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PROJECT TITLE
Performance of Thin Roller Compacted Concrete Pavement under Accelerated Loading

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"Moving Advancements into Practice"

MAP Brief May 2016

Best practices and promising technologies that can be used now to enhance concrete paving

Performance of Thin Roller Compacted Concrete Pavement under Accelerated Loading

Definition

RCC is broadly defined as a stiff, low-water concrete that is mixed and placed at a no-slump consistency, then compacted with vibratory rollers. RCC has similar strength properties and consists of the same basic ingredients as conventional concrete—well-graded aggregates, cementitious materials, and water—but has different mixture proportions. The major difference between RCC mixtures and conventional concrete mixtures is that RCC has a higher percentage of fine aggregates, which allows for tight packing and consolidation. RCC is a durable, economical, low-maintenance material for many pavement applications. It has been used for pavements carrying heavy loads in low speed areas because of its relatively coarse surface. However, in recent years its use in commercial areas and for local streets and highways has been increasing.

Why the interest in thin RCC pavements?

Traditionally, RCC pavements have been built on the order of 8–12 in. thick. With the increasing use of ports, intermodal facilities, shale gas exploration, agricultural activities, and logging activities (figures 1-3) on the low volume roadways, the Louisiana Department of Transportation and Development (LADOTD) and the Louisiana Transportation Research Center (LTRC) are interested in thin applications of RCC on the order of 4–8 in. thick.

Figure 1. Fracking tanker

Figure 2. Rural road with extreme fatigue cracking due to shale gas exploration

Figure 3. Heavily overloaded timber truck

Objective

The objectives of this study were to: (a) determine the structural performance with failure mechanism and load carrying capacity of thin RCC pavements; and (b) determine the applicability of using a thin RCC pavement structure with cement treated or cement stabilized base as a design option for low- and high-volume pavement design in Louisiana.

Design

To meet the objectives, six test sections were constructed (figure 4). Two base designs were utilized: a 150 psi unconfined compressive strength (UCS) cement treated soil base with a thickness of 12 in. (sections 1, 2, and 3) and a 300 psi UCS soil cement base with a thickness of 8.5 in. over a 10-in. cement-treated subgrade (sections 4, 5, and 6). The 10-in. cement-treated subgrade contains a cement content of about 4%, or just enough to provide a dried stable working platform on which to build the stronger base. Over each base, a 4-, 6-, and 8-in. RCC pavement section was constructed. The RCC mix consisted of a well-graded aggregate blend using #67 limestone and manufactured sand with a Type I Portland cement of 11.4% and optimum moisture content of 6.5%. Each section is about 72 ft long and 13 ft wide. The finished lanes are shown in figure 5.

Construction

All RCC layers were constructed in one day on two separated test lanes, each 215 feet long and 13 feet wide. RCC production was accomplished using a twin shaft pugmill operation on the paving site (figure 6). A high density asphalt paver was used to place the RCC and achieve initial density (figure 7). A 10-ton steel drum roller was used for final compaction of the RCC pavement structure.

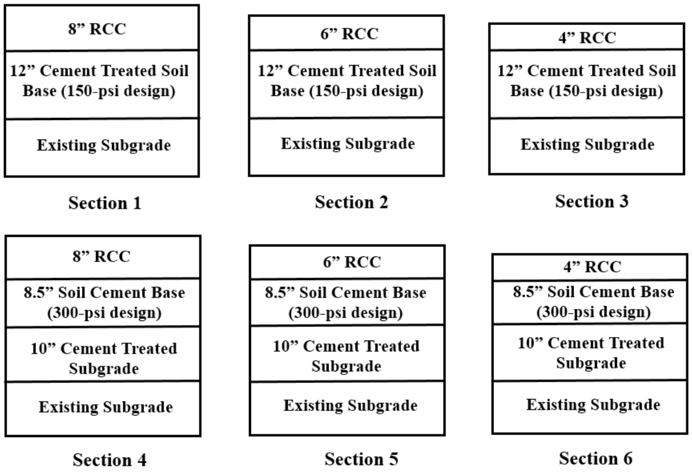


Figure 4. Test sections as designed

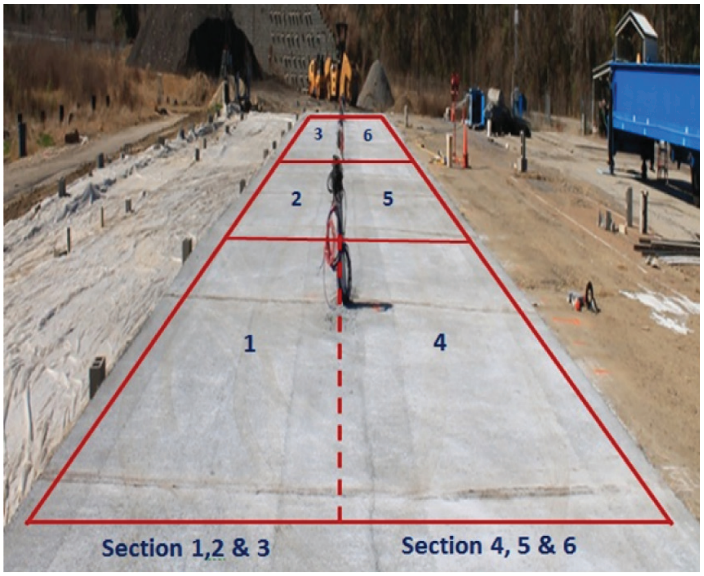


Figure 5. Test sections as constructed

Figure 6. Twin shaft pugmill

Figure 7. High density asphalt paver

Each lane included three test sections with RCC layer thicknesses varied in 4, 6, and 8 in. Paving started from an 8-in. section, moved to a 6-in. section and ended on a 4-in. section, using an in-between thickness transition zone of approximately 20 ft. All RCC layers were placed in single lift and no construction joints were formed.

Operation of saw-cutting joints began after RCC was hard enough to withstand spalling damage. The saw-cut joints were typically spaced at 20-, 15- and 10-ft intervals for the 8-, 6- and 4-in. RCC layers, respectively, with the corresponding joint depths of 1.5, 1.0, and 0.5 in. Finally, a white pigmented water based concrete curing compound was sprayed on the finished RCC surfaces.

Results

ATLaS30, a heavy vehicle load simulation device, was used to load the constructed RCC test sections, figure 8. The ATLaS30 wheel assembly is designed to model one-half of a single truck axle with a dual-tire load up to 30,000 lbf at a tire pressure of 130 psi. The weight and movement of traffic is simulated repetitively over a 40-ft long loading area in a bi-directionally moving mode at a top speed of six mph.

Table 1 presents the ATLaS30 loading passes with various load magnitudes applied on each of the RCC test sections tested in the center of the lanes. Four RCC sections (sections 2, 3, 5, and 6) were successfully loaded to a cracking failure in the end; whereas, testing of the two 8-in. RCC sections (sections 1 and 4) was discontinued after a limited number of loading cycles due to the projected time it will take to fail the sections. Figure 9 shows the final pavement surfaces of the four failed RCC sections.

The overall test results indicated that all tested RCC test sections except section 3 (4-in. RCC over 12-in. cement treated base section) exhibited a very high load carrying capacity. According to the 1993 AASHTO's equivalent single axle load (ESAL) factors, the pavement fatigue lives in terms of the estimated ESALs for sections 2, 5, and 6 were 19.4, 87.4, and 19.2 million, respectively. A direct comparison between sections 5 and 6 showed an extra 2-in. RCC thickness has a significant increase in the loading carrying capacity for section 5.

Figure 8. The ATLaS30 device

Table 1. APT Loading Passes and Load Magnitudes

Load (kips)	ATLaS30 Dual-Tire Loading Passes					
	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
9	≈ 50,000	108,000	73,000	78,500	112,000	78,500
16		265,000	73,000	78,500	404,000	392,500
20		108,000	50,000	78,500	398,000	78,500
22		108,000		78,500	108,000	78,500
25		106,000		78,500	487,000	78,500
27.5					241,850	
Total Passes	≈ 50,000	695,000	196,000	392,500	1,750,850	706,500
Estimated MESALs	-	19.4	2.7	-	87.4	19.2

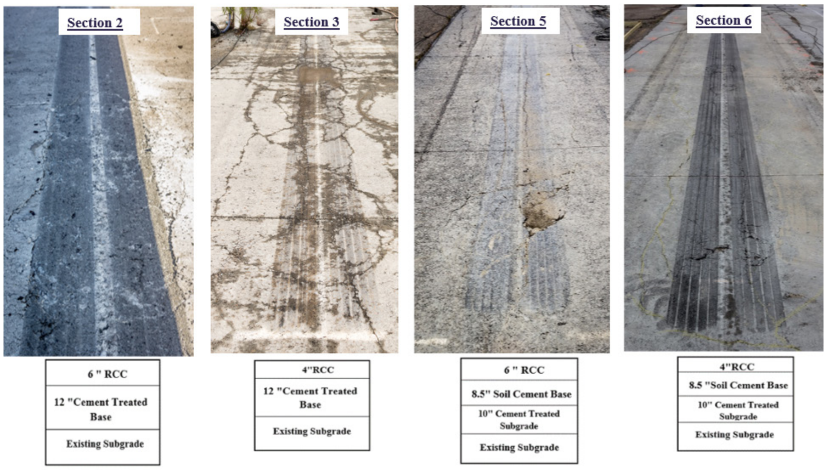


Figure 9. Failed RCC sections

On the other hand, the 8.5-in. soil cement (300 psi base) plus a 10-in. cement treated subgrade pavement structure for section 5 outperformed the 12-in. cement-treated base (150 psi base) pavement structure of section 2 by a significantly large margin in terms of the estimated ESALs (Table 1). In addition, the performance data shown in Table 1 also indicate that sections 2 and 6 could be equivalent structures with a similar pavement fatigue life in ESALs. That means the more substantial foundation (i.e., the 8.5-in. soil cement plus a 10-in. cement-treated subgrade) provided for sections 4–6 are roughly equivalent to two in. of RCC built over a 12-in. cement-treated base, as for sections 1–3.

The reasons that section 3 only lasted 2.7 million ESALs of loading could be attribute to its relatively weaker base layer and some construction compaction-related issues during the RCC paving on this section (1).

Figure 10 shows the cracking development of section 6 (4-in. RCC over 8.5-in. soil cement test section). As seen in Figure 10, a hairline longitudinal surface crack was first noticed along a centerline of the right tire print after 390,000 ATLaS30 wheel load repetitions (approximately 8 million ESALs). It was observed that fine materials (possibly from the soil cement base) were pumped out through the crack opening and some saw-cut joints when loading under a wet weather condition.

The first longitudinal crack initiated inside of one tire print seems to be due to high tensile stresses at the bottom of the thin (4-in.) RCC slab. Under the continuously wheel trafficking, the longitudinal crack started to extend and propagate resulting in more pumping-out of materials onto the pavement surface. After about 480,000 load repetitions (approximately 16 million ESALs) additional longitudinal cracks developed along the outsides of tire-print paths.

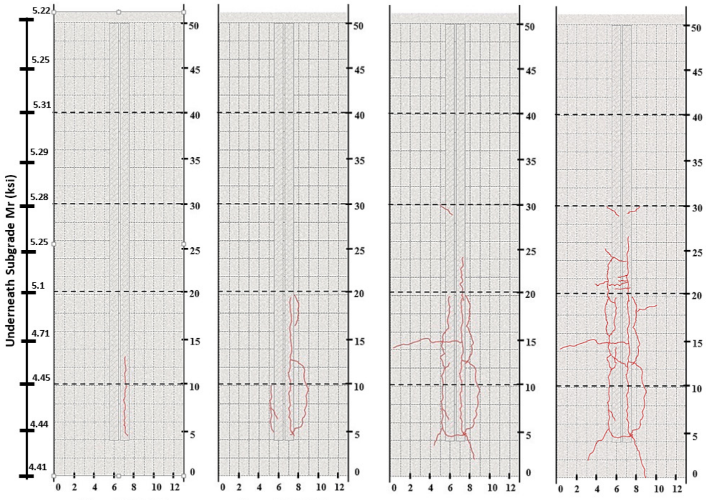
The inside and outside longitudinal cracks were gradually extended and connected to each other and finally more than 50% of the loading area developed a significant surface cracking failure at the end of 706,500 load repetitions (approximately 19.2 million ESALs). A spalling/punch-out type failure was noticed at the end of testing (figure 9). It is interesting to note that the observed cracking failure on this section was largely confined to one-half of the whole loading area. This may be attribute to a relatively weaker subgrade support when referred to the subgrade moduli plotted on the left vertical axis of figure 10.

Figure 11 shows the cracking development observed on section 5 (6-in. RCC over 8.5-in. soil cement test section). Similar to section 6, the development of surface cracking started in a longitudinal direction and the longitudinal cracks became noticeable after 1,050,000 load repetitions (approximately 23.4 million ESALs). Under the continuous ALTLaS30 wheel loading, the first group of longitudinal cracks extended and merged into a major longitudinal crack closely located at one edge of the right tire print after 1,230,000 load repetitions (approximately 34.6 million ESALs).

Meanwhile, two other longitudinal cracks outside from the tire prints were also developed. The longitudinal cracks gradually propagated and merged into each other diagonally under loading, and eventually resulted in a significant surface cracking failure after 1,750,850 load repetitions (approximately 87.4 million ESALs). The final cracking pattern was found much wider in section 5 than that in section 6, presumably due to the better load spreading of the thicker RCC slab used on this section.

The cracking development on sections 2 and 3 were generally similar to their counterpart RCC sections of sections 5 and 6, respectively, except under less loading passes to a cracking failure.

The cracking failure mechanism for a thin RCC over a soil cement or cement treated soil base pavement may be summarized as: The repeated heavy axle loads would first crack through saw-cutting joints of a thin RCC layer (possibly due to the bottom bending), and subsequently create pumping actions at the cracked joints under a wet condition. The pumping-out of fine materials would gradually weaken the overall pavement strength by forming voids in



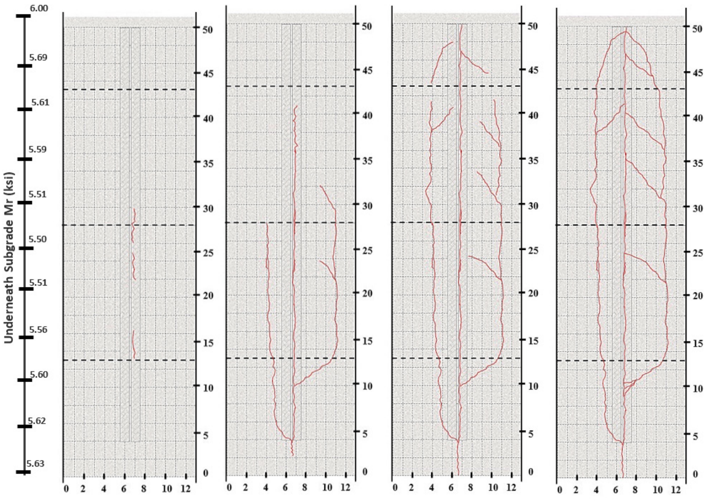
After 390,000 Load Repetition

After 480,000 Load Repetition

After 560,000 Load Repetition

After 706,500 Load Repetition

Figure 10. Cracks vs. load repetitions for Section 6



After 1,050,000 Load Repetition

After 1,230,000 Load Repetition

After 1,500,000 Load Repetition

After 1,750,850 Load Repetition

Figure 11. Cracks vs. load repetitions for Section 5

the base under or near the joints. Continuous heavy wheel loading over a weak subgrade and/or voided base locations would start to break a thin RCC slab longitudinally and eventually result in an overall fracture failure due to the repetitive fatigue bending as well as the temperature-induced slab curling, especially under a naturally warm and wet southern Louisiana pavement condition.

In this study, all tested thin RCC test sections started cracking along a longitudinal direction. This may be explained by their associated slab geometry. By considering the spacing of saw-cutting joints, a slab geometry for a 4-in. RCC pavement would be 10 feet long by 13 feet wide. Such a geometry of a thin concrete slab (plate) tends to generate a critical high transverse tensile stress (i.e., leads to a longitudinal cracking potential) at the bottom of the RCC slab. On the other hand, a thin plate geometry of 15 feet long by 13 feet wide for a 6-in. RCC pavement would result in a high shear stress under the edge of a dual tire wall due to its relatively better load spreading from a thicker RCC slab. More research on numerical simulation of fatigue cracking analysis for thin RCC pavements are underway.

Summary

The results showed that a thin RCC over soil cement pavement structure has a superior load carrying capability. The 6-in. RCC sections carried an estimated 87.4 million and 19.4 million ESALs to failure for the strong and weak base, respectively. The 4-in. RCC section on the strong base performed well with an estimated 19.2 million ESALs to failure. The data also indicate that the more substantial foundation used in sections 4–6 generally provided additional structural capacity that may be equivalent to a 2-in. thickness of RCC as compared to the less substantial foundation used in sections 1–3.

Reference

Rupnow, T., Icenogle, P. and Wu, Z. (2015). "Laboratory Evaluation and Field Construction of Roller Compacted Concrete for Testing Under Accelerated Loading." Journal of Transportation Research Record, No. 2504, 107-116

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