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STRUCTURAL EVALUATION OF RIGID PAVEMENT USING FALLING WEIGHT DEFLECTOMETER (FWD)

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ABSTRACT:- ***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 conditions. 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. One of the most difficult exercises for a pavement engineer is analyzing deflection data collected with 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 judgments, can take appropriate measures to prevent continuing damage to concrete pavements.***

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. This study may help to understand the periodical measurements, performance, traffic, climatic condition, etc.

Key words**:** ***Back Calculation, Concrete Pavement, Elastic Modulus, Falling Weight Deflectometer, Modulus of subgrade reaction.***

1. INTRODUCTION

To have durable maintenance-free roads even under adverse moisture, climatic, heavy traffic conditions and various distresses such as intensity of cracking, pumping, crack stiffness, load transfer efficiency, mud pumping etc. many concrete pavements are constructed across the country. The structural performance of the pavements should be evaluated for taking up any further measures. The strength parameters are Subgrade reaction (k), deflections and Elastic modulus of the layers. The moduli of subgrade reaction (k) are usually adopted from their correlation with CBR values. A stiff sub base of DLC covered with a plastic sheet has a very high modulus of subgrade reaction. Its validity is to be established.

These guidelines are meant for evaluating the structural condition of in-service rigid pavements using FWD 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 withstand future traffic loading i.e. balance life of the pavement, can be determined using cumulative fatigue damage principle as laid down in IRC: 58-2015.

1.1 OBJECTIVES

The main objective of the present study is to compare the radius of relative stiffness (l), modulus of subgrade reaction (k) and modulus of elasticity (E) through back-calculation by various methods/software. Apart from this, in view of the discussions presented above, the present study was taken up with the following objectives:

1. Evaluation of sub grade modulus of the selected pavement stretches.
2. Evaluation of elastic modulus and strength of concrete pavements selected.
3. Detection of voids/ cavities under the slab if any.
4. Evaluation of load transfer efficiency of Dowel joints.
5. Based on the above study suitable Suggestions for improving Pavement Management System (PMS).

2. PREVIOUS RESEARCH

It is noted that the back-calculated value of the modulus of sub-grade reaction (k) depends on the location of the load application-at the slab interior or near its free edge (Uzan 1992). Halls et al, (1995) in their paper presented guidelines k-value selection for concrete pavement design. The research included a review of the evolution of k-value concepts and methods, a review of k-value results from several field studies, an examination of the AASHTO Guide's k-value methods, and proposed new guidelines for selection of design k values by a variety of methods. The k value was originally considered a useful and simple parameter for characterizing slab support provided by natural soils of fairly low shear strength. Based on the historical review, review of results from several field studies, and a thorough examination of the k-value methods introduced in the 1986 AASHTO Guide, it is recommended that k values be selected for natural soil materials, and that base layers be considered in concrete pavement design in terms of their effect on the slab response, rather than their supposed effect on k value. The rigid pavement joint stiffness properties were also predicted using as ANN technique based on dimensional analysis (Ioannides et al., 1996). AREA methods: These methods use (i) the AREA parameter of the deflection basin (Ioannides 1990) or (ii) the actual area of the deflection basin (Tai et al., 1989; Rufino et al., 2002) or (iii) the normalized actual area of the deflection basin (Crovetti and Tirado-Crovetti 1994). The ILLI-BACK is the first closed-form analytical rigid pavement back-calculation algorithm developed at the University of Illinois, USA.

3. METHODOLOGY

3.1 FALLING WEIGHT DEFLECTOMETER

Mid-slab surface deflection data obtained by conducting an FWD test at 40kN loading on the mid-slab with seven geophones positioned at given intervals/ configuration is used to back-calculate various values of pavement performance parameters such as radius of relative stiffness (l), modulus of sub-grade reaction (k) and elastic modulus of slab (E_{slab}). The geophone configuration may be taken at regular intervals of 30 cm (Fwa et al., 2000) or any given spacing such as 0, 20.3, 30.5, 45.7, 61.0, 91.4 and 152.4 cm (Frabizzio and Buch 2000) or – 30.5, 0, 30.5, 45.7, 61.0, 91.4, 154.2 cm of radial distance from the centre of the loading plate (Jiang and Tayabji 2000). Back-calculation of the above parameters can also be determined by using the deflection basins obtained by conducting FWD tests at the edge centre of the slab and geophones placed along the edge.

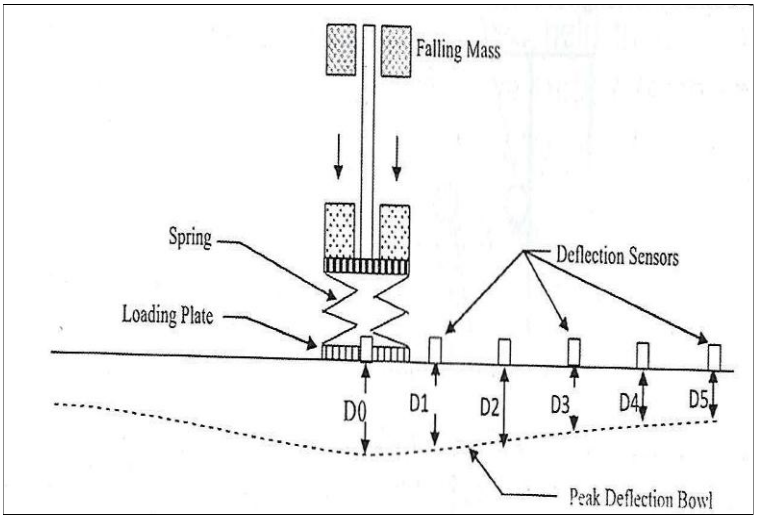

Figure 01: Working Principle of FWD (Srinivasa, 2014)

3.2 LOAD TRANSFER EFFICIENCY

Structural performance of any rigid pavement is evaluated by determining the load transfer across cracks or transverse joints. The transverse joints may be with or without dowel bars. In case of a transverse joint without dowel bars, the load across the joint takes place by aggregate interlocking. Whatever the type of joint or crack, their performance characteristics are determined in terms of load transfer efficiency (LTE).

LTE is determined by conducting an FWD test on the side of a crack or transverse joint. 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 pavement the joint efficiency is nearly 100 per cent since the deflections at both sides of the joint are almost equal and the ratio decreases as the joint deteriorate under repeated loading.

When deflection sensors at either side of the joint with deflection D_1 and D_2 on the loaded and the unloaded side as shown in the Figure 02, the Load Transfer Efficiency is defined as:

$$LTE = 100 * (D_2 / D_1) \quad (3.1)$$

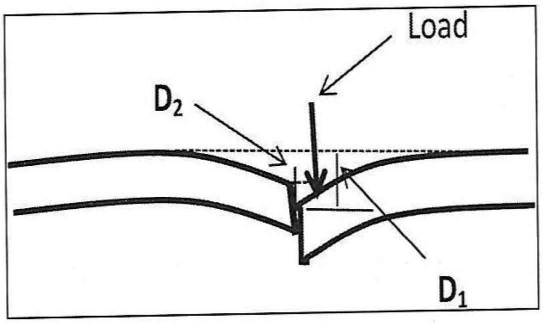

Figure 02: Deflections on loaded and unloaded sides of the joint

- 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 are in critical condition
- If $D_2/D_1 < 0.4$, Longitudinal Joints are in critical condition

3.3 DETECTION OF VOIDS UNDERNEATH THE PAVEMENT CONCRETE

Loss of support under a slab creates non-uniform distribution of the wheel load stresses which leads to undesirable conditions of concentrated stress zone in the slab. The effect is manifested as cracks or faulting. The loss of support and voids under the slab may occur due to many reasons such as mud pumping, densification of the supporting layer and curling up and down of the slab corner and edges.

Detection of voids below the 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 than the normal may indicate presence of voids.

There is also another way to detect the voids. A plot should be drawn between measured deflection values on the x-axis and the corresponding load values on the y-axis. FWD tests performed on slab with void and without void at different load levels yields the following results.

4. STUDY AREA AND DATA COLLECTION

4.1 STUDY AREA

The study areas selected for the present study are the Peddamberpet toll plaza at Nehru Outer Ring Road (ORR) and a stretch of NH – 65 near the Peddamberpet junction. The following Figures 03 and 04 shows the google satellite image of the study area.

Figure 03: Peddamberpet toll plaza

Figure 04: NH – 65 Hyderabaad and Vijayawada

The rigid pavement composition for the above selected stretches is presented below in table 4.1. The panels at the study areas are of size 3.5 m *4.5m.

Table 4.1: Composition of Concrete Pavement (At both locations)

Designation of the pavement layer	**Thickness(mm)**
Granular Sub base	200
Dry Lean Concrete (DLC) (M15)	150
Pavement Quality Concrete (PQC) (M40)	300
Length of the Dowel bar	500
Diameter of the dowel bar	32
Spacing of the dowel bar	300

4.2 DATA COLLECTION

The data is collected along the selected stretches by FWD. this data is presented in the following tables.

Table: 4.2: FWD Data along the ORR at Peddamberpet

Point	Pavement Type	Remarks	Lane	Drop	Deflection in microns				Load
					D(1)	D(2)	D(3)	D(4)	KN
					0	300	600	900	
1	Concrete	slab 1	Centre	1	142	118	102	93	89.46
	Concrete		Centre	2	143	117	101	93	90
	Concrete		Centre	3	143	118	102	94	90.17
2	Concrete	slab 1	Centre	1	141	117	101	92	89.63
	Concrete		Centre	2	140	115	100	91	90.06
	Concrete		Centre	3	140	114	100	92	90.03
3	Concrete	slab1	Transverse Joint	1	139	115	99	91	89.78
	Concrete		Transverse Joint	2	140	116	100	92	89.78
	Concrete		Transverse Joint	3	140	116	100	92	90.28
4	Concrete	slab1	Corner	1	141	120	105	97	89.25
	Concrete		Corner	2	140	119	104	96	89.68
	Concrete		Corner	3	140	119	103	96	89.57
5	Concrete	slab1	Corner	1	112	95	84	77	70.87
	Concrete		Corner	2	111	95	83	77	70.43
	Concrete		Corner	3	112	95	84	77	70.28
6	Concrete	slab1	Corner	1	82	70	62	57	52.01
	Concrete		Corner	2	81	68	60	56	51.33
	Concrete		Corner	3	80	67	60	55	50.83
7	Concrete	slab2	Centre	1	83	70	62	57	51.63
	Concrete		Centre	2	82	69	61	56	50.91
	Concrete		Centre	3	81	68	61	55	50.46
8	Concrete	slab2	Centre	1	97	81	72	66	58.32
	Concrete		Centre	2	98	82	73	66	59.06
	Concrete		Centre	3	98	83	73	67	59.51
9	Concrete	slab2	Transverse Joint	1	116	91	73	65	61.24
	Concrete		Transverse Joint	2	115	90	73	64	60.83
	Concrete		Transverse Joint	3	114	89	72	63	60.29
10	Concrete	slab2	Corner	1	96	78	66	58	60.56
	Concrete		Corner	2	94	77	64	57	60.61
	Concrete		Corner	3	94	76	64	57	60.31
11	Concrete	slab2	Corner	1	79	64	54	48	51.92
	Concrete		Corner	2	77	62	53	47	51.34
	Concrete		Corner	3	76	62	53	47	50.97
12	Concrete	slab2	Corner	1	152	123	102	91	88.8
	Concrete		Corner	2	154	124	103	92	89.38
	Concrete		Corner	3	154	125	104	92	89.54
13	Concrete	slab3	Corner	1	187	145	121	109	88.56
	Concrete		Corner	2	188	146	122	109	88.67
	Concrete		Corner	3	189	147	122	109	89.01
14	Concrete	slab3	Corner	1	168	130	109	96	79.94
	Concrete		Corner	2	157	121	101	88	75.42
	Concrete		Corner	3	152	118	98	87	72.96

15	Concrete	slab3	Corner	1	149	115	96	85	72.01
	Concrete		Corner	2	147	114	95	84	70.84
	Concrete		Corner	3	146	113	94	83	70.21
16	Concrete	slab3	Corner	1	137	106	89	79	66.26
	Concrete		Corner	2	130	101	84	73	63.98
	Concrete		Corner	3	126	98	81	71	61.84
17	Concrete	slab3	Corner	1	124	95	79	69	61.21
	Concrete		Corner	2	123	95	79	69	60.57
	Concrete		Corner	3	122	95	79	69	60.36
18	Concrete	slab3	Transverse Joint	1	104	89	79	73	59.52
	Concrete		Transverse Joint	2	105	89	80	74	59.28
	Concrete		Transverse Joint	3	105	89	80	74	59.62
19	Concrete	slab3	Centre	1	95	70	62	56	59.53
	Concrete		Centre	2	95	70	62	56	59.66
	Concrete		Centre	3	96	71	63	57	59.95

Table4.3: FWD data along NH – 65 at Peddamberpet

Point	Pavement Type	Remarks	Lane	Drop	Deflection in microns				Load
					D(1)	D(2)	D(3)	D(4)	KN
					0	300	600	900	
1	Concrete	slab1	Centre	1	55	42	38	35	59.92
	Concrete		Centre	2	55	42	38	35	60.05
	Concrete		Centre	3	55	42	38	35	59.83
2	Concrete	slab1	Transverse Joint	1	60	44	39	34	59.93
	Concrete		Transverse Joint	2	60	44	39	34	59.66
	Concrete		Transverse Joint	3	59	44	38	34	59.66
3	Concrete	slab1	Corner	1	88	69	56	49	59.04
	Concrete		Corner	2	87	70	57	49	59.27
	Concrete		Corner	3	87	70	57	49	58.97
4	Concrete	slab1	Corner	1	105	84	68	59	69.11
	Concrete		Corner	2	106	85	69	60	69.51
	Concrete		Corner	3	106	85	69	60	69.53
5	Concrete	slab1	Corner	1	135	109	88	77	89.15
	Concrete		Corner	2	136	110	89	77	89.59
	Concrete		Corner	3	137	110	89	78	89.84
6	Concrete	slab2	Corner	1	224	174	143	124	88.37
	Concrete		Corner	2	228	177	145	126	88.47
	Concrete		Corner	3	232	180	147	128	88.99
7	Concrete	slab2	Corner	1	190	147	122	104	71.68
	Concrete		Corner	2	188	146	121	104	71.01
	Concrete		Corner	3	187	145	121	103	70.49
8	Concrete	slab2	Corner	1	162	125	102	89	60.94
	Concrete		Corner	2	162	125	102	89	60.83
	Concrete		Corner	3	160	124	101	88	60.33
9	Concrete	slab2	Centre	1	78	59	48	43	58.64
	Concrete		Centre	2	78	58	48	43	59.28
	Concrete		Centre	3	79	59	49	43	59.47

10	Concrete	slab2	Transverse Joint	1	85	63	49	41	59.49
	Concrete		Transverse Joint	2	85	63	49	41	59.73
	Concrete		Transverse Joint	3	85	63	49	42	59.96
11	Concrete	slab3	Centre	1	67	51	44	39	59.95
	Concrete		Centre	2	67	52	46	40	60.19
	Concrete		Centre	3	66	51	44	39	59.71
12	Concrete	slab3	Transverse Joint	1	84	64	54	48	59.56
	Concrete		Transverse Joint	2	85	65	54	48	60.11
	Concrete		Transverse Joint	3	85	65	55	48	60.21
13	Concrete	slab3	Corner	1	93	67	53	44	63.35
	Concrete		Corner	2	91	65	51	42	61.59
	Concrete		Corner	3	90	64	51	41	60.99
14	Concrete	slab3	Corner	1	106	75	59	51	68.65
	Concrete		Corner	2	106	76	59	51	69.18
	Concrete		Corner	3	107	76	60	51	69.36
15	Concrete	slab3	Corner	1	142	103	80	67	87.79
	Concrete		Corner	2	144	104	81	68	88.89
	Concrete		Corner	3	145	105	81	68	89.63

5. ANALYSIS OF DATA

5.1 IRC 117:2015, Ioannides Approach

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

$$A = 6\left[1 + 2\left(\frac{D_1}{D_0}\right) + 2\left(\frac{D_2}{D_0}\right) + \left(\frac{D_3}{D_0}\right)\right] \quad (5.1)$$

Where,

A is the area parameter of the deflection basin
D_0 = deflection at the centre of the loading plate in mm
D_1 = deflection in mm at 300mm from the centre of loading plate
D_2 = deflection in mm at 600mm from the centre of the loading plate
D_3 = deflection in mm at 900mm from the centre of the loading plate

The value of A is 11.8 for single elastic layer. For extremely rigid layer with a very high elastic modulus, the value of A is 36. For a concrete pavement, A will be less than 36.

- From the area the value of ‘l’ can be found easily by Iaonnides approach. From this the value of normalised deflection is obtained (Iaonnides Approach).

$$l = 10^{[(0.000226 \times A^3) - (0.0164 \times A^2) + (0.4343 \times A) - 2.858)]} \quad (5.2)$$

- Subgrade modulus is found by following formulae and average of all should be taken as subgrade modulus.

$$k_l = \frac{pd_i}{l^2 D_i} \quad (5.3)$$

Where,

i= 1, 2, 3, 4
l= Radius of relative stiffness
P= Load in KN
D_i = Measured deflections at various radial distances
d_i= Normalised deflections at various radial distances

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

- Elastic Modulus in concrete is found by using the formulae

$$E_c = \frac{12(1-\mu_c)kl^4}{1000h^3} \tag{5.4}$$

Where,

μ_c = Poisson's ratio of concrete
h = thickness of concrete pavement in mm
l = Radius of relative stiffness in mm
k= Modulus of subgrade reaction in MPa/m
E = elastic modulus of concrete, MPa

5.2 Hall's Approach

The details of the back-calculation procedure proposed by Hall's are given below.

- Mid-slab surface deflections measured at four radial distances, 0, 30.48, 60.96 and 91.44 cm from the centre of the FWD loading plate are used to determine the normalized actual AREA of the deflection basin is given below:

$$AREA_{SHRP} = \frac{4d_0 + 6d_8 + 5d_{12} + 6d_{18} + 9d_{24} + 18d_{36} + 12d_{60}}{d_0} \tag{5.5}$$

- The value of the radius of relative stiffness (ℓ) of the slab can be estimated using the regression equation developed by Hall (cited in Crovetti and Tirado-Crovetti 1994), which is based on the theoretical deflections calculated using the Losberg model. Hall's equation is given below.

$$\ell = \left[\frac{\ln\left(\frac{60 - AREA_{SHRP}}{289.708}\right)}{-0.698} \right]^{2.566} \tag{5.6}$$

- The k value of the supporting layer of the slab can be determined by the following equation.

$$k = \frac{Pd_r^*}{d_r l^2} \tag{5.7}$$

where, P = load, d_r = measured deflection at radial distance r, d_r^* = non-dimensional deflection coefficient for radial distance r.

Where,

$$d^* = 0.12497e^{-0.46308\left(\frac{r}{l}\right)^{1.55212}} \tag{5.8}$$

- Elastic modulus of the PCC slab (E_{slab}) can be obtained from Westergaard's equation of the radius of relative stiffness using the values of adjusted ℓ, slab thickness, Poisson's ratio of concrete and estimated k value.

$$E_c = \frac{12(1-\mu_c)kl^4}{1000h^3} \tag{5.9}$$

The Elastic modulus, Load Transfer Efficiency for the ORR and NH Road section is calculated and presented in the following tables by various approaches.

Table 5.1: Back calculation of Elastic Modulus (E) and Load Transfer Efficiency (LTE) for ORR road section by IRC 117:2015, Ioannides Approach

Point	Load (KN)	Deflection (inches)				Area	*l* *(mm)*	K value (MPa/m)	E (MPa)	Flexural Strength (MPa)	LTE %
		D(1)	D(2)	D(3)	D(4)						
		0	300	600	900						
1	89.460	0.003	0.003	0.002	0.002	31.02	964.103	91.858645	34523.375	4.83	92.33
	90.000	0.003	0.003	0.002	0.002	30.66	911.333	102.12721	30644.347	4.29	90.91
	90.170	0.003	0.003	0.002	0.002	30.90	944.727	95.488019	33088.296	4.63	91.69

	89.630	0.003	0.003	0.002	0.002	30.96	955.117	94.38512	34168.818	4.78	92.20
2	90.060	0.003	0.003	0.002	0.002	30.81	932.206	100.02205	32858.123	4.60	91.27
	90.030	0.003	0.002	0.002	0.002	30.76	925.371	101.23771	32292.857	4.52	90.48
	89.780	0.003	0.003	0.002	0.002	30.89	944.280	97.954588	33878.818	4.74	91.93
	89.780	0.003	0.003	0.002	0.002	30.95	953.283	95.482904	34301.428	4.80	92.06
3	90.280	0.003	0.003	0.002	0.002	30.95	953.283	96.014664	34492.458	4.83	92.06
	89.250	0.003	0.003	0.002	0.002	31.86	1110.893	70.05523	46411.965	6.50	94.56
	89.680	0.003	0.003	0.002	0.002	31.81	1100.399	72.224538	46066.441	6.45	94.44
4	89.570	0.003	0.003	0.002	0.002	31.71	1082.095	74.497036	44432.443	6.22	94.44
	70.870	0.003	0.003	0.002	0.002	31.89	1116.866	69.310478	46914.006	6.57	94.25
	70.430	0.003	0.003	0.002	0.002	32.01	1139.925	66.773099	49046.296	6.87	95.10
5	70.280	0.003	0.003	0.002	0.002	31.89	1116.866	68.733461	46523.442	6.51	94.25
	52.010	0.003	0.003	0.002	0.002	32.10	1159.196	64.604348	50744.533	7.10	94.85
	51.330	0.003	0.003	0.002	0.002	31.68	1075.452	74.556448	43385.89	6.07	93.28
6	50.830	0.003	0.003	0.002	0.002	31.75	1088.895	73.036242	44666.61	6.25	93.06
	51.630	0.003	0.003	0.002	0.002	31.78	1095.272	70.733243	44280.399	6.20	93.71
	50.910	0.003	0.003	0.002	0.002	31.69	1077.712	72.862352	42757.641	5.99	93.50
7	50.460	0.003	0.003	0.002	0.002	31.76	1091.066	71.451125	44046.68	6.17	93.28
	58.320	0.003	0.003	0.002	0.002	31.57	1054.829	73.53299	39601.43	5.54	92.78
	59.060	0.003	0.003	0.002	0.002	31.58	1056.864	73.531316	39906.894	5.59	92.97
8	59.510	0.003	0.003	0.002	0.002	31.78	1095.114	69.117373	43243.787	6.05	94.10
	61.240	0.003	0.003	0.002	0.002	28.59	691.092	145.93	14480.648	2.03	87.16
	60.830	0.003	0.003	0.002	0.002	28.61	692.912	145.58157	14598.824	2.04	86.96
9	60.290	0.003	0.003	0.002	0.002	28.51	685.363	148.63134	14265.683	2.00	86.74
	60.560	0.003	0.003	0.002	0.002	30.03	830.840	122.85222	25465.493	3.57	90.28
	60.610	0.003	0.003	0.002	0.002	30.04	832.560	125.08225	26143.087	3.66	91.02
10	60.310	0.003	0.002	0.002	0.002	29.90	816.329	129.06302	24932.318	3.49	89.83
	51.920	0.003	0.002	0.002	0.002	29.97	823.751	129.96129	26031.42	3.64	90.01
	51.340	0.003	0.002	0.002	0.002	29.98	825.633	131.17987	26516.497	3.71	89.47
11	50.970	0.003	0.002	0.002	0.002	30.30	863.444	121.18262	29300.587	4.10	90.64
	88.800	0.003	0.003	0.002	0.002	29.73	797.386	122.99198	21629.759	3.03	89.91
	89.380	0.003	0.003	0.002	0.002	29.64	787.669	125.0235	20934.705	2.93	89.47
12	89.540	0.003	0.003	0.002	0.002	29.81	806.216	119.95415	22045.516	3.09	90.19
	88.560	0.004	0.003	0.003	0.002	28.85	713.235	122.88223	13833.137	1.94	86.16
	88.670	0.004	0.003	0.003	0.002	28.87	714.984	121.89704	13857.3	1.94	86.29
13	89.010	0.004	0.003	0.003	0.002	28.82	710.650	123.17605	13666.266	1.91	86.42
	79.940	0.004	0.003	0.003	0.002	28.78	706.907	125.77041	13662.418	1.91	85.98
	75.420	0.004	0.003	0.003	0.002	28.59	691.417	132.54116	13176.838	1.84	85.63
14	72.960	0.004	0.003	0.003	0.002	28.76	705.675	127.27978	13730.21	1.92	86.26
	72.010	0.004	0.003	0.003	0.002	28.68	699.122	130.40161	13551.74	1.90	85.76
	70.840	0.004	0.003	0.003	0.002	28.77	705.951	127.70752	13797.94	1.93	86.17
15	70.210	0.004	0.003	0.003	0.002	28.69	699.908	129.54619	13523.453	1.89	86.00
	66.260	0.004	0.003	0.003	0.002	28.82	710.694	126.45518	14033.553	1.96	85.97
	63.980	0.004	0.003	0.003	0.002	28.72	701.891	132.08057	13944.928	1.95	86.32
16	61.840	0.004	0.003	0.003	0.002	28.70	700.268	132.23967	13833.065	1.94	86.42
	61.210	0.004	0.003	0.003	0.002	28.42	677.885	141.34071	12983.483	1.82	85.13
	60.570	0.004	0.003	0.003	0.002	28.60	692.339	135.53364	13546.317	1.90	85.82
17	60.360	0.004	0.003	0.003	0.002	28.79	707.677	130.68528	14258.271	2.00	86.52
	59.520	0.003	0.003	0.003	0.002	32.22	1185.407	55.771405	47905.05	6.71	95.09
	59.280	0.003	0.003	0.003	0.002	32.16	1172.388	56.156457	46151.381	6.46	94.18
18	59.620	0.003	0.003	0.003	0.002	32.16	1172.388	56.478542	46416.082	6.50	94.18
	59.530	0.003	0.002	0.002	0.002	28.46	680.753	176.86923	16523.819	2.31	81.87
19	59.660	0.003	0.002	0.002	0.002	28.46	680.753	177.25548	16559.903	2.32	81.87
	59.950	0.003	0.002	0.002	0.002	28.57	689.742	171.92545	16927.255	2.37	82.18

Table: 5.2: Back calculation of Elastic Modulus (E) and Load Transfer Efficiency (LTE) for NH – 65 road section by IRC 117:2015, Ioannides Approach

Point	Load (KN)	Deflection (inches) D(1) 0	D(2) 300	D(3) 600	D(4) 900	Area	*l* (*mm*)	K value (MPa/m)	E (MPa)	Flexural Strength (MPa)	LTE %
1	59.920	0.002	0.001	0.001	0.001	29.64	787.669	232.79556	38980.723	5.46	84.85
	60.050	0.002	0.001	0.001	0.001	29.64	787.669	233.30063	39065.294	5.47	84.85
	59.830	0.002	0.001	0.001	0.001	29.64	787.669	232.4459	38922.174	5.45	84.85
2	59.930	0.002	0.001	0.001	0.001	28.22	662.919	297.17212	24966.097	3.50	81.48
	59.660	0.002	0.001	0.001	0.001	28.22	662.919	295.83328	24853.618	3.48	81.48
	59.660	0.002	0.001	0.001	0.001	28.37	674.296	291.13971	26182.071	3.67	82.86
3	59.040	0.003	0.002	0.002	0.002	28.65	696.403	182.94576	18718.247	2.62	87.12
	59.270	0.003	0.002	0.002	0.002	29.22	746.183	163.44179	22041.681	3.09	89.40
	58.970	0.003	0.002	0.002	0.002	29.22	746.183	162.61451	21930.115	3.07	89.40
4	69.110	0.003	0.002	0.002	0.002	29.05	730.454	164.27801	20344.724	2.85	88.89
	69.510	0.003	0.002	0.002	0.002	29.14	739.310	159.92991	20784.293	2.91	89.10
	69.530	0.003	0.002	0.002	0.002	29.14	739.310	159.97593	20790.273	2.91	89.10
5	89.150	0.003	0.002	0.002	0.002	29.26	750.048	156.71785	21576.149	3.02	89.71
	89.590	0.003	0.002	0.002	0.002	29.28	752.437	155.55892	21690.747	3.04	89.87
	89.840	0.003	0.002	0.002	0.002	29.16	741.010	159.15848	20874.932	2.92	89.21
6	88.370	0.004	0.004	0.003	0.003	28.56	688.945	109.75721	10756.526	1.51	86.31
	88.470	0.005	0.004	0.003	0.003	28.51	685.363	109.01715	10463.5	1.46	86.26
	88.990	0.005	0.004	0.003	0.003	28.47	681.939	108.78677	10234.312	1.43	86.21
7	71.680	0.005	0.004	0.003	0.003	28.53	686.292	105.82123	10211.967	1.43	85.96
	71.010	0.005	0.004	0.003	0.003	28.62	694.165	103.63348	10467.678	1.47	86.29
	70.490	0.005	0.004	0.003	0.003	28.64	695.309	103.1533	10488.06	1.47	86.16
8	60.940	0.005	0.004	0.003	0.003	28.35	672.213	109.57819	9733.1161	1.36	85.73
	60.830	0.005	0.004	0.003	0.003	28.35	672.213	109.3804	9715.5473	1.36	85.73
	60.330	0.005	0.004	0.003	0.003	28.42	677.676	108.21694	9928.518	1.39	86.11
9	58.640	0.002	0.002	0.002	0.001	27.97	644.416	236.4733	17739.758	2.48	84.05
	59.280	0.002	0.002	0.002	0.001	27.79	632.643	247.15181	17222.597	2.41	82.62
	59.470	0.002	0.002	0.002	0.001	27.86	636.841	242.16361	17327.336	2.43	82.98
10	59.490	0.003	0.002	0.002	0.001	26.78	570.837	278.28342	12853.884	1.80	82.35
	59.730	0.003	0.002	0.002	0.001	26.78	570.837	279.40609	12905.74	1.81	82.35
	59.960	0.003	0.002	0.002	0.001	26.86	575.215	275.95068	13141.728	1.84	82.35
11	59.950	0.002	0.002	0.001	0.001	28.79	707.608	235.49595	25683.5	3.60	84.58
	60.190	0.002	0.002	0.002	0.001	29.48	771.887	200.72594	30996.9	4.34	86.24
	59.710	0.002	0.002	0.001	0.001	29.13	738.080	219.92344	28391.227	3.97	85.86
12	59.560	0.002	0.002	0.002	0.002	28.54	687.358	197.30088	19158.447	2.68	84.66
	60.110	0.003	0.002	0.002	0.002	28.43	678.819	201.65499	18626.255	2.61	84.97
	60.210	0.003	0.002	0.002	0.002	28.59	691.256	195.31409	19399.41	2.72	84.97
13	63.350	0.003	0.002	0.002	0.001	26.36	548.092	291.65492	11449.374	1.60	80.05
	61.590	0.003	0.002	0.002	0.001	26.07	533.745	304.56531	10752.688	1.51	79.37
	60.990	0.003	0.002	0.002	0.001	26.07	533.785	305.23887	10779.702	1.51	79.01
14	68.650	0.003	0.002	0.002	0.001	26.06	533.236	290.72173	10224.815	1.43	78.62
	69.180	0.003	0.002	0.002	0.001	26.19	539.473	287.06255	10576.818	1.48	79.66
	69.360	0.003	0.002	0.002	0.001	26.12	536.281	288.28556	10372.694	1.45	78.92
15	87.790	0.003	0.002	0.002	0.002	26.33	546.562	266.21751	10334.607	1.45	80.59
	88.890	0.003	0.002	0.002	0.002	26.28	543.967	268.01901	10208.361	1.43	80.25
	89.630	0.003	0.002	0.002	0.001	26.23	541.543	270.78423	10131.088	1.42	80.46

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Table 5.3: Back calculation of Elastic Modulus (E) and Load Transfer Efficiency (LTE) for ORR road section by Hall's Approach

Point	Load	Deflection (inches)							Area (in)	*l* (mm)	k (MPa/m)	E (MPa)	Flexural strength Mpa
		D(0)	D(8)	D(12)	D(18)	D(24)	D(36)	D(60)					
		0	200	300	450	600	900	1500					
	89.46	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.57	625.52	201.28	46856.84	6.56
1	90	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.49	623.45	202.42	46655.09	6.53
	90.17	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.63	627.08	200.45	47015.81	6.58
	89.63	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.80	631.69	199.15	47745.07	6.68
2	90.06	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.30	644.95	193.33	49331.21	6.91
	90.03	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.18	641.85	195.13	49077.79	6.87
	89.78	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.42	648.36	192.08	49793.62	6.97
3	89.78	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.16	641.26	194.95	48896.39	6.85
	90.28	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.42	648.26	191.82	49706.02	6.96
	89.25	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.33	645.90	189.67	48612.22	6.81
4	89.68	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.83	659.65	184.03	50242.81	7.03
	89.57	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.82	659.52	183.87	50171.54	7.02
	70.87	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.51	650.71	186.81	48958.42	6.85
5	70.43	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.50	650.62	187.38	49086.14	6.87
	70.28	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.17	641.46	190.64	47860.36	6.70
	52.01	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.67	655.31	184.64	49421.37	6.92
6	51.33	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.68	655.43	184.40	49386.33	6.91
	50.83	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.60	653.30	186.10	49355.31	6.91
	51.63	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.33	619.46	202.64	45817.75	6.41
7	50.91	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.46	622.89	200.04	45982.31	6.44
	50.46	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.28	618.13	203.82	45786.00	6.41
	58.32	0.003	0.002	0.002	0.002	0.002	0.002	0.001	33.39	596.15	211.49	42617.83	5.97
8	59.06	0.003	0.002	0.002	0.002	0.002	0.002	0.001	33.34	594.84	212.92	42624.41	5.97
	59.51	0.003	0.002	0.002	0.002	0.002	0.002	0.001	33.63	601.91	209.53	43459.71	6.08
	61.24	0.004	0.002	0.002	0.002	0.002	0.002	0.001	28.81	499.55	264.46	31357.88	4.39
9	60.83	0.004	0.002	0.002	0.002	0.002	0.002	0.001	28.73	498.19	266.42	31333.56	4.39
	60.29	0.004	0.002	0.002	0.002	0.002	0.002	0.001	28.76	498.71	265.82	31360.52	4.39
	60.56	0.003	0.002	0.002	0.002	0.002	0.002	0.001	33.92	609.09	212.56	45686.78	6.40
10	60.61	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.77	630.86	202.53	48366.40	6.77
	60.31	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.49	623.59	206.26	47571.97	6.66
	51.92	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.37	646.90	196.32	50551.88	7.08
11	51.34	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.78	658.24	192.37	52184.45	7.31
	50.97	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.67	655.23	195.28	52249.94	7.31
	88.8	0.003	0.002	0.002	0.002	0.002	0.002	0.001	31.70	557.56	234.92	38730.56	5.42
12	89.38	0.003	0.002	0.002	0.002	0.002	0.002	0.001	31.47	552.62	237.58	38136.33	5.34
	89.54	0.003	0.002	0.002	0.002	0.002	0.002	0.001	31.54	554.04	236.78	38303.13	5.36
	88.56	0.004	0.002	0.002	0.002	0.002	0.002	0.001	26.25	455.52	285.31	25650.70	3.59
13	88.67	0.004	0.002	0.002	0.002	0.002	0.002	0.001	26.22	455.02	284.77	25517.73	3.57
	89.01	0.004	0.002	0.002	0.002	0.002	0.002	0.001	26.16	454.13	285.47	25430.08	3.56
	79.94	0.004	0.002	0.002	0.002	0.002	0.002	0.001	26.31	456.50	285.44	25827.63	3.62
14	75.42	0.004	0.002	0.002	0.002	0.002	0.002	0.001	26.43	458.47	285.70	26187.23	3.67
	72.96	0.004	0.002	0.002	0.002	0.002	0.002	0.001	26.47	459.03	284.78	26198.25	3.67
	72.01	0.004	0.002	0.002	0.002	0.002	0.002	0.001	26.56	460.55	284.84	26465.08	3.71
15	70.84	0.004	0.002	0.002	0.002	0.002	0.002	0.001	26.53	460.08	284.60	26362.45	3.69
	70.21	0.004	0.002	0.002	0.002	0.002	0.002	0.001	26.51	459.66	284.51	26283.29	3.68
	66.26	0.004	0.002	0.002	0.002	0.002	0.002	0.001	26.73	463.38	281.58	26647.85	3.73
16	63.98	0.004	0.002	0.002	0.002	0.002	0.002	0.001	27.01	468.04	280.85	27388.87	3.83
	61.84	0.004	0.002	0.002	0.002	0.002	0.002	0.001	27.02	468.15	279.94	27319.85	3.82
17	61.21	0.004	0.002	0.002	0.002	0.002	0.002	0.001	27.04	468.55	281.08	27501.06	3.85

	60.57	0.004	0.002	0.002	0.002	0.002	0.002	0.001	27.01	467.91	281.17	27397.44	3.84
	60.36	0.004	0.002	0.002	0.002	0.002	0.002	0.001	27.15	470.36	279.55	27670.46	3.87
18	59.52	0.003	0.002	0.002	0.002	0.002	0.002	0.001	32.38	572.53	218.26	38960.48	5.45
	59.28	0.003	0.002	0.002	0.002	0.002	0.002	0.001	32.13	566.99	219.54	38061.78	5.33
	59.62	0.003	0.002	0.002	0.002	0.002	0.002	0.001	32.30	570.82	217.85	38538.31	5.40
19	59.53	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.33	619.51	204.11	46158.59	6.46
	59.66	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.40	621.20	203.44	46386.05	6.49
	59.95	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.17	615.29	206.21	45686.62	6.40

Table 5.4 : Back calculation of Elastic Modulus (E) and Load Transfer Efficiency (LTE) for NH - 65 road section by Hall's Approach

Point	Load	Deflection (inches)							Area (in)	*l* (mm)	k (MPa/m)	E (MPa)	Flexural strength, Mpa
		D(0)	D(8)	D(12)	D(18)	D(24)	D(36)	D(60)					
		0	200	300	450	600	900	1500					
1	59.92	0.002	0.002	0.002	0.002	0.002	0.002	0.001	57.39	3409.88	11.71	441714.96	61.84
	60.05	0.002	0.002	0.002	0.002	0.002	0.002	0.001	57.51	3494.98	11.17	453720.44	63.52
	59.83	0.002	0.002	0.002	0.002	0.002	0.002	0.001	57.31	3353.87	12.09	433806.26	60.73
2	59.93	0.002	0.002	0.002	0.002	0.002	0.002	0.001	51.75	1660.03	45.31	197152.98	27.60
	59.66	0.002	0.002	0.002	0.002	0.002	0.002	0.001	51.18	1581.75	49.68	187009.55	26.18
	59.66	0.002	0.002	0.002	0.002	0.002	0.002	0.001	52.62	1796.38	39.17	215984.99	30.24
3	59.04	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.14	640.74	204.29	51113.76	7.16
	59.27	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.54	651.71	200.52	52791.16	7.39
	58.97	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.38	647.31	202.22	52169.91	7.30
4	69.11	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.50	623.92	211.37	48828.50	6.84
	69.51	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.36	620.22	213.10	48359.64	6.77
	69.53	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.48	623.17	211.15	48603.54	6.80
5	89.15	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.71	629.32	208.44	49414.17	6.92
	89.59	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.53	624.71	211.01	48932.05	6.85
	89.84	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.54	624.90	209.92	48725.48	6.82
6	88.37	0.005	0.002	0.002	0.002	0.002	0.002	0.001	22.11	395.16	315.83	18536.38	2.60
	88.47	0.005	0.002	0.002	0.002	0.002	0.002	0.001	21.77	390.72	317.75	18026.64	2.52
	88.99	0.005	0.002	0.002	0.002	0.002	0.002	0.001	21.59	388.47	317.74	17717.58	2.48
7	71.68	0.005	0.002	0.002	0.002	0.002	0.002	0.001	21.17	383.12	321.30	17186.04	2.41
	71.01	0.005	0.002	0.002	0.002	0.002	0.002	0.001	21.23	383.93	320.33	17242.80	2.41
	70.49	0.005	0.002	0.002	0.002	0.002	0.002	0.001	21.15	382.90	321.41	17161.78	2.40
8	60.94	0.005	0.002	0.002	0.002	0.002	0.002	0.001	21.12	382.48	321.45	17107.49	2.40
	60.83	0.005	0.002	0.002	0.002	0.002	0.002	0.001	21.09	382.09	321.52	17059.28	2.39
	60.33	0.005	0.002	0.002	0.002	0.002	0.002	0.001	21.13	382.64	321.94	17155.25	2.40
9	58.64	0.003	0.002	0.002	0.002	0.002	0.002	0.001	39.12	764.23	160.91	68315.49	9.56
	59.28	0.003	0.002	0.002	0.002	0.002	0.002	0.001	39.10	763.35	163.04	68981.24	9.66
	59.47	0.003	0.002	0.002	0.002	0.002	0.002	0.001	38.59	745.47	169.34	66725.86	9.34
10	59.49	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.98	664.10	198.38	55264.96	7.74
	59.73	0.003	0.002	0.002	0.002	0.002	0.002	0.001	35.91	661.92	200.49	55305.93	7.74
	59.96	0.003	0.002	0.002	0.002	0.002	0.002	0.001	36.17	669.47	196.75	56152.13	7.86
11	59.95	0.002	0.002	0.002	0.002	0.002	0.002	0.001	46.46	1130.14	87.58	120237.54	16.83
	60.19	0.002	0.002	0.002	0.002	0.002	0.002	0.001	46.77	1151.74	84.66	123026.27	17.22
	59.71	0.002	0.002	0.002	0.002	0.002	0.002	0.001	47.04	1172.12	82.32	126086.31	17.65
12	59.56	0.003	0.002	0.002	0.002	0.002	0.002	0.001	37.07	696.25	182.84	58699.70	8.22
	60.11	0.003	0.002	0.002	0.002	0.002	0.002	0.001	36.94	692.12	184.55	58197.01	8.15
	60.21	0.003	0.002	0.002	0.002	0.002	0.002	0.001	36.89	690.80	185.56	58183.23	8.15
13	63.35	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.68	628.57	215.53	50910.74	7.13
	61.59	0.003	0.002	0.002	0.002	0.002	0.002	0.001	34.16	615.08	223.64	49498.67	6.93
	60.99	0.003	0.002	0.002	0.002	0.002	0.002	0.001	33.95	609.91	227.73	49144.67	6.88
14	68.65	0.003	0.002	0.002	0.002	0.002	0.002	0.001	33.13	589.95	232.62	45430.30	6.36

	69.18	0.003	0.002	0.002	0.002	0.002	0.002	0.001	33.45	597.60	228.45	46374.23	6.49
	69.36	0.003	0.002	0.002	0.002	0.002	0.002	0.001	33.02	587.23	234.99	45261.40	6.34
15	87.79	0.003	0.002	0.002	0.002	0.002	0.002	0.001	31.62	555.80	250.18	40857.45	5.72
	88.89	0.003	0.002	0.002	0.002	0.002	0.002	0.001	31.65	556.36	249.29	40835.94	5.72
	89.63	0.003	0.002	0.002	0.002	0.002	0.002	0.001	31.64	556.20	249.78	40879.94	5.72

6. RESULTS

The voids underneath the slabs in selected study stretches are obtained by plotting the graphs between the observed deflections and measured loads. The following graphs show the presence of voids under the slabs.

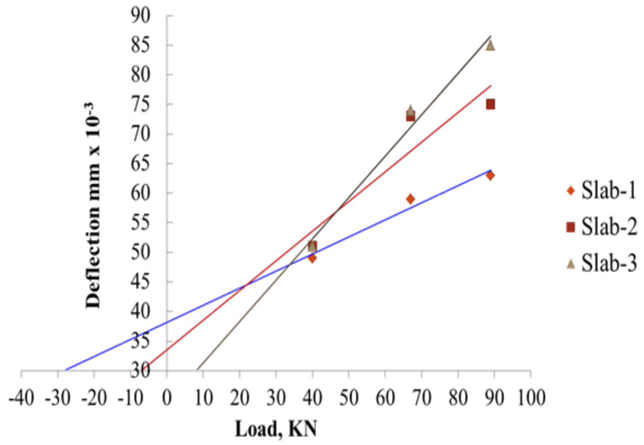

Figure 05: Load Vs. Deflection Curve – Interpretation of Voids under the Slab for ORR Section

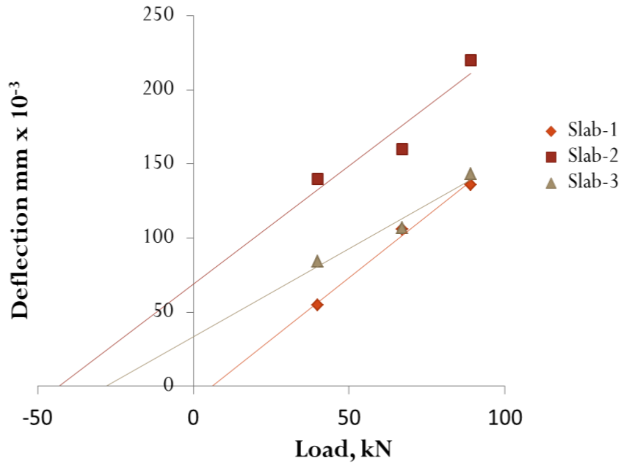

Figure 06: Load Vs. Deflection Curve – Interpretation of Voids under the Slab for NH – 65 Section

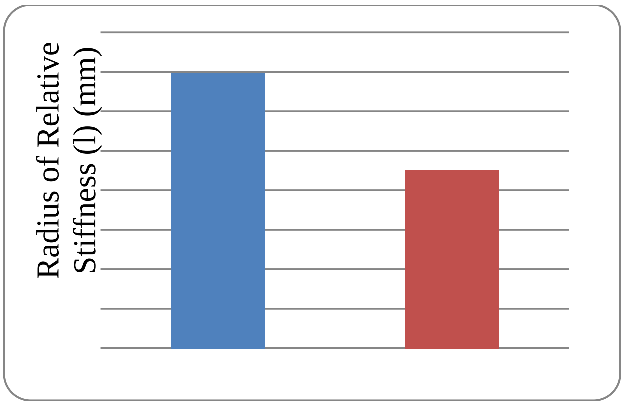

Figure 07: Comparison of Radius of Relative stiffness 'l' values for ORR Section

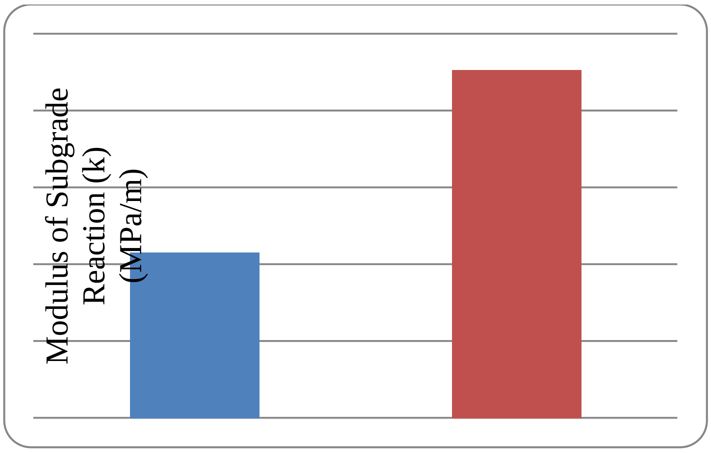

Figure 08: Comparison of Radius of Modulus of Sub-grade Reaction 'k' values for ORR Section

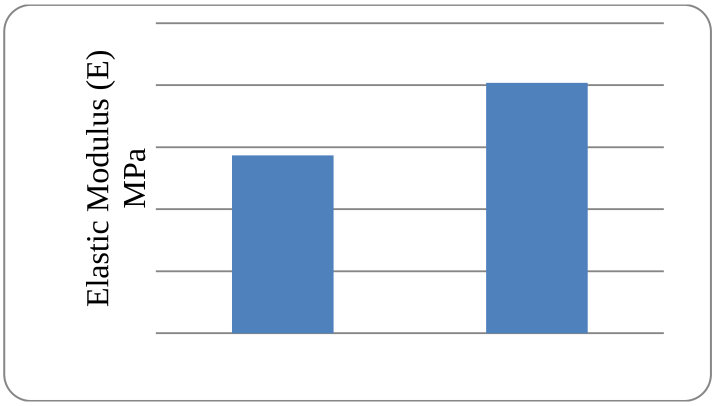

Figure 09: Comparison of Elastic Modulus (E) values for ORR Section

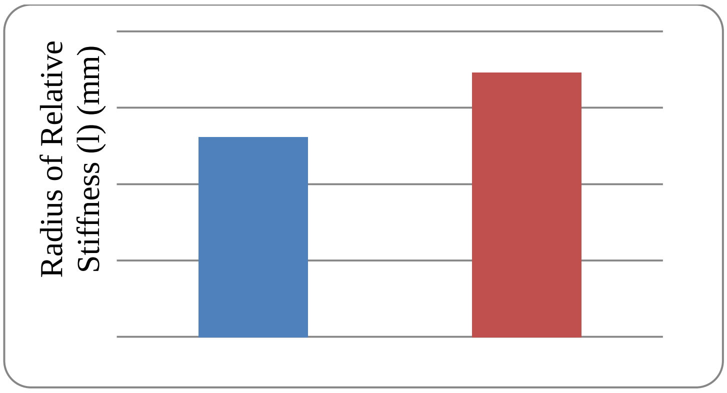

Figure 10: Comparison of Radius of Relative stiffness 'l' values for NH – 65 Road Section

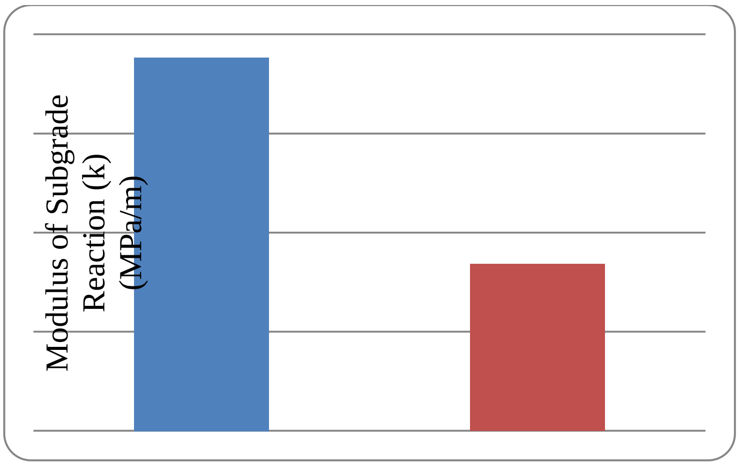

Figure 11: Comparison of Radius of Modulus of Sub-grade Reaction 'k' values for NH – 65 Road Section

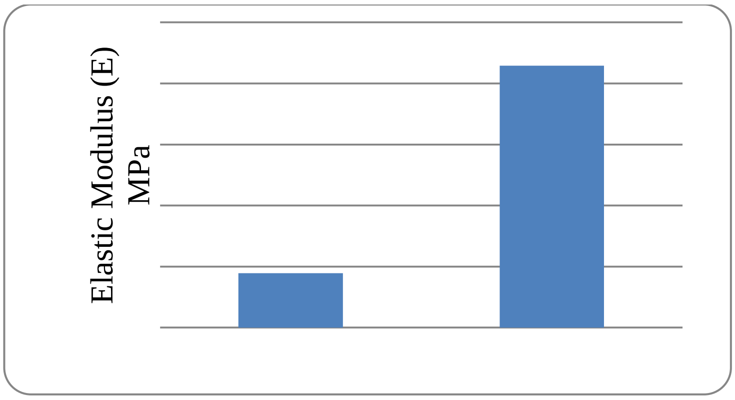

Figure 12: Comparison of Elastic Modulus (E) values for NH – 65 Road Section

CONCLUSIONS

The following points are observed from the present study:

- It is known that voids are present under Slab 2 and slab 3 at ORR
- It is known that voids are present under Slab 1 and slab 2 at NH-65
- The Load Transfer Efficiency is more than 50% at transverse joints, that is there is no critical condition at both ORR and NH-65.

Comparisons are made for the two approaches at the study areas and are presented in the following tables 6.1 and 6.2.

Table 6.1:Percentage variation in Radius of relative stiffness (l), Modulus of Sub-grade reaction (k) and Elastic Modulus (E) at ORR section.

Percentage of difference for Two approaches at ORR		
Radius of Relative Stiffness (l)	Modulus of Sub Grade reaction (k)	Elastic Modulus in concrete (E)
35.204%	110.37%	40.83%

Table 6.2:Percentage variation in Radius of relative stiffness (l), Modulus of Sub-grade reaction (k) and Elastic Modulus (E) at NH – 65 section

Percentage of difference for Two approaches at NH-65		
Radius of Relative Stiffness (l)	Modulus of Sub Grade reaction (k)	Elastic Modulus in concrete (E)
32.19%	4.98%	381.28%

REFERENCES

1) AASHTO. *AASHTO Guide for Design of Pavement Structures.* American Association of State Highway and Transportation Officials. 1993.
2) Ali, N. A. and P. N. Khosla. Determination of layer moduli using a falling weight deflectometer. *Transportation Research Record No. 1117*. pp. 1–10. Transportation Research Board. 1987.
3) Ali Sangghaleh et al., (2013), “Backcalculation of pavement layer elastic modulus and thickness with measurement errors”, International Journal of Pavement Engineering , Volume 15, 2014 - Issue 6
4) Bagus and Supriyono (2017), “ Evaluation of proposed back calculation procedure in Indonesia overlay design guide”, Procedia Engineering 171, 1405-1412.
5) Brown, S. F., J. M. Brunton. and P. S. Pell. The development and implementation of analytical pavement design for British conditions. *Proc. of the 5th International Conference on Structural Design of Asphalt Pavements.* Vol. I. pp.3–16. 1982.
6) Brown, S. F., W. S. Tam, and J. M. Brunton. Structural evaluation and overlay design: analysis and implementation. *Proceedings of the 6th International Conference Structural Design of Asphalt Pavements.* pp.1013–1028. 1987

7) Crovetti, J. A. and M. R. Tirado-Crovetti. Evaluation of support conditions under jointed concrete pavement slab. pp. 455–472 in *Nondestructive testing of Pavements and Back-calculation of Moduli, Vol. II, STP 1198.* Edited by H. L. Quintus, A. J. Bush III and G. Y. Baladi. Philadelphia: American Society of Testing and Materials. 1994.

8) Frabizzio, M. A. and N. J.Buch. Characterization of transverse cracks in jointed concrete pavements (JCPs) using nondestructive test (NDT) methods. pp. 231–245 in *Nondestructive Testing of Pavements and Backcalculation of Moduli: Vol. 3, ASTM STP 1375.* Edited by S. D. Tayabji and E. O. Lukanen. Philadelphia: American Society for Testing and Materials. 2000.

9) IRC:58-2015, 'Guidelines for the Design of Plain Jointed Rigid Pavements for Highways'.

10) IRC: 117-2015, "Guidelines for the Structural Evaluation of Rigid Pavement By Falling Weight (FWD)".

11) Ioannides, A. M. Concrete pavement back-calculation using ILLI-BACK 3.0. pp.103–124 in *Nondestructive Testing of Pavements and Backcalculation of Moduli: Vol. 2, ASTM STP 1198*. Edited by Harold L. Von Quintas, Albert J. Bush III and Gilbert Y. Baladi. Philadelphia: American Society for Testing and Materials. 1994.

12) Khosla, P. N. and N. A. Ali. A mechanistic method for evaluation of layer moduli and overlay design. pp.355–367 in *Non-Destructive Testing of Pavements and Backcalculation of Moduli, ASTM STP 1026.* Edited by A. J. Bush III and G. Y. Baladi. Philadelphia: American Society of Testing Materials. 1989.

13) Srinivasa, K. R., K. S. Reddy, M. Mazumdar, C. C. Bhattacharya and B. B. Pandey. Pavement evaluation with impulse loading apparatus. *Proceedings of the International Seminar on Highway Rehabilitation and Maintenance*. p III-135 to III-148. New Delhi. 1999.