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Historical Performance of Rubblized Jointed Portland Cement Concrete Pavement Overlaid with Asphaltic Concrete in the State of Louisiana, USA

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Abstract: Rubblizing existing Portland cement concrete pavement (RPCC) and overlaying with asphaltic concrete (RPCC-AC) has been a popular and effective method of increasing the life span of existing Portland cement concrete (PCC) pavements. Historical performance of RPCC-AC pavements has been well documented in the USA.

The purpose of the research was to determine the performance of RPCC-AC pavements in the State of Louisiana, USA. Fifteen projects were available for pavement distress analysis with service life's ranging from newly constructed to 11.23 years. Six projects were available for structural performance analysis with service life's ranging from newly constructed to 9.12 years of age. Regression models were used to verify the results obtained from other studies, develop a model to predict future responses, as well as authenticate the association between the response variable and one explanatory variable.

The results of the analysis indicated that pavement distresses such as transverse, longitudinal, and alligator cracking have been minimal and practically negligible on RPCC-AC roadways in Louisiana, indicating superior performance. Ride quality was predicted to have a IRI value of 95 cm/km at 15 years of service. Structural layer evaluations indicated that the layer moduli for the AC, RPCC, and BC increased as the pavement aged, indicating a superior performing pavement. In place structural number, $SN_{eff(FWD)}$, was measured and predicted to increase by as much as 52 percent over the 15 year period.

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***Key words:** Rubblization; Portland cement concrete pavement rehabilitation; Composite pavements, Asphaltic concrete overlays.*

Introduction

Transportation agencies are facing the task of reconstructing and rehabilitating existing deteriorated Portland cement concrete pavements (PCC). Reconstructing PCC pavements is effective, but costly. It contributes to traffic congestion during construction as well. Because of that, agencies search for more cost effective means of mitigating deteriorated PCC pavements with rehabilitation methods such as joint repair, patching, Asphaltic concrete (AC) overlays, and fracturing the existing pavements with methods such as rubblization, crack/seat, and break/seat.

Many agencies in the United States of America (USA) have turned to fracturing the existing PCC followed by an AC overlay as a cost-effective and environmentally friendly approach to rehabilitating deteriorated PCC [1-43]. For the most part, rubblizing PCC (RPCC) with a resonate frequency breaker as opposed to crack/seat and break/seat, followed by an AC overlay (RPCC-AC) has been the preferred method in the USA.

The purpose of the paper was to document the performance of RPCC-AC in the State of Louisiana and discover if it had similar performance to other States in the USA.

Literature Review

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Historical performance of RPCC-AC pavements has been exhaustively documented by State agencies in the USA. Many States, California [1], Iowa [2-8]), Texas [9, 10], Colorado [11], Arkansas [12, 13], Ohio [12], Alabama [14-17], Michigan [18-20], Indiana [21, 22], Illinois [23, 24], Wisconsin [25, 26], Nevada [27, 28], Pennsylvania [29], and Florida [30, 31], have all either published or had others publish reports or papers on the performance of RPCC-AC within their boundaries. Nation-wide studies have been conducted in the USA on this topic as well with one study publishing about Portland cement concrete pavement over RPCC [32-43]. The consensus of the state agencies on RPCC-AC is as follows:

- PCC-AC pavements perform as well as AC pavement constructed over traditional base courses such as aggregate.
- PCC modulus exceeds the modulus of granular base courses.
- Reflective cracks from the PCC joints are eliminated as long as the slab is fractured properly.
- Weak subgrades (fine grain soils whose resilient modulus is less than 24 MPa) inhibit the rubblization process and should be avoided.
- Rubblization is preferred to crack/seat or break/seat pavement fracture methods with the Resonant Frequency Breaker (RFB) being utilized the most to rubblize (fracture) concrete pavements.
- RPCC costs less than PCC reconstruction and concrete pavement restoration (CPR).
- Public relations and safety is enhanced due to reduced construction time and maintenance of traffic during construction.

Table 1. Rubblized Projects Used in Pavement Distress Analysis.

Project No:	RPCC (mm)	Joint Spacing (m)	AC Avg. Thick. (mm)	Lane Width (m)	ADT (Approx.)	% Trucks (Approx.)	Length (km)	Age(1) (Yrs.)
012-11-0037	254	6.1	189	3.66	10,018	13	5.7	0
450-04-0084	254	17.83	191	3.66	34,559	28	11.08	3.87
450-05-0046	254	17.83	189	3.66	57,715	18	16.44	8.29
451-02-0048	254	17.83	221	3.66	45,747	21	9.31	2.12
451-06-0092	254	17.83	165	3.66	51,832	15	4.26	11.2
451-07-0063	254	17.83	191	3.66	17,082	23	8.58	3.87
450-03-0037	254	17.83	227	3.66	37,419	15	17.19	7.64
450-03-0064	254	17.83	240	3.66	37,419	23	18.8	7.84
450-91-0076	254	17.83	227	3.66	58,073	20	12.7	4.24
450-91-0139	254	17.83	212	3.66	58,073	23	15.69	3.59
450-91-0140	254	17.83	210	3.66	58,073	26	16.59	2.08
450-18-0088	254	17.83	218	3.66	67,093	17	10.65	4.24
450-04-0069	254	17.83	216	3.66	45,352	18	10.94	4.11
450-04-0065	254	17.83	216	3.66	45,352	18	18.99	7.53
454-02-0026	254	17.83	254	3.66	43,427	21	16.25	9.83

(1) years of service at last PMS assessment; RPCC - Rubblized PCC, AC -Asphaltic concrete, ADT - Average daily traffic, RPCC-rubblized PCC pavement, AC-Asphaltic Concrete, ADT-Average daily traffic, %Trucks-percentage of trucks in traffic.

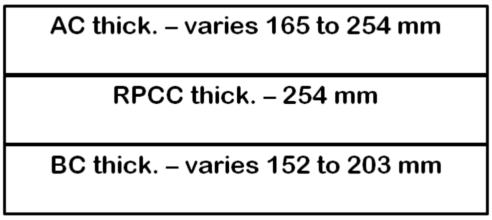

Fig. 1. Pavement Layer Thicknesses (AC – Asphaltic Concrete, RPCC – Rubblized Portland Cement Concrete, BC – Soil Cement Base Course).

Table 2. Pavement Distress Categories.

Distress Categories	Types per Category
Cracking	Fatigue (Alligator), Block, Edge, Longitudinal, Reflection at Joints, and Transverse
Patching/Potholes	Patch/Patch Deterioration, Potholes
Surface Deformation	Rutting, Shoving
Surface Defects	Bleeding, Polished Aggregate, Raveling
Miscellaneous Defects	Lane to Shoulder Drop off, Water Bleeding and Pumping

- PCC service life is enhanced.
- RPCC is an environmentally friendly method to recycle existing PCC.

Since an exhaustive amount of published material exists on the methods and fracture mechanics of rubblizing concrete pavements, the authors will focus on the pavement distress and structural performance of RPCC-AC pavements in Louisiana with comparisons to the results published by others.

Research Methodology / Design of Experiment

The authors began by data mining the Louisiana Department of Transportation and Developments (LADOTD) pavement management system (PMS) data base searching for projects that had been rubblized. In Louisiana, PCC pavements have been fractured by rubblization, crack and seat, and break and seat methods. This paper will focus on those pavements that were rubblized with resonant frequency breakers. Fifteen projects were discovered from the data mining and are presented in Table 1. Fig. 1 presents a typical section showing the AC, RPCC, and BC thickness ranges of those pavements.

Pavement Distresses

Distresses in AC pavements are generally placed in five categories, cracking, patching/potholes, surface deformation, surface defects, and miscellaneous distresses, as shown in Table 2 [44].

The LADOTD PMS collects and warehouses the pavement distress data every other year since 1995. The pavement distress indices selected were transverse (TRCR), longitudinal (LNCR), and alligator (fatigue) (ALCR) cracks, rutting, and roughness as quantified by the International Roughness Index (IRI) [44]. Though eliminating transverse cracks produced by reflective cracks at the PCC joints is the main reason for using rubblization, the authors wanted to capture the overall performance of the pavement. It should be noted that, in Louisiana, rut depths less than 2.54 mm are reported as 2.54 mm in the PMS data base in most data collection surveys.

Structural Layer Assessment

The Falling Weight Deflectometer (FWD) was used to assess the RPCC-AC pavement structure. Layer moduli (MPa) for the AC, RPCC, soil cement base course (BC) and subgrade were backcalculated using Dynatest's ELMOD 5 software and LADOTD's FWD data reduction procedures [45][46]. The in-place structural number [$SN_{eff(FWD)}$] was also computed for the RPCC-AC

Table 3. Rubblized Projects Used in Structural Layer Analysis.

Project No.	AC Thick. (mm)	RPCC Thick. (mm)	BC Thick. (mm)	Years of Service
450-04-0069	216	254	152	0.01
450-04-0069	216	254	152	7.18
450-30-0085	203	254	152	0.10
450-04-0065	216	254	152	8.78
450-03-0037	203	254	203	8.12
545-02-0026	254	254	203	9.12

AC-Asphaltic Concrete, RPCC- Rubblized PCC, BC- Soil Cement.

section based on the AASHTO 1993 design guide [41]. The structural number is a dimensionless number that indicates the strength of a pavement structure as well as its ability to sustain the design traffic loading [41]. On one project, FWD data were available on the newly constructed RPCC-AC and at 7 years of service. Table 3 presents the six projects assessed with the FWD as well as their service age at the time(s) of assessment.

Statistical Analysis

Regression models were used to verify the results obtained from other studies, develop a model to predict future unobserved responses given a set of predictor values, as well as authenticate the association between the response [dependant (Y_i)] variable and one explanatory [independent (X_i)] variable, all at the alpha = 0.01 percent level [47-49]. Confidence and prediction intervals were computed and plotted with the least squares regression line for each analysis. The confidence interval (CI) represents the range of the means from multiple tests that can be expected from field sampling while the prediction interval (PI) represents the expected range of a single value obtained from field sampling [48, 49]. Areas with CI and/or PI negative values were not plotted. The regression assumptions of normality of residuals and homogeneity of variance were assessed with the Kolmogorov-Smirnov procedure and residual plots [49]. All variables used in this analysis were independent and outliers were removed with statistical diagnostics [47-49].

The response variables were transformed linearly in order to meet the normality of residuals criteria with an additional adjustment to compensate for the “zero” values in the TRCR, LNCR, and ALCR variables. The $\ln(Y_i+1)$ and $\{Y_i^{0.5} + (Y_i+1)^{0.5}\}$ (Freeman-Tukey) transforms were explored with the $\ln(Y_i+1)$ transform being selected based upon data results and equation reducibility [49, 50]. For the remaining response variables, $\ln(Y_i)$ transforms were utilized. The transformed regression models used were:

Functional Distresses

- Transverse cracks: $LN(TRCR_{ij}+1) = b_0 + b_1Age_i$; with $TRCR_{ij}$ in units of m/km and Age_i being the age (years) of pavement at the time of assessment.
- Longitudinal cracks: $LN(LNCR_{ij}+1) = b_0 + b_1Age_i$; with $LNCR_{ij}$ in units of m/km and Age_i being the age (years) of pavement at the time of assessment.
- Alligator cracks: $LN(ALCR_{ij}+1) = b_0 + b_1Age_i$; with $ALCR_{ij}$ in units of m^2/km and Age_i being the age (years) of pavement at the time of assessment.
- Rutting: $LN(Rut_{ij}) = b_0 + b_1Age_i$; with RUT_{ij} in units of mm and Age_i being the age (years) of pavement at the time of assessment.
- IRI: $LN(IRI_{ij}) = b_0 + b_1Age_i$; with IRI_{ij} in units of cm/km and Age_i being the age (years) of pavement at the time of assessment.

Structural Layer Values

- AC: $LN(EAC_{ij}) = b_0 + b_1 LN(Age_i)$; with EAC_{ij} being the modulus of AC in units of MPa and Age_i being the age (years) of pavement at the time of assessment.
- RPCC: $LN(ERPCC_{ij}) = b_0 + b_1 LN(Age_i)$; with $ERPCC_{ij}$ being the modulus of RPCC in units of MPa and Age_i being the age (years) of pavement at the time of assessment.
- BC: $LN(EBC_{ij}) = b_0 + b_1 LN(Age_i)$; with EBC_{ij} being the modulus of BC in units of MPa and Age_i being the age (years) of pavement at the time of assessment.
- Subgrade: $LN(ESubgrade_{ij}) = b_0 + b_1 LN(Age_i)$; with $ESubgrade_{ij}$ being the modulus of Subgrade in units of MPa and Age_i being the age (years) of pavement at the time of assessment.
- $SN_{eff(FWD)}$: $LN(SN_{eff(FWD)ij}) = b_0 + b_1 LN(Age_i)$; with $SN_{eff(FWD)ij}$ being the in-place structural number dimensionless and Age_i being the age (years) of pavement at the time of assessment.

Histograms (percentage) for the values used in the pavement distress data set variables are presented in Fig. 2a-2f. The age of the treatments ranged from 0 to 11.23 years with an average of 3.6 years as presented in Fig. 2a. Very minimal amounts of cracking were discovered for the indices of TRCR, ALCR, and LNCR throughout the 11.23 years as presented in Fig. 2b-2d. The average IRI was 87 cm/km and the average rutting was 3.3 mm over the 11.23 period as presented in Fig. 2e-2f. Pavement distress index values as presented above indicate a superior performing pavement [1-43].

Structural data set variable values were obtained from FWD back calculations and catalogued in percentage histograms as shown in Fig. 3a-3f. The age of the pavement at the time of structural evaluation ranged from just after construction to 7.23 years with an average age of 5.8 years. The AC, RPCC, BC, and subgrade moduli average values were 3,647, 2,137, 1,365, and 55 MPa, respectfully, over the 7.23 period as presented in Fig. 3b-3e. The $SN_{eff(FWD)}$ average value was 6.8 over the 7.23 period as presented in Fig. 3f.

Analysis of Results

Regression modeling indicated that statistically significant relationships exist for the pavement distress and structural layer parameters evaluated. There were 7,998 data points used in the function distress analysis and 60 points used in the structural layer analysis. Hence, the data set for both can be considered robust and used with confidence within the age range of the dataset [48-49]. Inferences about the behavior of the parameters were projected to 15 years. The following presents the regression equations developed

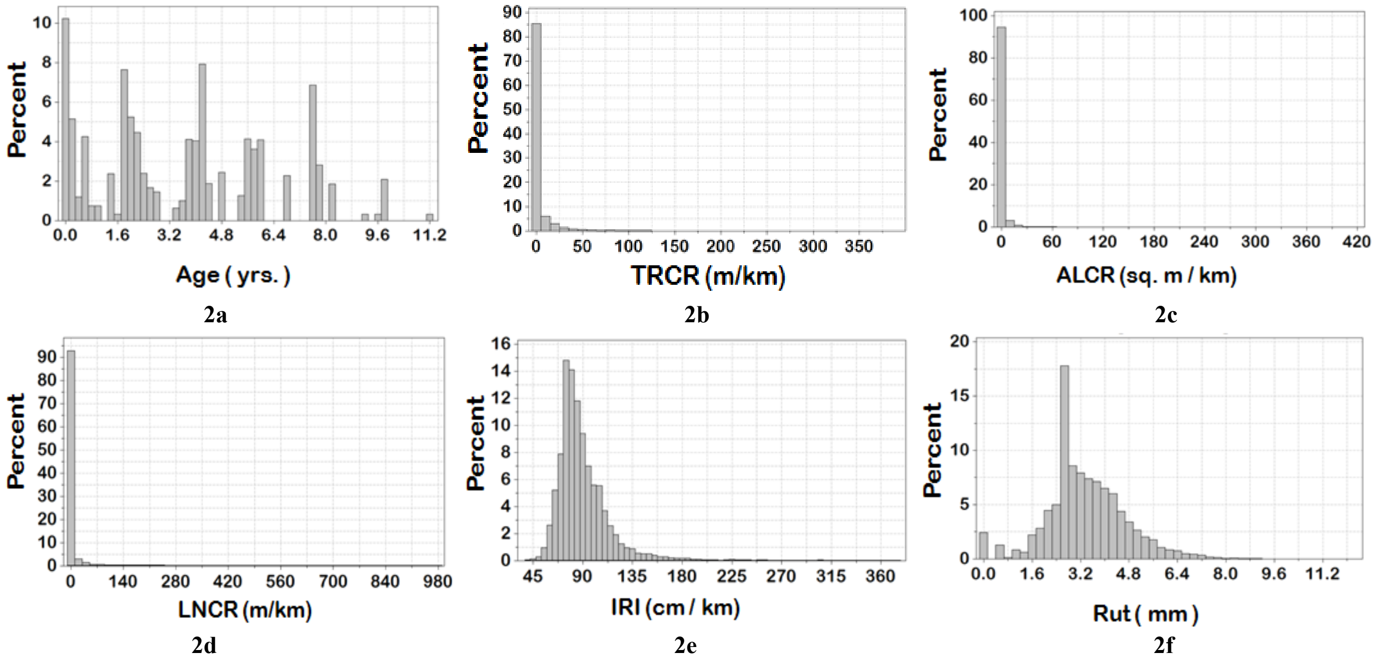

Fig. 2. Histograms of Pavement Distress Data Set: 2(a) Age, 2(b) Transverse Cracks, 2(c) Alligator Cracks, 2(d) Longitudinal Cracks, 2(e) IRI, and 2(f) Rutting.

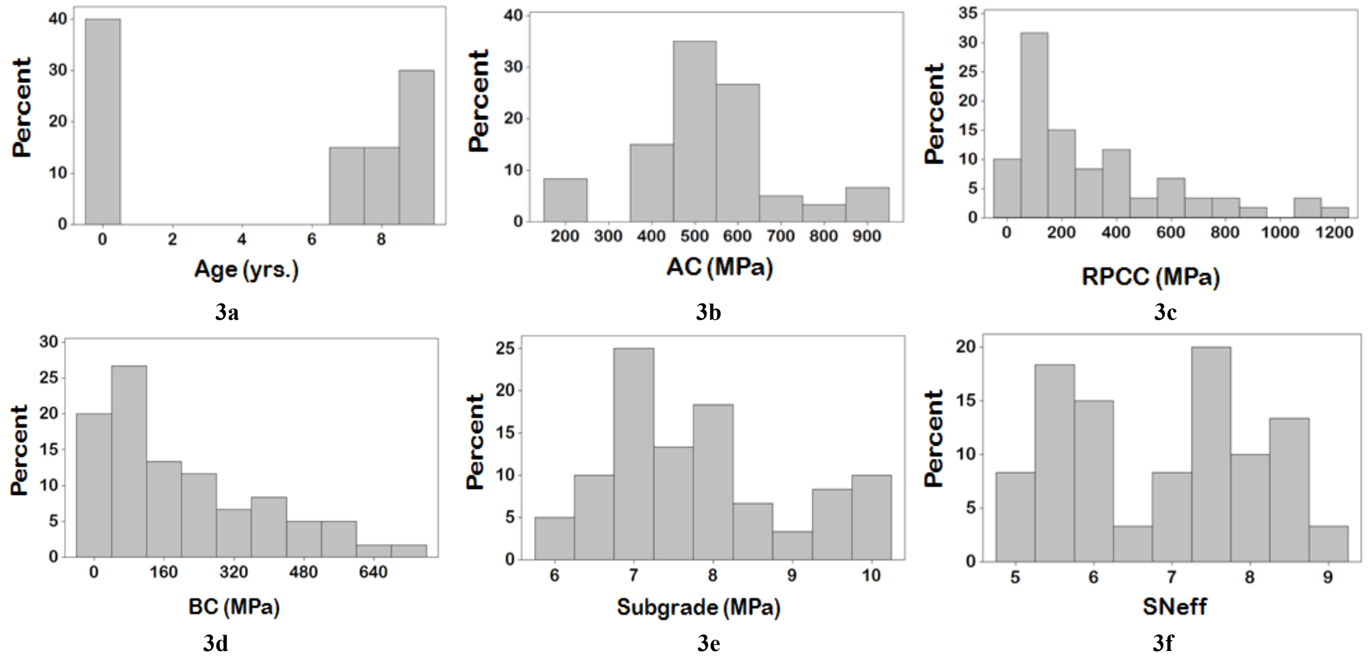

Fig. 3. Histograms of Structural Layer Data Set: 3(a) Age, 3(b) AC, 3(c) RPCC, 3(d) BC, 3(e) Subgrade, and 3(f) SN_{eff}.

from this data set.

Pavement Distresses

Transverse Cracks

The regression model had an F-value of <0.0001 with intercept and explanatory coefficients both having p values of <0.0001, indicating statistical significance at the *alpha* = 0.01 level. The r^2 value was 0.01 indicating that the least squares regression curve did not fit the data very well. This may be due to the fact that a huge proportion of the data had zero values [48-49]. The reduced equation for this variable was:

$$\hat{Y}_i = 1.214898 * e^{0.08472X_i} - 1 \qquad r^2 = 0.01 \qquad (1)$$

with, $\hat{Y}_i = TRCR_i$ (m/km), $X_i = Age_i$ (years)

The least squares regression line with corresponding confidence and predictions intervals are presented in Fig. 4a. At 15 years of service, the expected range of transverse cracks, according to the prediction interval, is approximately between 0 and 62.5 meters per

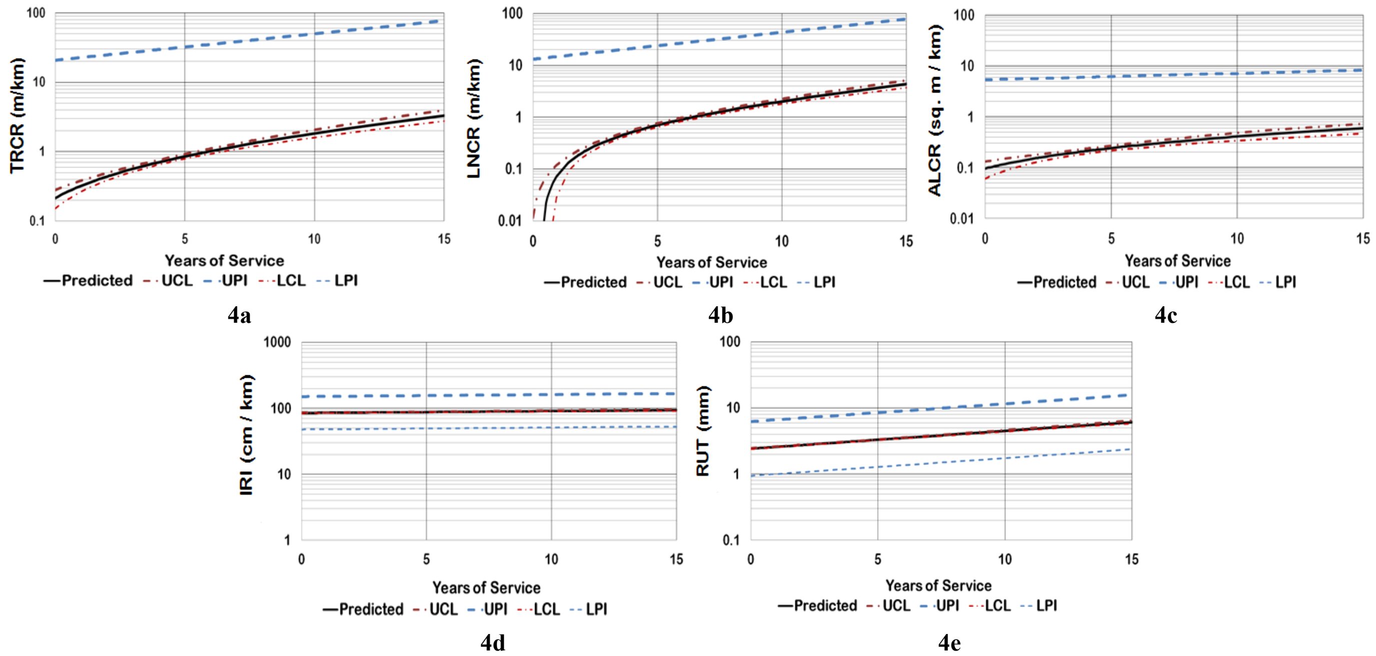

Fig. 4. Pavement Distresses 4(a) Transverse Cracks, 4(b) Longitudinal Cracks, 4(c) Alligator Cracks, 4(d) IRI, and 4(e) Rutting. (UCL – Upper Confidence Limit, LCL – Lower Confidence Limit, UPI – Upper Prediction Interval, and LPI – Lower Prediction Interval).

kilometer. The expected mean value from the regression line at 15 years is 5.7 m/km. Fundamentally, the range of the confidence interval is similar to the actual mean value of the regression line. For this distress category, the prediction interval had negative values for the entire age range and was not plotted. This indicates that it is possible to have no transverse cracks at all for a period of 15 years. As obvious from the graph, the rubblization process eliminated transverse joint reflective cracks on the projects evaluated in this study, which corresponds to the findings of others [1, 2, 9, 13, 15, 17, 18, 22, 24, 25, 27, 29, 30, 32, 39].

Longitudinal Cracks

The regression model had an F-value of < 0.001 with intercept and explanatory coefficients having p values of 0.0483 and < 0.0001, respectively, indicating statistical significance for the explanatory coefficient but not the intercept at the alpha = 0.01 level. The r^2 value was 0.01 indicating that the least squares regression curve did not fit the data very well. This may be due to the fact that a huge proportion of the data had zero values [48-49]. The reduced equation for this variable was:

$$\hat{Y}_i = 0.682973 * e^{0.1143X_i} - 1 \qquad r^2 = 0.08 \qquad (2)$$

with, $\hat{Y}_i = LNCR_i$ (m/km) , $X_i = Age_i$ (years)

The least squares regression line with corresponding confidence and predictions intervals are presented in Fig. 4b. At 15 years of service, the expected range of longitudinal cracks, according to the prediction interval, is approximately between 0 and 68 m/km. The expected mean value from the regression line at 15 years is 5.7 m/km. As with the transverse crack parameter, the range of the confidence interval is similar to the actual mean value of the regression line. For this distress category, the prediction interval had negative values for the entire age range and was not plotted. This indicates that it is possible to have no longitudinal cracks at all for a period of 15 years. Others have reported issues with longitudinal cracks at lane-shoulder or lane-lane interfaces, but this issue has not been significant in Louisiana [9, 12, 18, 19, 20, 39, 40].

Alligator Cracks

The regression model had an F-value of < 0.0001 with intercept and explanatory coefficients both having p values < 0.001, indicating statistical significance at the alpha = 0.01 level. The r^2 value was 0.01 indicating that the least squares regression curve did not fit the data very well. This may be due to the fact that a huge proportion of the data had zero values [48-49]. The reduced equation for this variable was:

$$\hat{Y}_i = 1.096025 * e^{0.02504X_i} - 1 \qquad r^2 = 0.01 \qquad (3)$$

with, $\hat{Y}_i = ALCR_i$ (m^2/km), $X_i = Age_i$ (years)

The least squares regression line with corresponding confidence and predictions intervals are presented in Fig. 4c. At 15 years of service, the expected range of alligator cracks, according to the prediction interval, is approximately between 0 and 7.5 m^2/km. The expected mean value from the regression line at 15 years is 0.578 m^2/km. As with the transverse and longitudinal crack parameters, the range of the confidence interval is similar to the actual mean value of the regression line. For this distress category, the prediction interval had negative values for the entire age range and was not plotted. This indicates that it is possible to have no alligator cracks at all for a period of 15 years.

IRI

The regression model had an F-value of < 0.0001 with intercept and explanatory coefficients both having p values of < 0.0001, indicating statistical significance at the *alpha* = 0.01 level. The r^2 value was 0.01. When the slope of the regression line is near zero, indicating relatively little change in the data, it will yield a very low r^2 value as presented in Fig. 3d [48-49].

The reduced equation for this variable was:

$$\hat{Y}_i = 86.86231 * e^{0.00695X_i} \qquad r^2 = 0.01 \qquad (4)$$

with, $\hat{Y}_i = IRI_i$ (cm/km), $X_i = Age_i$ (years)

The least squares regression line with corresponding confidence and predictions intervals are presented in Fig. 4d. At 15 years of service, the expected range of IRI, according to the prediction interval, is approximately between 52 and 167 cm/km. The expected mean value from the regression line at 15 years was 95. Excellent ride quality performance was also discovered by others [1, 2, 9, 12, 15, 17, 18, 22, 24, 25, 27, 29, 30, 32, 39, 51].

Rutting

The regression model had an F-value of < 0.0001 with intercept and explanatory coefficients both having *p* values of < 0.0001, indicating statistical significance at the *alpha* = 0.01 level. The r^2 value was 0.01 indicating that the least squares regression curve did not fit the data very well. Part of the reason for this may be due to the fact that values less than 2.54 mm are reported as 2.54 mm by LADOTD's PMS. Because of that, the true rate of deterioration is unknown [48-49]. The reduced equation for this variable was:

$$\hat{Y}_i = 2.42886 * e^{0.06177X_i} \qquad r^2 = 0.17 \qquad (5)$$

with, $\hat{Y}_i = Rutting_i$ (mm), $X_i = Age_i$ (years)

The least squares regression line with corresponding confidence and predictions intervals are presented in Fig. 4e. At 15 years of service, the expected range of rutting, according to the prediction interval, is approximately between 2.3 to 15.8 mm. The expected mean value from the regression line at 15 years was 6.1 mm. As shown in Fig. 2e, initial rutting (year 0) was 2.54 mm. This is because the LADOTD PMS section reports rut depths less than 2.54 mm as 2.54 mm. Good performance was also noted by others [9, 12, 14, 17, 18, 30, 32, 39].

Summary of Pavement Distress Results

Rubblized pavements in Louisiana have excellent performance based on the results of this study. Practically speaking, distress cracking of any type has been negligible. The ride quality of the pavement has been exceptional with little deterioration over the projected 15 year service life with rutting depths attributable to normal pavement densification.

Structural Layer Values

AC Layer Modulus

The regression model had an F-value of < 0.0001 with intercept and explanatory coefficients both having *p* values of < 0.0001, indicating statistical significance at the *alpha* = 0.01 level. The r^2 value was 0.41 indicating that the least squares regression curve did not fit the data very well [48-49]. This reason for this is unknown to the authors.

The reduced equation for this variable was:

$$\hat{Y}_i = 3485.92949 * X_i^{0.07796} \qquad r^2 = 0.4139 \qquad (6)$$

with, $\hat{Y}_i = EAC_i$ (MPa), $X_i = Age_i$ (years)

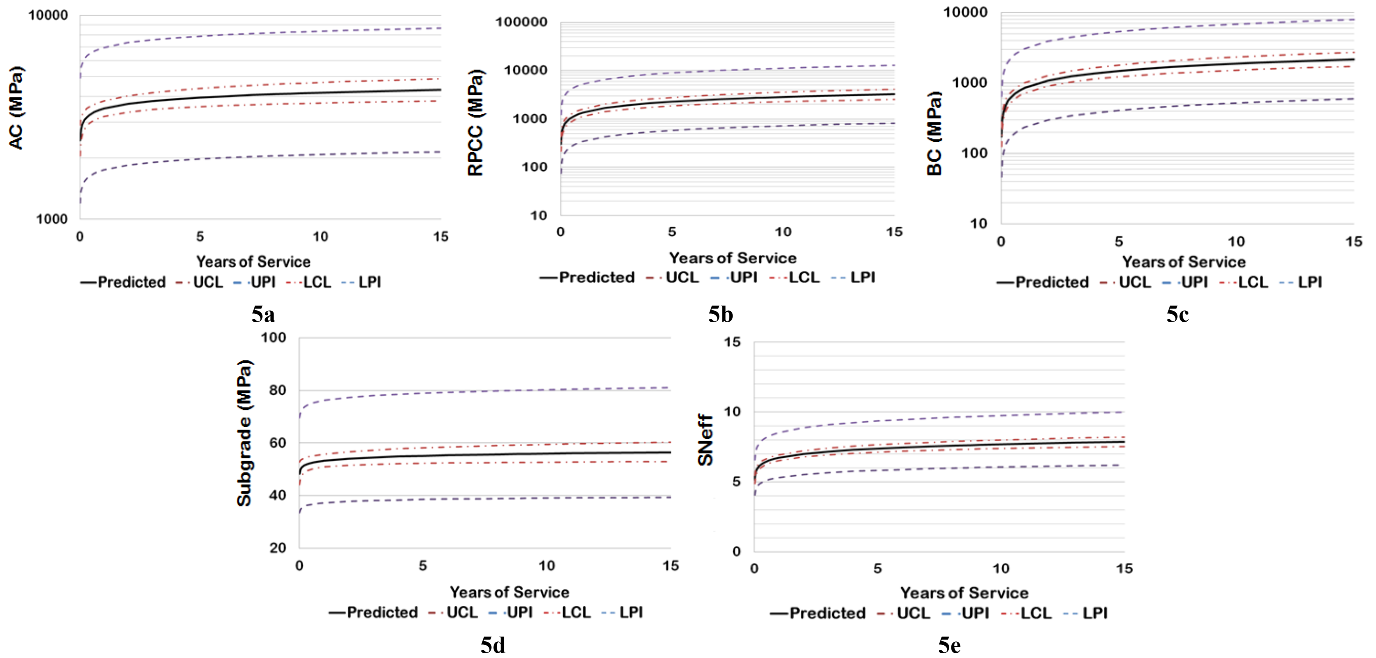

Fig. 5. Structural Layer Values**:** 5(a) AC – Asphaltic Concrete, 5(b) RPCC – Rubblized Portland Cement Concrete, 5(c) BC – Base Course (Soil Cement), 5(d) Subgrade, and 5(e) SN_{eff} – Structural Number. (UCL – Upper Confidence Limit, LCL – Lower Confidence Limit, UPI – Upper Prediction Interval, and LPI – Lower Prediction Interval)

Table 4. RPCC Modulus Values.

Reference	RPCC modulus (MPa)		
Number	Range		Avg.
4	262	1,117	
9	827	11,445	
12			462
17	393	1,441	
21	621	2,413	
25	241	827	
38			1,379
39	345	1,034	
52	552	2,758	
53	931	1,620	
54			483
Louisiana	Range		Avg.
Initial	248	945	483
7 to 9 years	648	4,723	2,096

The least squares regression line with corresponding confidence and predictions intervals are presented in Fig. 5a. Near the time of initial construction (year 0.01), the expected range of the AC modulus, according to the prediction interval, is approximately 1,200 and 4,936 MPa, with a mean value of 2,434 MPa. At 15 years of service, the expected range of the AC modulus, according to the prediction interval, are approximately between 2,137 and 8,618 MPa. The expected mean value from the regression line at 15 years was 4,310 MPa. AC modulus values in excess of 3,100 MPa are considered to be in good condition [39, 42, 46].

RPCC Layer Modulus

The regression model had an F-value of < 0.0001 with intercept and explanatory coefficients both having *p* values of < 0.0001, indicating statistical significance at the *alpha* = 0.01 level. The r^2 value was 0.76 indicating that the least squares regression curve had an reasonable fit to the data [48-49].

The reduced equation for this variable was:

$$\hat{Y}_i = 1348.77223 * X_i^{0.32417} \qquad r^2 = 0.76 \qquad (7)$$

with, $\hat{Y}_i = ERPCC_i$ (MPa), $X_i = Age_i$ (years)

The least squares regression line with corresponding confidence and predictions intervals are presented in Fig. 5b. Near the time of initial construction (year 0.01), the expected range of the RPCC modulus, according to the prediction interval, is approximately 76 and 1,228 MPa, with a mean value of 303 MPa. At 15 years of service, the expected range of the RPCC modulus, according to the prediction interval, are approximately between 813 and 12,858 MPa. The expected mean value from the regression line at 15 years was 3,247 MPa.

Table 4 presents the results of RPCC layer assessments performed by Louisiana and others [4, 9, 12, 17, 21, 25, 38, 39, 52-54]. In Louisiana, pavements assessed near the time of initial construction had an RPCC modulus range of 248 to 945 MPa with an average of 482 MPa while pavements with ages ranging from 7 to 9 years had RPCC modulus ranges of 648 to 4,723 MPa with an average of 2,096 MPa. The RPCC modulus ranges reported by others ranged from 241 to 11,445 MPa. Therefore, the RPCC modulus ranges discovered in Louisiana are within the ranges reported by others.

BC (Soil Cement) Layer Modulus

The regression model had an F-value of < 0.0001 with intercept and explanatory coefficients both having *p* values of < 0.0001, indicating statistical significance at the *alpha* = 0.01 level. The r^2 value was 0.8 indicating that the least squares regression curve had a reasonable fit to the data [48-49].The reduced equation for this variable was:

$$\hat{Y}_i = 847.83 * X_i^{0.34621} \qquad r^2 = 0.80 \qquad (8)$$

with, $\hat{Y}_i = EBC_i$ (MPa), $X_i = Age_i$ (years)

The least squares regression line with corresponding confidence and predictions intervals are presented in Fig. 5c. Near the time of initial construction (year 0.01), the expected range of the BC modulus, according to the prediction interval, are approximately 48 and 641 MPa, with a mean value of 1,724 MPa. At 15 years of service, the expected range of the BC modulus, according to the prediction interval, is approximately between 593 and 7,901 MPa. The expected mean value from the regression line at 15 years was 2,165 MPa. Modulus values in excess of 1,379 MPa are considered to be in good condition [39, 42, 46].

Subgrade Layer Modulus

The regression model had an F-value of 0.0012 with intercept and explanatory coefficients having *p* values of < 0.0001 and 0.0012, respectfully, indicating statistical significance at the *alpha* = 0.01 level. The r^2 value was 0.17 indicating that the least squares regression curve did not fit the data very well. The reason for this is unknown to the authors [48-49].

The reduced equation for this variable was:

$$\hat{Y}_i = 53.25757 * X_i^{0.02152} \qquad r^2 = 0.17 \qquad (9)$$

with, $\hat{Y}_i = Esubgrade_i$ (MPa), $X_i = Age_i$ (years)

The least squares regression line with corresponding confidence and predictions intervals were presented in Fig. 5d. Near the time of initial construction (year 0.01), the expected range of the subgrade modulus, according to the prediction interval, is approximately 34 and 70 MPa, with a mean value of 48 MPa. At 15 years of service, the expected range of the subgrade modulus, according to the prediction interval, are approximately between 39 and 81 MPa. The expected mean value from the regression line at 15 years was 56 MPa. Modulus values of these magnitudes on interstate highways are typical in Louisiana.

Structural Number ($SN_{eff(FWD)}$)

The regression model had an F-value of < 0.0001 with intercept and explanatory coefficients both having *p* values of < 0.0001, indicating statistical significance at the alpha = 0.01 level. The r^2 value was 0.77 indicating that the least squares regression curve had an reasonable fit to the data [48-49].

The reduced equation for this variable was:

$$\hat{Y}_i = 6.729763 * X_i^{0.0578} \qquad r^2 = 0.77 \qquad (10)$$

with, $\hat{Y}_i = SN_{eff(FWD)i}$ (dimensionless) , $X_i = Age_i$ (years)

The least squares regression line with corresponding confidence and predictions intervals were presented in Fig. 5e. Near the time of initial construction (year 0.01), the expected range of the $SN_{eff(FWD)}$, according to the prediction interval, is approximately 4.05 and 6.57 SN, with a mean value of 5.15 SN. At 15 years of service, the expected range of the $SN_{eff(FWD)}$, according to the prediction interval, are approximately between 6.2 and 9.99 SN. The expected mean value from the regression line at 15 years was 7.87 SN.

In Louisiana, layer coefficients of 0.1732 and 0.0984 SN/cm. are used in pavement design for AC and RPCC layers [41]. Therefore, it would be expected that a new pavement section with 21.5- cm. AC and 25.4-cm. RPCC would have an SN of 6.24 (21.5*0.1732 + 25.4*0.0984), which is similar to what was measured on new RPCC-AC pavements in this study.

Summary of Structural Layer Results

An interesting trend was discovered in the data set, the pavement structure's strength increased over time, especially within the first year. Typically, one would expect deterioration to occur as the pavement aged [39][41]. Moduli values increased for the AC, RPCC, and BC layers while the subgrade layer remained fairly consistent. While an increase in AC modulus can be attributed to age hardening, the same can't be said about the RPCC and BC layers [39, 41, 55, 56]. This increase in strength trend was also discovered in the $SN_{eff(FWD)}$ parameter, which increased from 5.15 to 7.87 (52 percent).

The authors postulate that the rubblization process dramatically reduces the Portland cement concrete pavement and base course modulus, initially [12]. However, the placement and compaction of the AC pavement coupled with traffic loading allows both the RPCC and BC (soil cement in this case) to regain some of its strength over time as measured with the FWD.

Conclusions

State and nation-wide studies have been conducted in the USA on the performance of RPCC-AC pavements. The performance of these pavements has been "par excellent" in Louisiana similar to the experience of other agencies within the USA.

Pavement distresses such transverse, longitudinal, and alligator cracking have been minimal and practically negligible on RPCC-AC roadways in Louisiana, indicating superior performance. Ride quality was predicted to have an IRI value of 95 cm/km at 15 years of service.

Structural layer evaluations indicated that the layer moduli for the AC, RPCC, and BC increased as the pavement aged, indicating a superior performing pavement. In place structural number, $SN_{eff(FWD)}$, was measured and predicted to increase by as much as 52 percent over the 15-year period. The authors postulate that this increase was due to the placement and compaction of the AC pavement in conjunction with traffic loading over time. This trend should be validated through additional research before accepting this as a "normal trend" for RPCC-AC pavements. However, this strength increase does point to one important fact; the pavement did not "weaken" nor deteriorate as normal pavement structures would. Therefore, RPCC-AC pavements can be used with confidence and considered a very durable pavement.

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