LONG TERM PERFORMANCE OF EXISTING PORTLAND CEMENT CONCRETE PAVEMENT SECTIONS – CASE STUDY

DESEMPEÑO A LARGO PLAZO DE SECCIONES DE PAVIMENTOS EXISTENTES DE CONCRETO CON CEMENTO TIPO PORTLAND – ESTUDIO DE CASO

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ABSTRACT: This paper presents the performance of seventeen rigid pavements made of Portland Cement Concrete (PCC) located in the State of Ohio, USA. The Falling Weight Deflectometer (FWD) testing method was used in a total of 58 km of PCC pavement sections to assess the pavement structural condition. Each section is classified as excellent, good, fair, or poor based on the normalized deflections obtained from FWD tests, spreadability, load transfer, and joint support ratio parameters. The overall performance of the analyzed sections is from good to excellent. The field testing methodology along with the performance data analyses presented in this publication are a valuable tool to evaluate the actual structural condition of pavements and as a result short or medium term rehabilitation programs can be issued to ensure the serviceability of the pavement.

KEYWORDS: Pavement, Rehabilitation, Rigid pavements, Testing methods, Field tests, Pavement rating, Falling weight deflectometer.

RESUMEN: La presente investigación presenta el desempeño de diecisiete pavimentos rígidos hechos de Concreto con Cemento Portland (PCC) localizados en el Estado de Ohio, USA. La metodología de ensayos con el Deflectómetro de Impacto (FWD) se usó en un total de 58 km de secciones de pavimentos PCC para evaluar la condición estructural del pavimento. Cada sección se clasifica como excelente, buena, regular o deficiente basado en los parámetros de deflexiones normalizadas obtenidas de los ensayos FWD, deformabilidad, transferencia de carga y relación de soporte de las juntas. El desempeño global de las secciones analizadas está entre bueno y excelente. La metodología de ensayo de campo, junto con los análisis de datos del desempeño presentados en esta publicación, son una herramienta valiosa para evaluar la condición estructural actual de pavimentos y como resultado proponer planes de rehabilitación a corto o mediano plazo que garanticen el buen funcionamiento del pavimento.

PALABRAS CLAVES: Pavimentos, Rehabilitación, Pavimentos rígidos, Métodos de ensayo, Ensayos de campo, Evaluación de pavimentos, Deflectómetro de impacto.

1. INTRODUCTION

Rigid pavements are composed of a stiff Portland Cement Concrete (PCC) layer resting on a subgrade (base and subbase layers that need to be evaluated on a per project basis). Due to its stiffness and structure, the traffic load applied to the PCC pavement layer is transmitted under a wider area of subgrade, inducing a moderate stress and strain to the soil [1]. Portland cement concrete pavements are classified into three categories: Joint Plain Concrete Pavement (JPCP), Joint Reinforced Concrete Pavement (JRCP), and Continuously Reinforced Concrete Pavement (CRCP). The most common type of pavement in the State of Ohio, USA, is the JPCP and normally consists of slabs spacing between 12 and 20 ft long, having transversal joints reinforced with dowel bars to improve the performance of the joints. JRCP is not as common as the JPCP and the only difference is that the former consists of slabs with transversal joints at intervals of up to 50 ft. CRCP does not require transversal joints because is reinforced entirely over its length with longitudinal and transverse steel bars to prevent cracking due to variability in environmental conditions and traffic loading. JRCP and CRCP are no longer constructed due to their poor long-term performance [2].

There are several parameters involved in the PCC pavement performance, load transfer being the most crucial. Load transfer is the ability of the slab to transmit the load to the adjacent slab through the joint to decrease the acting stresses and thus improve the pavement performance. Two of the most common mechanisms used to increase joint efficiency are dowel bars and aggregate interlock. Dowel bars have proved to effectively improve joint performance. Their main advantage is to allow slab movement in the horizontal direction and restrict the movement in the vertical direction while transferring the load. The dowel bars have a diameter between 32 and 38 mm, a length of 450 mm and are normally spaced 305 mm from each other. The dowel bars also limit the most common distress mechanisms in PCC pavement such as faulting, pumping, and corner break. The total load transfer between slab sections is due to the contribution of both the aggregate interlock and the dowel bars. However, the contribution due to the aggregate interlock can be considered negligible in cracks wider than 0.9 mm [2].

A study of the most significant design and construction parameters affecting long-term pavement performance of 2791.6 km (two directions) of CRCP in the State of Illinois, USA, is presented in Gharaibeh et al. [3]. Although some of the sections were exposed to extreme weather and traffic conditions, they had excellent performance during their design life. The study was conducted by analyzing data from field surveys collected since 1977. The database included a variety of information for each one of the pavements such as: section location, slab thickness, steel reinforcement content, base type and thickness, average annual temperature and precipitation. From this study, it was found that among the parameters affecting the CRCP, the reinforcement content and the slab thickness had the most critical influence on the pavement performance.

In a different study [4], the performance of transverse cracking on forty-nine JPCP sections located in the State of Michigan was presented. The purpose of this project was to determine the key parameters influencing the transverse cracking in JPCPs and the conclusions are as follows: a) the average number of cracks per slab increases as the joint spacing increases; b) the type of coarse aggregate of the concrete mix has a significant influence in the number of transverse cracks developed in the slabs; c) joint performance is directly related to temperature (i.e., high temperature increases the load transfer and thereby decreasing the crack width); and d) the load transfer value is an indicator of the crack condition in which values higher than 70% represent satisfactory crack performance (i.e., adequate aggregate interlock load transfer across the cracks).

The causes leading to surface longitudinal cracking and punch-outs on IH-30 (Interstate Highway) in the State of Texas are presented in Chen et al. [5]. Several field and laboratory tests were conducted to determine the causes of distress mechanisms. The authors concluded that longitudinal cracks were developed at early stages due to weather changes and to an increase of 30-50% of the design load. An evaluation of the performance of unbounded JRCP overlays used over existing concrete pavements is presented in Padilla-Llano [6]. Results from this investigation showed that environmental effects are more critical to the pavement than the effect of the traffic load. The strains induced to the pavement by the change in the environment are much greater than the strains induced during the FWD test.

2. FIELD TESTING AND SITE DESCRIPTIONS

A total of seventeen Portland cement concrete sections distributed along the State of Ohio, United States, were investigated. These sections were grouped based on the district location and classified either as excellent or average pavements depending on the structural condition at the time of testing. Figure 1 shows the districts subdivision of the state of Ohio.

Figure 1. District subdivision. State of Ohio

Figure 2 shows the Pavement Condition Rating (PCR) performance data for rigid pavements in the State of

Ohio [7]. The studied sections were a subset of data of those used to define Figure 2. Table 1 presents the location, length, district, year, and initial condition of the pavement sections. The county, roadway and district locations are referred as "Co-Rte" and "Distr." respectively. The directions are referred as upstation (U), downstation (D) or with the dual index (DU) for the cases when the section was tested in both directions. The year refers to construction date. The condition refers to the initial performance condition of the section as giving by the PCR index.

A Falling Weight Deflectometer (FWD) was used to evaluate the structural integrity of these sections. A description of this equipment and testing procedures are presented in Sargand et al. [8]. The FWD device used for this project consisted of seven sensors, aligned radially from the application of the load, to measure and record the deflections induced by the FWD. The separation between the sensors can be adjusted to measure settlements at different points of interest. The settlements measured from sensors 1 – 5 are used to evaluate the pavement structural condition, meanwhile settlements measured from sensors 6 and 7 are used to estimate the stiffness of the subgrade.

2.1. Data interpretation

The modulus of elasticity of the subgrade was calculated by taking an average of the values obtained from sensors 6 and 7, as described below [9], calibrated in U.S. units:

$$M_R(psi) = 9000 \times \frac{0.2892}{24 \times (d_{24}/1000)} \tag{1}$$

$$M_R(psi) = -466 + 9000 \times \frac{0.00762}{(d_{36}/1000)} \tag{2}$$

Eqs. (1) and (2) correspond to the deflections recorded for sensors six and seven, respectively. d_{24} and d_{36} are the settlement readings from the sensors located at a distance of 24 in. and 36 in., respectively from the application of the load. In these equations the values of d_{24} and d_{36} must be given in microinches (μ-in).

The normalized deflections and spreadability for each geophone were computed as follows [10], calibrated in U.S units:

$$Df_{Norm}(mils/kip) = \frac{Df_i(mils)}{Load(kip)} \tag{3}$$

$$Spreadability(\%) = \frac{100 \times \sum_{i=1}^{7} Df_i}{7 \times Df_1} \tag{4}$$

Df_i corresponds to the geophone readings i= 1 to 7 and the load is normalized to 9000 lb (40 kN).

Two additional parameters used to evaluate the structural pavement condition of PCC pavement sections are the load transfer parameter and the joint support ratio. The load transfer parameter is an indicator of the joint performance that depends on the applied load, aggregate interlock, and temperature acting on the pavement. The load transfer is calculated using the following equations for the approaching and leaving joint positions, respectively:

$$LT_A(\%) = (Df_3/Df_1) \times 100 \tag{5}$$

$$LT_L(\%) = (Df_2/Df_1) \times 100 \tag{6}$$

Df_1, Df_2, and Df_3 are the geophone readings number 1, 2, and 3, respectively.

The pavement joint condition, as presented in Sargand [10], is classified as good, fair or poor for the corresponding load transfer ranges of 80-100%, 50-80%, and less than 50%, respectively.

The Joint Support Ratio (JSR) parameter is an indicator of the pavement condition under the slabs and is calculated as follows:

$$JSR = Df_{1L}/Df_{1A} \tag{7}$$

Df_{1L} and Df_{1A} are the geophone readings number one at the leaving and approaching positions, respectively. Table 2 shows the values of deflections, spreadability, load transfer, and joint support ratio used to classify the structural pavement condition [11].

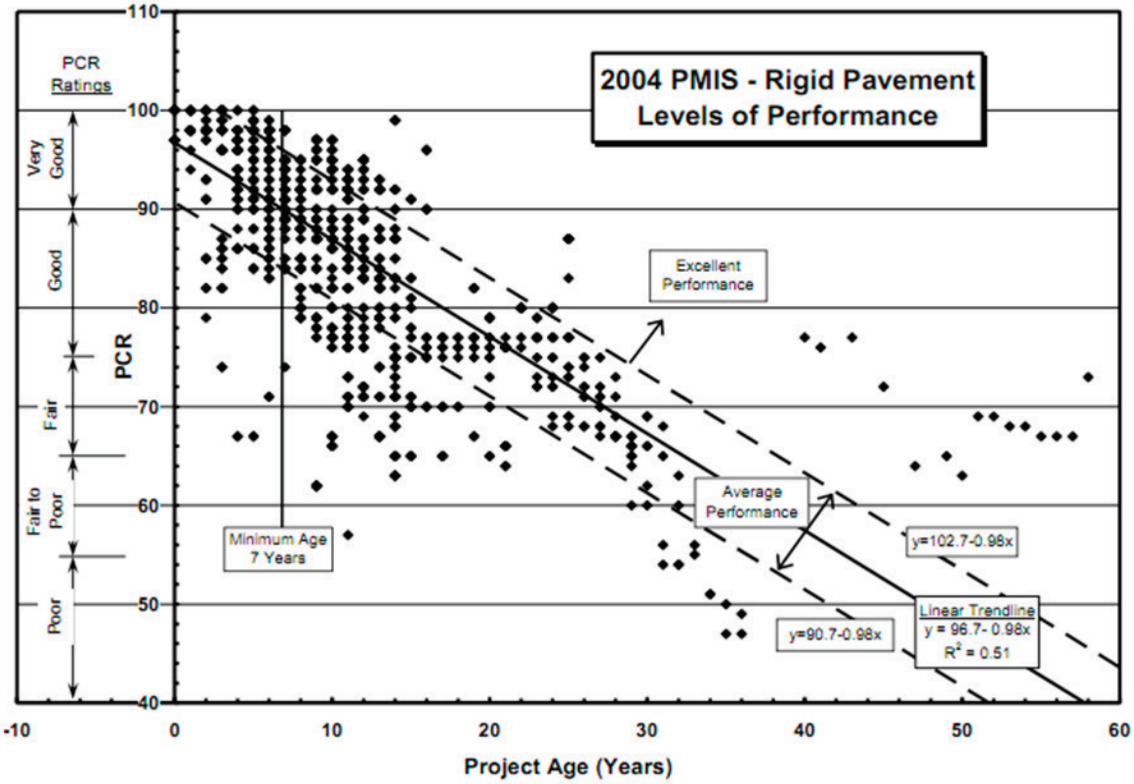

Figure 2. Pavement Condition Rating (PCR) for Rigid Pavements in Ohio. Source Chou et al. [7].

Table 1. Portland cement concrete pavement sections

Proj. No.	Co-Rte	SLM Limits	Dir.	L (mi)	Distr.	Year	Cond.
1	ATH 50	11.46-11.8	U	0.34	10	1986	Avg.
2	ATH 682	0.16-0.64	DU	0.48	10	1976	Avg.
3	CUY 82	3.22-3.66	D	0.44	12	1994	Exc.
		2.05-3.82	U	1.77			Exc.
4	GAL 7	5.71-10.21	U	4.50	10	1946	Exc.
5	HAM 126	11.35-13.31	DU	1.96	8	1990	Exc.
6	JEF 7	18.9-19.21	D	0.31	11	1990	Avg.
7	JEF 22	15.02-16.32	U	1.30	11	1990	Avg.
8	LOG 33	21.79-25.63	D	3.84	7	1994	Avg.
		21.51-25.63	U	4.12			Exc.
9	MOT 35	14.37-15.07	DU	0.70	7	1988	Exc.
10	MOT 202	2-3.25	U	1.25	7	1991	Exc.
11	SUM 76	11.8-13.32	D	1.52	4	1992	Exc.
			U				Avg.
12	SUM 76	13.32-15.32	D	2.00	4	1993	Exc.
			U				Avg.
13	TUS 39	2.84-7.12	U	4.28	11	1990	Avg.

3. PAVEMENT RESPONSES

Figures 3-8 show a typical set of plots for project # 2 (see Vega-Posada [12] for the complete evaluation) including normalized midslab deflection (Df_1 and Df_7), spreadability, normalized maximum joint deflection, joint transfer, joint support ratio, and subgrade modulus of elasticity, respectively. The modulus of elasticity of the subgrade was back-calculated from the FWD collected data.

Figures 3 and 4 show a decrease in pavement stiffness, both concrete and subgrade layers, between SLM 0.3 and 0.4 in the upstation direction. Figures 5-7 show that the overall condition of the pavement joints is from good to excellent.

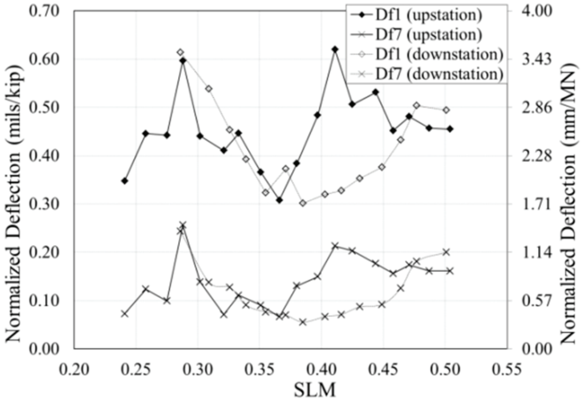

Figure 3. Midslab deflection

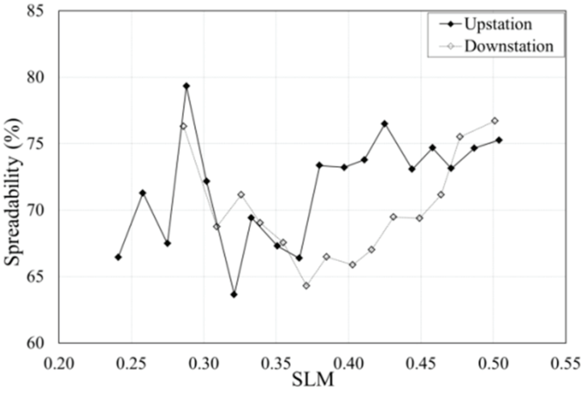

Figure 4. Midslab spreadability

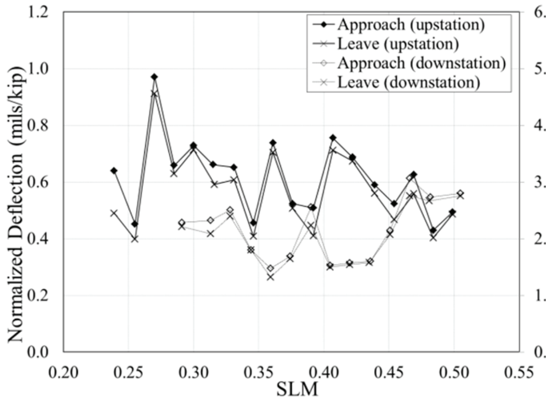

Figure 5. Max. joint deflections

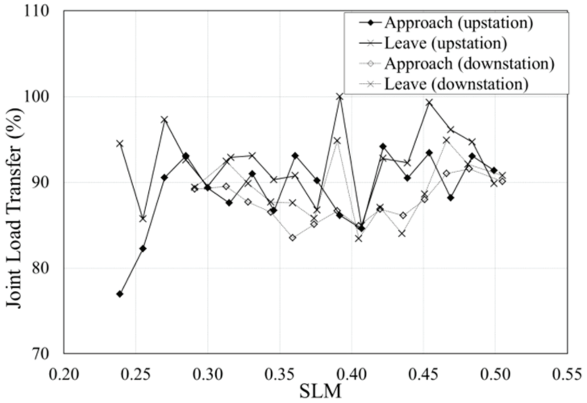

Figure 6. Joint load transfer

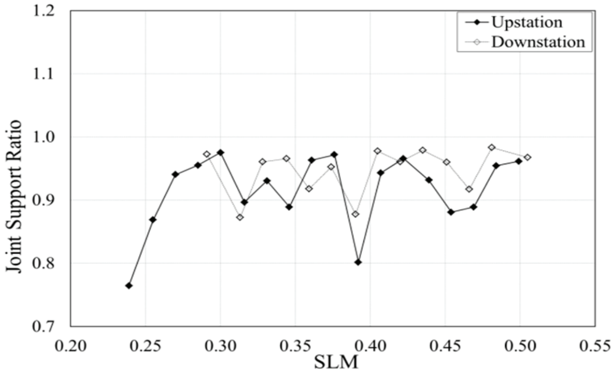

Figure 7. Joint support ratio

Figure 8 presents the back-calculated modulus of elasticity of the subgrade. M_R ranged from 31 ksi (upstation) to 36 ksi (downstation), which in geotechnical terms is considered as a competent layer. From figures 3, 4, and 8, it can be concluded that the stiffness deficiency between SLM 0.3 and 0.4 in the upstation direction is related to a deterioration of the PCC slab and not to a reduction of the subgrade layer capacity. Although the spreadability is classified as good in the upstation direction, there is a lack in the pavement ability to distribute the load across the section.

The pavement performance in both directions is similar and therefore the conclusions are applicable for both cases. The average modulus of elasticity in the upstation and downstation directions is 31 ksi (214 MPa) and 36 ksi (248 MPa), respectively. The determination of this parameter from actual field observations as presented in this research not only provides an indication of the pavement deterioration in comparison to the initial design modulus but also is a reliable parameter that can be used to estimate the pavement behavior and performance based on computer models.

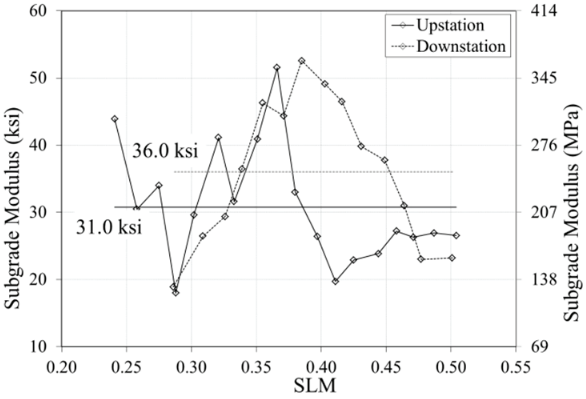

Figure 8. Subgrade modulus

Table 2. Max. values for deflections, spreadability, load transfer, and joint support ratio. Souce: Edward et al. [11]

Cond.	Df_1, mm/MN	Df_7, mm/MN	SPR (%)	D_{1A}, mm/MN	D_{1L}, mm/MN	LT (%)	JSR
Exc.	< 2.40 (0.42)	< 1.20 (0.21)	> 80	< 3.54 (0.62)	< 3.71 (0.65)	> 85	0.90-1.10
Good	2.45-3.25 (0.43-0.57)	120-1.77 (0.21-0.31)	72-79	3.60-4.45 (0.63-0.78)	3.77-4.74 (0.66-0.83)	70-85	1.11-1.25
Fair	3.31-4.17 (0.58-0.73)	1.77-2.40 (0.31-0.42)	64-71	4.51-5.48 (0.79-0.96)	4.80-5.82 (0.84-1.02)	50-69	1.26-1.49
Poor	> 4.22 (0.74)	> 2.40 (0.42)	<63	> 5.54 (0.97)	> 5.88 (1.03)	< 50	> 1.50

Note: The values in parenthesis are in units *mils/kip*, as obtained directly from Eq. (3)

Table 3 presents the pavement built-up sequence and the back-calculated modulus of elasticity of each pavement layer. The following abbreviations are used for the material specification: a) JRC: Joint Reinforced Concrete Pavement; b) PCC: Portland Cement Concrete Pavement; c) "310": Bituminous Aggregate Base; d) ATB: Asphalt Treated Base; e) DGAB: Dense Graded Aggregate Base; f) NSDB: Non-Stabilized Drainage Base.

A complete definition of these material specifications can be found in ODOT [13]. A Dynatest Model 8000 FWD was used to conduct the field testing program [14]. Tables 4-6 show the structural condition of these pavement sections based on FWD deflections and spreadability, maximum joint deflection, and joint load transfer and joint support ratio, respectively. In general, the structural condition of the studied sections are classified as excellent and good, except for project # 4 that showed a load transfer deficiency in both the approaching and leaving positions.

Table 3. Back-calculated modulus of elasticity

No.	Layer Modulus (M_R in MPa), Thickn. (mm)			
1	Layer	JRC	310	Subgrade
	M_R-Thk.	20,217-229	945-152	148-N/A
2	Layer	JRC	310	Subgrade
	M_R-Thk.	26,151-229	422-152	255-N/A
3	Layer	JRC	DGAB	Subgrade
	M_R-Thk.	26,220-279	1,263-152	274-N/A
4	Layer	JRC	310	Subgrade
	M_R-Thk.	18,975-229	564-152	173-N/A
5	Layer	JRC	310	Subgrade
	M_R-Thk.	31,119-254	5,147-152	324-N/A

Continuation Table 3.

No.	Layer Modulus (M_R in MPa), Thickn. (mm)			
6	Layer	JRC	310	Subgrade
	M_R-Thk.	23,391-229	1,097-152	295-N/A
7	Layer	JRC	310	Subgrade
	M_R-Thk.	26,427-229	642-152	272-N/A
8	Layer	PCC	NSDB	DGAB
	M_R-Thk.	24,357-305	3,222-102	1,035-76
9	Layer	PCC	310	Subgrade
	M_R-Thk.	26,358-229	2,539-152	414-N/A

No.	Layer Modulus (M_R in MPa), Thickn. (mm)			
10	Layer	PCC	310	Subgrade
	M_R-Thk.	24,564-229	547-254	164-N/A
11	Layer	JRC	ATB	Subgrade
	M_R-Thk.	38,502-229	9,798-152	242-N/A
12	Layer	JRC	ATB	Subgrade
	M_R-Thk.	24,219-229	2,187-152	515-N/A
13	Layer	JRC	310	Subgrade
	M_R-Thk.	28,635-229	856-152	167-N/A

Table 4. Pavement condition based on FWD deflections and spreadability

Proj. No.	Dir	L	FWD Defl. (%)				Spreadability (%)			
		(km)	Exc.	Good	Fair	Poor	Exc.	Good	Fair	Poor
1	U	0.55	9	55	27	9	-	73	27	-
2	DU	0.77	57 28	36 61	7 11	- -	- -	21 61	72 33	7 6
3	D	0.71	95	5	-	-	26	63	11	-
	U	2.85	100	-	-	-	94	6	-	-
4	U	7.25	3	55	35	7	7	46	40	7
5	DU	3.16	100 100	- -	- -	- -	- 20	75 60	25 20	- -
6	D	0.5	82	18	-	-	-	36	64	-
7	U	2.09	84	8	8	-	-	23	77	-
8	D	6.18	86	14	-	-	14	79	7	-
	U	6.63	93	7	-	-	22	78	-	-
9	DU	1.13	100 100	- -	- -	- -	- -	69 56	31 44	- -
10	U	2.01	10	90	-	-	-	90	10	-
11	D	2.45	100	-	-	-	29	64	7	-
	U	2.45	91	9	-	-	18	82	-	-
12	D	3.22	100	-	-	-	-	69	31	-
	U	3.22	100	-	-	-	23	65	12	-
13	U	6.89	10	74	16	-	7	79	14	-

Table 5. Maximum joint deflection

Proj. No.	Dir	L	Condition - Approaching (%)				Condition - Leaving (%)			
		(km)	Exc.	Good	Fair	Poor	Exc.	Good	Fair	Poor
1	U	0.55	27	46	27	-	-	64	36	-
2	DU	0.77	100 44	- 50	- -	- 6	100 72	- 22	- 6	- -
3	D	0.71	95	5	-	-	95	-	5	-
	U	2.85	81	19	-	-	100	-	-	-

Continuation Table 5.

Proj. No.	Dir	L	Condition - Approaching (%)				Condition - Leaving (%)			
		(km)	Exc.	Good	Fair	Poor	Exc.	Good	Fair	Poor
4	U	7.25	-	7	25	68	2	23	7	68
5	DU	3.16	19 90	31 10	50 -	- -	25 85	31 15	31 -	13 -
6	D	0.50	100	-	-	-	100	-	-	-
7	U	2.09	92	8	-	-	54	46	-	-
8	D	6.18	50	25	25	-	71	29	-	-
	U	6.63	100	-	-	-	-	100	-	-
9	DU	1.13	100 89	- 11	- -	- -	100 89	- 11	- -	- -
10	U	2.01	80	20	-	-	90	10	-	-
11	D	2.45	100	-	-	-	100	-	-	-
	U	2.45	100	-	-	-	100	-	-	-
12	D	3.22	100	-	-	-	100	-	-	-
	U	3.22	100	-	-	-	100	-	-	-
13	U	6.89	32	38	14	16	41	27	14	19

Table 6. Joint load transfer and joint support ratio

			Joint Load Transfer								Joint Support Ratio			
No.	Dir.	L	Condition - Approaching (%)				Condition - Leaving (%)				Condition - Approaching (%)			
		(km)	Exc.	Good	Fair	Poor	Exc.	Good	Fair	Poor	Exc.	Good	Fair	Poor
1	U	0.55	81	19	-	-	91	9	-	-	64	36	-	-
2	DU	0.77	86 83	14 17	- -	- -	86 94	14 6	- -	- -	86 61	14 39	- -	- -
3	D	0.71	63	32	-	5	79	16	-	5	84	16	-	-
	U	2.85	62	25	13	-	69	19	12	-	63	37	-	-
4	U	7.25	5	2	19	74	10	2	17	71	56	44	-	-
5	DU	3.16	94 100	6 -	- -	- -	81 75	13 25	6 -	- -	63 70	37 30	- -	- -
6	D	0.5	27	-	73	-	9	82	9	-	-	64	27	9
7	U	2.09	100	-	-	-	31	69	-	-	15	54	31	-
8	D	6.18	28	36	36	-	29	50	21	-	64	36	-	-
	U	6.63	100	-	-	-	100	-	-	-	100	-	-	-
9	DU	1.13	62 67	31 33	- -	7 -	54 56	31 44	15 -	- -	77 100	23 -	- -	- -
10	U	2.01	100	-	-	-	100	-	-	-	100	100	-	-
11	D	2.45	14	79	7	-	22	64	14	-	79	21	-	-
	U	2.45	54	46	-	-	44	44	12	-	73	27	-	-
12	D	3.22	50	50	-	-	37	63	-	-	93	7	-	-
	U	3.22	6	94	-	-	24	71	5	-	71	29	-	-
13	U	6.89	83	17	-	-	61	39	-	-	81	14	5	-

4. SUMMARY AND CONCLUSIONS

The methodology presented in this paper is a valuable technique that can be used to determine, with field measurements, the actual structural condition of PCC pavement sections. Based on the structural condition classification, short or long term rehabilitation programs can be implemented to assure satisfactory service and serviceability of the PCC pavement.

The long term performance of seventeen Portland cement concrete sections located in the State of Ohio, USA, was studied. The performance of PCC pavement was influenced by the climate conditions, material properties, construction practices, and traffic loads.

The total length of the PCC pavement sections studied was 36 mi (58 km). The overall structural condition of the analyzed sections was as follows: a) Excellent 67.6% (39 km); b) Good 24.2% (14 km); c) Fair 7.2% (4 km); and d) Poor 1.0% (0.6 km). On the other hand, the overall condition of the pavement stiffness was: a) Excellent 15.8% (10 km); b) Good 63.9% (36 km); c) Fair 19.3% (11 km); and d) Poor 1.0% (1 km).

The overall performance of the pavement system was influenced by the stiffness of the base layer and the thickness of the surface layer. The performance of PCC pavement sections improved as the base stiffness and/or thickness of the surface layer increased. In general, the structural pavement condition of the PCC sections was classified as excellent and good, except for Project 4 in which the load transfer mechanism between the slabs negatively impacted the overall capacity of the rigid pavement.

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