LOUISIANA TRANSPORTATION RESEARCH CENTER
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Application of Mechanistic-Empirical Design Approach into RCC Pavement Thickness Design

INTRODUCTION

As a durable, economical, fast constructing and low maintenance construction material, roller compacted concrete (RCC) is steadily becoming a preferred choice for many highway pavement applications. A number of state transportation agencies nationwide (e.g., Texas, California, South Carolina, Georgia, and Virginia) have already completed their first RCC-surfaced pavement applications over the past few years. A completed accelerated pavement testing (APT) study in Louisiana further showed that a relatively thin RCC (4 ~ 6 in.) pavement built over a soil cement base can achieve an outstanding load carrying capacity and excellent field performance, especially suitable for low-volume pavement applications in Louisiana where heavy and overloaded trucks are abundant. However, the current RCC pavement thickness design procedures are solely empirically-based, not following the state-of-practice of the mechanistic-empirical (M-E) pavement design approach. In addition, the fatigue models used in the RCC thickness design procedures have generally been found to over-predict pavement fatigue damage under in-situ heavy truck loading. As DOTD's pavement design approach is in the transition from the 1993 AASHTO design procedure to the Pavement M-E method, there is a need to develop and implement an M-E-based RCC slab thickness design procedure for RCC pavement applications in Louisiana.

OBJECTIVE AND SCOPE

The objectives of this research included:

- Determine in-situ load-induced and temperature-related pavement responses, investigate pavement failure mechanism and structural performance, and quantify the equivalent axle load fatigue damages on RCC pavements under accelerated pavement testing;
- Conduct laboratory beam fatigue tests using in-situ saw-cutting RCC slab specimens and develop a new fatigue damage model for the use of thickness design and performance evaluation of RCC pavements; and
- Propose a mechanistic-empirical pavement design procedure for the thickness design of new RCC pavements.

To achieve the objectives, two RCC pavement sections were instrumented with fiber-optical strain plates and tested under an APT loading. In-situ transverse strain responses of RCC slabs due to wheel loading and temperatures were measured. The APT pavement performance of test sections were evaluated based on the crack-mapping, nondestructive testing, and finite element modeling. For laboratory experiments, 68 RCC field beams were saw cut from the test sections and tested using the beam fatigue and flexural strength testing protocols. Beam density tests were also performed. Laboratory test results were used to develop an RCC fatigue model with a capacity of incorporating the reliability into a pavement design. Load transfer factors based on the equivalency of fatigue damage for RCC pavements were further determined using a numerical modeling approach. Finally, field performance and laboratory experiment results were employed to propose an M-E pavement design procedure for RCC pavement thickness design.

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METHODOLOGY

This study consisted of three basic sections in the methodology: APT evaluation of RCC pavement sections, development of a fatigue model for RCC pavement using in-situ saw-cut RCC beams, and application of M-E approach into an RCC pavement thickness design.

APT evaluation of RCC pavement sections: Six full-scale RCC pavement test sections with varying slab thickness (4 ~ 8 in.) were constructed using normal highway construction equipment and procedures. A heavy vehicle load simulation device (ATLaS30) was used for the accelerated loading. Two 8-in. RCC pavement sections were instrumented with innovative strain plate for measuring the wheel load and temperature induced transverse strain responses of RCC slabs, Figure 1.

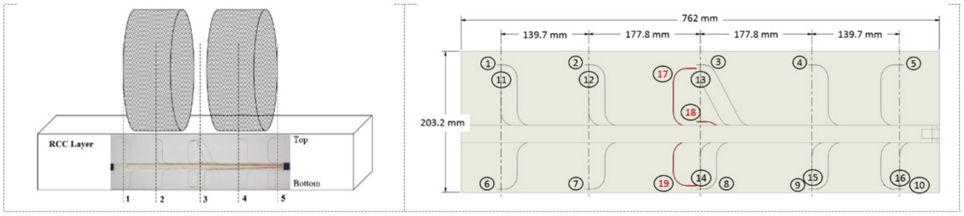

Figure 1. Fiber optic strain plate instrumentation

Development of a RCC fatigue model: The main objective of laboratory experimental design was to perform the laboratory fatigue test on in-situ saw-cut RCC beam samples and develop a new RCC fatigue life prediction model with the consideration of RCC construction and pavement structural variations and true pavement fatigue performance. This study also investigated the variation of RCC in-situ flexural strength due to the varying field compaction effort. Figure 2 shows sample preparation, test set-up and fatigue model development process used in the experiment design of this study.

Application of M-E approach into RCC pavement thickness design: Because the current RCC thickness design methods are empirically based, this study proposed an M-E based design procedure for RCC pavement thickness design. The proposed procedure incorporates the field performance and laboratory experiment results with detailed determinations of mechanistic components (load/stress/deflection) and empirical transfer functions considered into an RCC M-E pavement thickness design.

Table 1 presents the total number of loading repetitions applied on each RCC sections along with distresses observed at the end of APT testing.

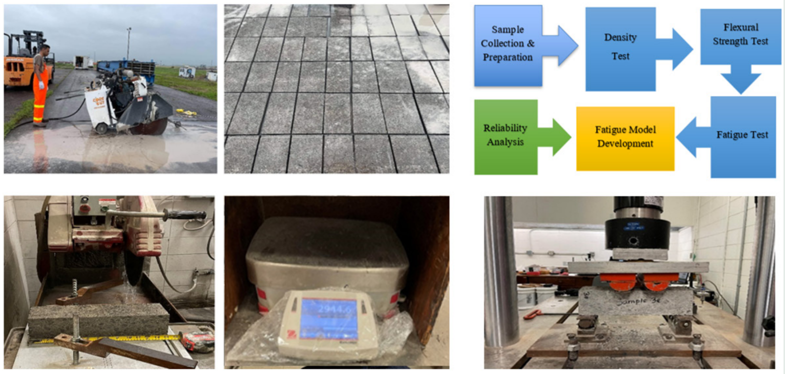

Figure 2. Sample preparation, test sect-up, and fatigue model development

Loading and Distresses	APT Test Sections					
	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
Total ATLaS30 Loading (passes)	727,500	695,000	196,000	742,500	1,750,850	706,500
Estimated ESALs (x 10^6)	9.9	19.4	2.7	16.2	87.4	19.2
Fatigue cracking (%)	10.6	53.5	46.8	20.4	40.9	41.0
Slab Differential Settlement (in.)	<0.1	0.3	0.15	<0.1	0.15	0.2
ΔIRI (in./mi.)	32.7	219.8	94.2	51.3	75.6	108.9

Table 1. Accelerated loading and distresses observed at the end of APT testing

CONCLUSIONS

Specific observations and conclusions include:

- All RCC test sections exhibited outstanding load carrying capacity and excellent structural performance. Four sections in Table 1 were loaded to a fatigue pavement failure evidenced by more than 40% of the trafficked area developed various surface cracks.
- In situ distress survey results indicated that the performance indicators related to pavement service life for RCC-surfaced pavements include the fatigue cracking, slab differential settlement at joints or cracks and extremely rough surface.
- Results from the fiber optic strain plates revealed that, under the ATLaS30's dual tire loading, a critical (maximum) compressive strain near top of an RCC slab was found under the middle of dual-tire prints, and the maximum bottom tensile strain was observed directly beneath the center of one individual tire.
- The obtained coefficient of thermal expansion (CTE) of RCC test sections varied from 9.44 to 12.53 με/ºC with a daily slab temperature gradient ranged between +18ºC and -9.5ºC.
- The developed RCC fatigue life prediction model (i.e., an S-N curve) was found to agree very well with the APT experimental results. This can be attributed to those in-situ saw-cut RCC beams used in the laboratory beam fatigue tests of this study.
- A positive-trended, strong linear correlation was observed between the static flexural strength and measured density among the saw-cut RCC beams, indicating a higher in-situ compaction can result in a greater flexural strength, which can lead to a longer RCC pavement fatigue life.
- Several major design factors associated in an M-E RCC pavement thickness design were investigated including the pavement base support and material erosion potentials. In addition, the fatigue performance has shown to be very sensitive to vehicle class distribution, primarily the percentage of Class 5 to 8 trucks and moderately sensitive to AADTT, CTE, and thermal conductivity as well as the curling/warp temperature difference.
- The proposed M-E based RCC pavement design procedure was developed by following the current Pavement ME design procedure for a jointed plain concrete pavement (JPCP) design. The major modification lies in that a primary performance indicator proposed for an RCC M-E pavement thickness design is the "fatigue cracking, % total slab lane area" with a field developed transfer function, not the "percent slabs with transverse cracks" used in JPCP design. It maintains the fundamental concepts as close as possible with the pavement M-E JPCP pavement design. Thus, the proposed M-E design procedure can be directly implemented into the pavement M-E design software for RCC pavement design.

RECOMMENDATIONS

Louisiana has many miles of low- to medium-volume roadways currently used by a significant large amount of heavy- and over-loaded trucks from shale oil/gas industries, logging and agricultural activities. Due to the heavy trafficking, the pavements experienced significant pavement distresses that typical maintenance activities cannot sufficiently address. According to the findings from this study, RCC could be used as a design alternative for those heavy-duty low-speed pavement applications. The developed RCC fatigue model and the M-E based thickness design procedure proposed in this study can be utilized to determine required RCC thickness for pavement application with heavy truck traffic. The associated M-E design models and transfer functions can be further enhanced and calibrated when more RCC mix designs and in-situ pavement performance become available from new RCC pavement applications.