.002559055	0.065
Deflection measured at 900 mm distance from the center of the load area **(w_3),Col F**	0.002204724	0.056
Result		
Area of defelection basin (Sq mm),Col F	31.2	20128.992
Radius of relative stiffness, **l** (mm),Col F	39.054	991.968
Normalised defelction, d_0 (mm),Col F	0.124	3.137
Normalised defelction, d_1 (mm),Col F	0.116	2.941
Normalised defelction, d_2 (mm),Col F	0.101	2.578
Normalised defelction, d_3 (mm).Col F	0.085	2.150
Modulus of subgrade reaction **k** (MPa/m) for Winkler foundation / Elastic modulus of foundation E_f (MPa) [for solid foundation],Col F	287.9829711	78.130
Elastic modulus of concrete E_c (MPa),Col F	4769344.766	32908.479
Cubestrengh strenght of concrete f_{ck} (MPa)		43.32
Flexural strength, Mpa		4.61

The k value shown in F27 is to be determined in different seasons for three to five years to determine the long term modulus for design In the interim period 50% of F27 may be considered for design as per AASHTO 93

11 REFERENCES

1. Ionnides, A.M., E.J. Barenberg, and J.A. Lary (1989), 'Interpretations of Falling Weight Deflectometer Results Using Principles of Dimensional Analysis' Proc. 4th Int. Conf. on Concrete Pavement Design and Rehabilitation, pp. 231-247.
2. AASHTO (1993), 'AASHTO Guide for Design of Pavement Structures', American Association of State Highway and Transport Officials, Washington D.C.
3. IRC:115-2014, 'Guidelines for the Structural Evaluation and Strengthening of Flexible Road Pavements using Falling Weight Deflectometer (FWD) Technique.
4. IRC:58-2011, 'Guidelines for the Design of Plain Jointed Rigid Pavements for Highways'.
5. Maitra, Swati Roy, 'Numerical and Experimental Investigation on Jointed Concrete Pavements', Ph.D. Thesis, IIT Kharagpur, 2011.
6. Huang, V.H., 'Pavement Analysis and Design' Pearson Education Inc, 2nd Ed, 2004.