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16. Abstract

Through its history, a variety of wearing surface systems for the orthotropic steel deck of the Luling Bridge (aka Hale Boggs Bridge) have been built and studied. The main problem with these systems was they did not last the expected service life (20 + years).

In 1999, a short test section was installed using steel reinforced concrete, and even though the reinforcing steel was not optimally designed and exhibited cracks, it is still serviceable. Based on the performance of this test section installed in 1999, a new test section was installed in 2004. This new test section is a steel fiber reinforced concrete (SFRC) deck. The composition of the deck system is ½ in. of bridge deck steel, a thin (approximately ⅛ in.) layer of epoxy with impregnated aggregate and 3½ in. of SFRC.

This study focused on the evaluation of the steel fiber reinforced concrete that was used in the new test section on the Luling Bridge. Test specimens of the same material that was to be used in construction of the wearing surface test section were produced. The specimens were then subjected to various test procedures, flexure strength and fatigue, flexural toughness, and chloride ion penetration among others.

One unexpected consequence discovered upon initial testing was that the bending failure mechanism of the composite deck system was not in the SFRC, as projected, but in the epoxy layer. Furthermore, repeated load fatigue testing of the specimens was inconclusive, but did reinforce the failure mechanism shown in previous results. That being said, no inference to projected fatigue life can be made from the laboratory results to the field results.

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Flexural Strength and Fatigue of Steel Fiber Reinforced Concrete (2004 Hale Boggs Deck)

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ABSTRACT

Through its history, a variety of wearing surface systems for the orthotropic steel deck of the Luling Bridge (aka Hale Boggs Bridge) have been built and studied. The main problem with these systems was they did not last the expected service life (20 + years).

In 1999, a short test section was installed using steel reinforced concrete, and even though the reinforcing steel was not optimally designed and exhibited cracks, it is still serviceable. Based on the performance of this test section installed in 1999, a new test section was installed in 2004. This new test section is a steel fiber reinforced concrete (SFRC) deck. The composition of the deck system is ½ in. of bridge deck steel, a thin (approximately ⅛ in.) layer of epoxy with impregnated aggregate and 3½ in. of SFRC.

This study focused on the evaluation of the steel fiber reinforced concrete that was used in the new test section on the Luling Bridge. Test specimens of the same material that was to be used in construction of the wearing surface test section were produced. The specimens were then subjected to various test procedures, flexure strength and fatigue, flexural toughness, and chloride ion penetration among others.

One unexpected consequence discovered upon initial testing was that the bending failure mechanism of the composite deck system was not in the SFRC, as projected, but in the epoxy layer. Furthermore, repeated load fatigue testing of the specimens was inconclusive, but did reinforce the failure mechanism shown in previous results. That being said, no inference to projected fatigue life can be made from the laboratory results to the field results.

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The U.S. Department of Transportation, Federal Highway Administration (FHWA), Louisiana Department of Transportation and Development (LADOTD), and the Louisiana Transportation Research Center (LTRC) financially supported this research project.

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OBJECTIVE

The objective of this research was to serve as a support study for the Luling Bridge SFRC test section. The main focus was to analyze the SFRC with a range of steel fiber addition amounts and their affect on the performance of the whole steel, epoxy, and SFRC composite system. It was desired that a better comprehension of the decking system be attained with specific emphasis on the effects of the steel fiber addition amounts and flexural strength of the concrete.

IMPLEMENTATION STATEMENT

The Luling Bridge is unique in its design which makes use of an orthotropic steel deck. Though similar bridges are currently being constructed worldwide, not much is known on how various decking materials perform on this dynamic steel decking. Current experience with hot mix asphalt cement (HMAC) decking and the two Portland cement concrete (PCC) test sections has lead to only a moderate understanding of what could be expected with these materials. This research is intended to provide LADOTD with information on what could be expected from a SFRC deck. Information on steel fiber additions, concrete mix types along with the adhering epoxy system in conjunction with fatigue analysis should provide designers with what to expect from a SFRC deck.

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INTRODUCTION

The Luling Bridge (Hale Boggs Memorial Bridge), shown in Figure 1, traverses the Mississippi River in St. Charles Parish, Louisiana. It was one of the first cable-stayed bridges in the United States which opened to traffic in 1983. Unique to its design are relatively few cables, the deck resembles a box girder more than a suspended deck, and the first major use of weathering steel on such a large bridge.

Figure 1
The Luling Bridge (The Hale Boggs Memorial Bridge)

During the bridge's life, several HMAC pavement types have been applied to the steel deck as the riding surface. None have performed satisfactory until recently. It should be noted that the deck, atop a box girder, has numerous channel reinforcing beams which produces a myriad of stress patterns from both dynamic loads and thermal effects. Due to the uniqueness of this structure and its design, there is little information or experience available on typical service life or performance. In 1999, a short concrete test section was constructed with conventional reinforcing utilizing small bent #3 and #4 bars. This 4 in. thick test section, shortly after construction, started to show signs of some random and longitudinal cracking along stress areas associated with the channel reinforcing underneath the deck.

Further assessment determined that the reinforcing steel in the 1999 test section was designed inappropriately for these stresses. Nevertheless, the 1999 test section has maintained its integrity without the associated cracking deteriorating any further.

With the lessons learned from the 1999 test section, it was decided to construct a new concrete test section in 2004 utilizing a SFRC mixture. It was thought that the omnidirectional reinforcing effect provided by the steel fibers would be superior in resisting the myriad of stresses inflicted on the concrete from the bridge. This section also showed signs of random cracking shortly after construction though these cracks have held tight without any significant detrimental effect on the test section.

Both of the concrete test sections, 1999 and 2004, were placed on top of a unique process of applying a coat of Concresive® 1090 to the bare deck steel then broadcasting crushed aggregate onto the wet epoxy to provide a better adhesive or bond surface for the SFRC, Figure 2.

Since it was determined that the second concrete test section, 2004, demonstrated the most promising design for a possible future decking of the complete bridge, an investigation into the SFRC, epoxy, and steel decking system was appropriate.

Figure 2
Deck steel with applied epoxy and broadcasted aggregate before SRFC placement

SCOPE

To accomplish the objectives of this support study, both field and laboratory studies were undertaken. The laboratory study evaluated compressive and flexural properties of concrete incorporating steel fibers at differing rates. The following ASTM standards were utilized in the laboratory study.

- ASTM C-78 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
- ASTM C1018 Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)
- ASTM C-1202 Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
- ASTM C-39 Compressive Strength of Cylindrical Concrete Specimens
- A Cyclic Load Testing Regime

From both a dynamic (wind and traffic) and thermal (expansion and contraction) perspective, the stresses applied to the deck of the Luling Bridge are diverse and complex to say the least. This research concentrated on the flexural characteristics of the steel, epoxy and SFRC decking system, considering them to be the most significant in resisting the applied stresses.

METHODOLOGY

A literature review was conducted, but due to the uniqueness of the orthotropic steel deck, the review did not result in any valuable findings.

The methodology was broken down into two distinct areas. The first was to evaluate the actual SFRC as used on the 2004 test section in flexural testing. The second area involves laboratory mixtures and sample modeling of the steel, epoxy, and SFRC decking for further lab testing and analysis.

SFRC Used on the 2004 Test Section

Flexural Strength Testing

Twenty 6 × 6 × 20 in. flexural beams were produced at the construction site from SFRC as delivered by the ready-mix trucks. These 18 beams were tested over a 57-day period at intervals of 1.5, 2.5, 3.5, 4.5, 8, 15, 29, and 57 days to develop a strength gain over time curve. These tests were conducted as per ASTM C-78 with the flexural beams being moist cured after 18 hours of field cure at the job site.

Laboratory Testing

Materials

The concrete mix design, as specified for the test section, was constant for all specimens with the exception of the steel fiber content. The specifications for the concrete mix were:

Portland Cement: One source was used for the entire project. Type III was not allowed.
Aggregates: Coarse aggregate met the following gradation:

US Sieve	% Passing
1/2"	90-100
3/8"	80-100
No. 4	15-50
No. 8	0-10
No. 16	0-5

Steel Fiber reinforcement:

<u>Wire Classification:</u> American Society for Testing and Materials (ASTM) A820, Type I, low carbon, cold-drawn, end-deformed steel wire

Fiber Characteristics:

1) Length: 60 mm (2.36 in.). Deviation: ±5 percent.
2) Maximum Diameter: 0.75 mm (0.029 in.) Deviation: ±5 percent.
3) Minimum Aspect Ratio (=L/D): 80–deviation @ ±5 percent, with an aspect ratio defined as the length of the fiber divided by its diameter.
4) Deformations: End deformed.
5) Surface Condition: Steel fibers shall be clean and free of rust, oil, and deleterious materials.
6) Configuration: Collated (glued bundles) for ease of mixing are allowed with round drawn wire and hook-ended for optimal anchorage in concrete required.
7) Fiber Minimum Ultimate Tensile Strength: 150,000 psi (1035 MPa).
8) The steel fibers incorporated into the concrete mix shall possess a minimum 28 day ASTM C 1018 Residual Strength Factor $R_{10,\ 50,}$ of 87 percent when the concrete mix is properly cured with steel fibers employed at a minimum dosage of 85 lb. per cubic yard.

Laboratory Testing and Modeling Program

As originally planned, the testing regime was to include:

- ASTM C-78 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
- ASTM C1018 Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)
- ASTM C-1202 Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
- ASTM C-39 Compressive Strength of Cylindrical Concrete Specimens
- A Cyclic Load Testing Regime

All testing was to be conducted at 28 days of age. All concrete mixtures imitated the original concrete mixture design as used on the 2004 test section. Steel fiber addition amounts were divided into four groups of: no steel fiber addition, 65 lb/yd^3, 85 lb/yd^3, and 100 lb/yd^3. These four groups and their mixture designs are shown in Table 1.

For the SFRC specimens that modeled the actual bridge deck (steel, epoxy, and SFRC) a total of six specimens were produced. This involved a 4 × 16 × ½ in. thick steel plate onto which a thin 1/8 in. layer of Concresive® 1090 epoxy was applied and ½ in. size limestone broadcast onto it as shown in Figure 3. The remainder of the 4 in. height mold was then consolidated with the SFRC. For the SFRC deck models, the steel fiber addition amounts were modified based on initial results to: 65 lb/yd^3, 85 lb/yd^3, and 95 lb/yd^3. Figure 4 shows the steel fibers used for this project. Initially, two specimens were produced for each of the three concrete mix designs shown in Table 2.

Table 1
Mix designs for laboratory testing

LTRC Lab. No.	**C-2641**	**C-2645**	**C-2647**	**C-2646**
0754 Holcim Type I Portland Cement (lb/yd³)	700	700	700	700
Sand, A133 TXI Dennis Mills (lb/yd³)	915	885	885	885
#8 Limestone, AB29 Martin Marietta (lb/yd³)	632	623	623	623
#11 Limestone, AB29 Martin Marietta (lb/yd³)	1566	1554	1554	1554
DRAMIX RC-80/60-BN steel fibers (lb/yd³)	**0**	**66**	**85**	**102**
% by volume Sand	29.9	29.1	29.1	29.0
% by volume #8 Limestone	20.2	20.1	20.0	20.0
% by volume #11 Limestone	50.0	50.1	50.0	49.9
% by volume steel fibers	0.0	0.7	0.9	1.1
Water (lb/yd³)	260	270	270	270
Water Cement Ratio	0.371	0.386	0.386	0.386
Admixture	ADVA 170	ADVA 170	ADVA 170	ADVA 170
Dosage (oz/100ct)	9.00	9.00	9.00	9.00
ASTM C 1064 Air Temperature	71.0	75.1	74.0	73.0
ASTM C 1064 Concrete Temperature	71.0	77.4	76.3	77.8
ASTM C 143 Slump (inches)	4.00	n/a	n/a	n/a
ASTM C 995 Inverted Slump (seconds)	n/a	16	13	12
ASTM C 231 Air Content (%)	2.50	3.70	2.80	3.50
ASTM C 138 Unit Weight (lb/ft³)	147.6	149.6	150.4	150.8

Figure 3
Broadcasting limestone onto epoxy layer of specimens

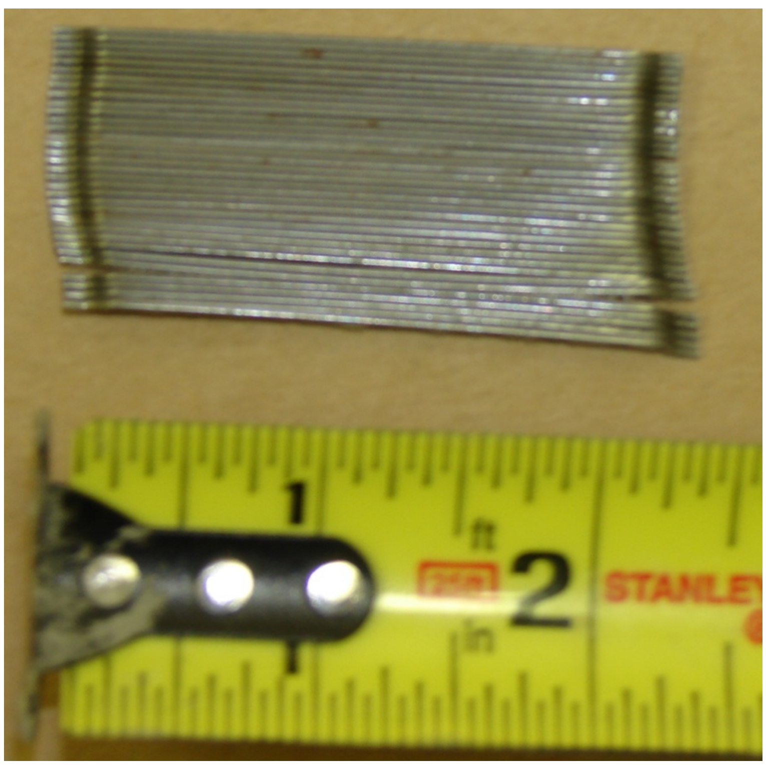

Figure 4
Steel fibers

Table 2
Mix designs for Luling Bridge deck model

LTRC Lab. No.	C-2908	C-2909	C-2910
0754 Holcim Type II Cement (lb/yd³)	700	700	700
A133 Fine Aggregate (lb/yd³) Sand (ACI grade)	1509	1509	1509
AB29 Coarse Aggregate (lb/yd³) #8 Limestone	1527	1527	1527
Steel Fibers (lb/yd³)	**65**	**85**	**95**
Water (lb/yd³)	210	210	210
Water Cement Ratio	0.30	0.30	0.30
Admixture	ADVA 170	ADVA 170	ADVA 170
Dosage (oz/100ct)	12.50	12.50	12.50
Admixture	Daravair 1000	Daravair 1000	Daravair 1000
Dosage (oz/100ct)	0.75	0.75	0.75
ASTM C 1064 Air Temperature	70.5	70.5	70.5
ASTM C 1064 Concrete Temperature	71.8	71.8	71.8
ASTM C 231 Air Content (%)	2.8	2.8	2.8
ASTM C 143 Slump (inches)	4.00	1.75	0.25
ASTM C 138M Unit Weight (lb/ft³)	152.0	152.0	152.0

For repeated load testing, the mixture with 65 lb/yd^3 of steel fibers was selected since it was the only remaining sample at the time of this report. The sample was initially subjected to 20 percent of the maximum flexural load (approximately 3900 lb.) for a period of 100,000 cycles. The reality was that the load was repeated for about 15,000 cycles due to an error in the data acquisition software. The load was then recalculated for 25 percent (approximately 4875 lb.) of the maximum load for a period of approximately 15,000 cycles. This was then repeated for a 30 percent load (approximately 5850 lb.) for the remaining number of cycles up to the target 100,000. A 50 percent load (approximately 9749 lb.) was then applied until failure. Parameters measured included load and deflection versus cycle (time). Note that a cycle consisted of a one second loading period and a one second resting period.

DISCUSSION OF RESULTS

SFRC Used in the 2004 Test Section

Flexural Strength Testing

Twenty 6 × 6 × 20 in. flexural beams were produced at the construction site from SFRC delivered by ready-mix trucks. These 20 beams were tested over a 57-day period at intervals of 1.5, 2.5, 3.5, 4.5, 8, 15, 29, and 57 days to develop strength gain over time curve. These tests were conducted as per ASTM C-78 with the flexural beams being moist cured after 18 hours of field cure on the job site. Figure 5 shows the flexural strength gain for field produced samples.

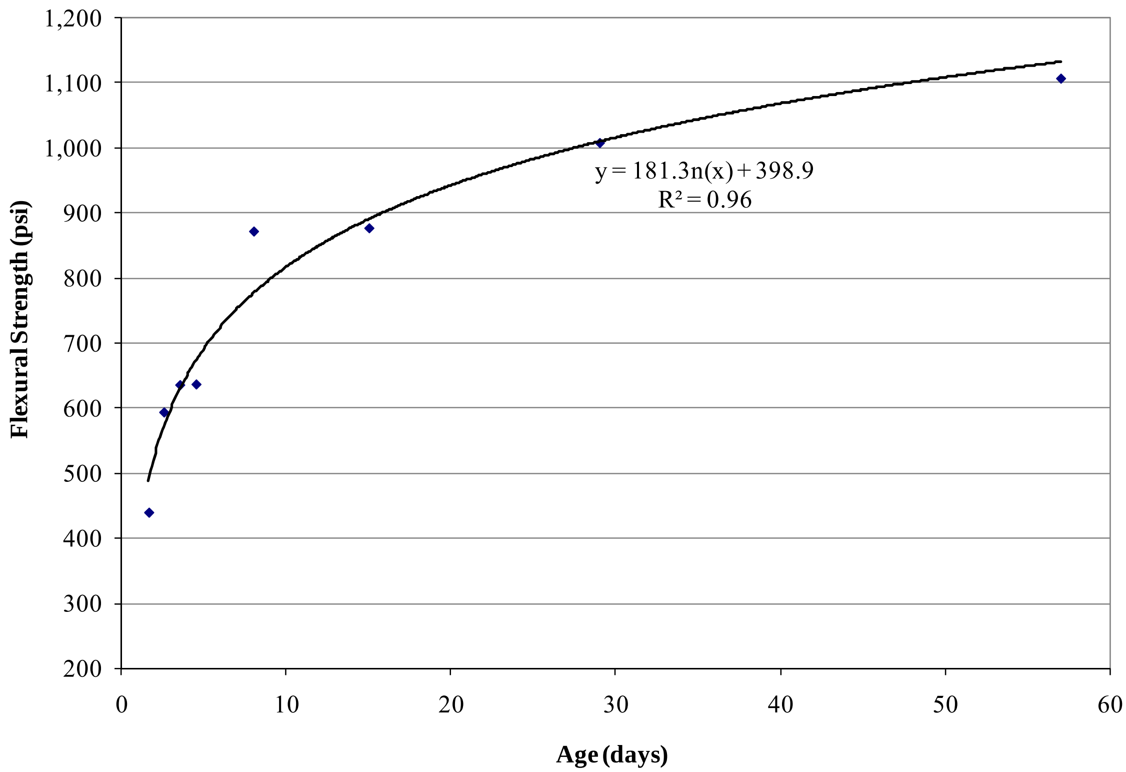

Figure 5
Results for flexural strength gain for field produced samples

The flexural strength results are as expected from a mix design incorporating 700 lb/yd^3 of cement along with 85 lb/yd^3 of steel fibers. With optimism to resisting the bridge's imposed stresses, strengths above 1100 psi were thought to be sufficient to resist major cracking.

Some cracking was anticipated, but the cracking in the test section was more severe than expected. The cracks were transverse in a random and meandering pattern. Although some cracking was more severe than desired, the majority of cracks were small. Figure 6 shows a larger than expected transverse crack. At this time, it is not known whether the cracking occurred due to shrinkage or dynamic movement, which is very perceptible. It should be noted that the SFRC has held all of the cracks tight, without any spalling, throughout the four years since placement.

Figure 6
Larger than anticipated transverse cracks in the field test section

Though limited in scope, compared to the complex nature of the generated stresses on the deck, specimens were subject to simple bending for analysis. During simple flexural testing on the initial steel, epoxy, and SFRC system samples, it was discovered that the failure mechanism of the decking system occurred solely in the epoxy layer. Independent of the type of SFRC or amount of steel fibers used, the shear strength at the SFRC epoxy interface was the controlling factor. This fact negated simple bending as an analysis method for the steel, epoxy, and SFRC model.

Laboratory Testing

Initial Laboratory Testing

Initial laboratory testing investigated four comparable mix designs with varying steel fiber additions at 100 lb/yd^3, 85 lb/yd^3, 65 lb/yd^3, and 0 lb/yd^3. The four mix designs mimicked the original mix design as specified on the 2004 test section. Compressive and flexural strength test results were an average of 10 (6 × 12 in.) cylinders and 10 (6 × 6 × 20 in.) beams, respectively. Test results for the modulus of elasticity were an average of five cylinders. The test results are presented in Table 3.

Table 3
Test results for laboratory SRFC samples

LTRC Lab. No.	C-2641	C-2645	C-2647	C-2646
ASTM C-39, Average Compressive Strength (psi)	9575	8959	9559	9403
ASTM C-469, Average Modulus of Elasticity	6,767,779	6,180,000	6,130,000	6,140,000
ASTM C-78, Average Flexural Strength (psi)	1201	1213	1179	1185

Although a significant difference was not expected, it was anticipated that the mixtures with increased steel fiber content would show a greater strength capacity than those with less steel fiber content. This was not the case.

For the compressive strengths, the mixture without any steel fibers actually had the greatest compressive strength. For the three mixtures with the varying amounts of steel fibers, there was no discernable trend as expected. Standard deviations for these tests ranged from 260 to l95 psi, which is within the acceptable range. From these test results, it can only be presumed that the steel fibers have little to no affect on the compressive strength of the concrete.

The flexural strength test results were also unanticipated. Here again it was expected that those mix designs with increased amounts of steel fibers would show greater flexural strength, which was not the case. Similar to the compressive strength results, the flexural strength results displayed no discernable trend either. Standard deviations for these tests ranged from 85 to 36 psi with the 85 psi standard deviation (mix with no steel fibers) being an outlier of the four mixes.

The test results for the modulus of elasticity were all high. The steel fiber mixes averaged 6.1×10^6 psi, and the mixture without any steel fibers had a modulus of elasticity of 6.7×10^6 psi.

Modeled Deck System of SFRC

After the results from the initial testing portion indicated that steel fiber addition amounts did not have a remarkable effect on the basic strength parameters of the concrete, it was decided to scale down the addition amounts to 65 lb/yd^3, 85 lb/yd^3, and 95 lb/yd^3. The mix design was simplified somewhat with regards to aggregate gradation but still within the original mix design specifications. The modeled specimens comprised of a 4 × 4 × 16 in. specimen beam, a (4 × 16 in.) ½ in. thick steel plate onto which a thin 1/8 in. layer of Concresive® 1090 epoxy was applied which had ½ in. size limestone broadcast onto it, and the remainder of the 4 in. height mold was then consolidated with the SFRC. The mix designs and test results are presented in Table 4.

Table 4
Mix design and test data for SFRC deck model

Mixture Design Data			
LTRC Lab. No.	**C-2908**	**C-2909**	**C-2910**
0754 Holcim Type II Cement (lbs/yd^3)	700	700	700
A133 Fine Aggregate (lbs/yd^3) Sand (ACI grade)	1509	1509	1509
AB29 Coarse Aggregate (lbs/yd^3) #8 Limestone	1527	1527	1527
Steel Fibers (lbs/yd^3)	**65**	**85**	**95**
Water (lbs/yd^3)	210	210	210
Water Cement Ratio	0.30	0.30	0.30
Admixture	ADVA 170	ADVA 170	ADVA 170
Dosage (oz/100ct)	12.50	12.50	12.50
Admixture	Daravair 1000	Daravair 1000	Daravair 1000
Dosage (oz/100ct)	0.75	0.75	0.75
ASTM C 1064 Air Temperature	70.5	70.5	70.5
ASTM C 1064 Concrete Temperature	71.8	71.8	71.8
ASTM C 231 Air Content (%)	2.8	2.8	2.8
ASTM C 143 Slump (inches)	4.00	1.75	0.25
ASTM C 138M Unit Weight (lbs/ft^3)	152.0	152.3	152.5
Mixture Physical Data			
28 Day ASTM C 39, Compressive Strength (psi)	9940	13110	12834
43 Day ASTM C 78, Flexure Strength (psi)	1360	1061	1362
43 Day, 4"x 4"x16" beams (concrete/epoxy/steel), ASTM C 78, Flexure Strength (psi)	3656	3395	6452

Comparable to the initial SFRC concrete mix used in the 2004 test section, the compressive and flexural strength data, intended for the lab mixes, did not reveal any trends. The three flexural beams averaged for the flexural strength had standard deviations of 130 psi (C-2908), 65 psi (C-2909), and 210 psi (C-2910). Except for mix C-2909, these were unusually high standard deviations based on past experience.

The results from the deck model beams, last line of Table 4, do not lend themselves to any discernable trend. From observing the loading of these specimens to failure, it became apparent that the failure mechanism was exclusively in the epoxy bond interface, regardless of the mix design of SFRC. Of the six beams tested, shear failure at the epoxy/steel interface accounted for five. The remaining beam failed at roughly 65 percent of the epoxy/concrete interface and 35 percent at the epoxy/steel interface. This revelation is attention-worthy to not only the designers of the SFRC deck, who were unaware of this critical aspect, but to the scope and methodology of this research.

The repeated load testing results showed very little permanent deformation of the composite section. It is important to note the section did not fail at 100,000 cycles, but a combination of cycles at differing loads from 25 percent to 50 percent of ultimate flexural strength. The first 15,000 cycles were at 25 percent load (approximately 4875 lb.), the next 85,000 cycles were at 30 percent load (approximately 5850 lb.). A 50 percent load (approximately 9750 lb.) was then applied until failure.

When increasing the load to 50 percent of the maximum flexural load (approximately 9750 lb.), the composite sample failed after about 6500 cycles (106,500 total cycles). Figure 7 shows the failed composite sample. Note that the failure mechanism was a shear failure within the epoxy layer followed by a cracking of the SFRC layer. Although the sample failed, it is important to note that the sample most likely has some residual flexural strength.

The subsequent analysis of the repeated load results showed inconsistencies such as discontinuities in the load versus deflection graphs for the various cycles that made the data and results invalid. These disappointing results are most likely due to the repeated starting and stopping of the test due to the inability of the software to conduct 100,000 continuous cycles. These inconclusive results lead the authors to note that no correlations should be made from the laboratory sample to the field sample as is evidenced by the well performing in-place field test section.

Figure 7
Failed composite sample after approximately 107,000 cycles

CONCLUSIONS

The most significant discovery from the testing was the revelation that the bending failure mechanism of the steel, epoxy, and SFRC deck model was shear developed at the epoxy interface, specifically at the epoxy/steel interface. Although limited to six specimens, it was apparent that this was the controlling failure mechanism under a bending load. This was unknown to the designers and should be of vital importance if a future concrete deck is built on the Luling Bridge or any orthotropic deck. If an epoxy interface or bonding layer is used, it is imperative that strict specifications be prescribed concerning the cleanliness of the steel deck to facilitate the best bond possible. Since the majority of failures were at the steel/epoxy interface, this bond is critical not only for bending stress failure, but also for possible delamination.

Another point of interest is the quantity, size, and quality of aggregate broadcast onto the epoxy after its application to the deck. Although sufficient shear resistance was developed in our deck model specimens, as evidenced from the location of shear failure, this should be a point of interest for future applications.

There was no definite consensus on the quantity of steel fiber to add to the mix design for optimization. The limited testing results from the SFRC specimens, which varied greatly, did not offer any evidence for a considered opinion.

The fatigue testing results were inconclusive and no correlations to current or expected field performance can be made. It is recommended that if the Department wants to consider this type of deck in the future, much larger model specimens should be constructed and tested in a repeated load manner.

RECOMMENDATIONS

Should the Department want to pursue the idea of placing a permanent concrete deck on the Luling Bridge, further exploration and research should be conducted into the concept of a SFRC deck material. With the non-definitive results obtained along with too short of an evaluation time for the 2004 SFRC section, only tentative recommendations are presented concerning SFRC.

Considering the complex nature of the imposed stresses on the deck of the Luling Bridge, any future research or continuation of this project on SFRC for the Luling Bridge would be better served by the academic groups that work for LTRC. A regime of fatigue testing that simulates actual bridge stresses would be mandatory for this research.

The most practical recommendation would be to delay any future research and allow the two in-place concrete tests section adequate time for their real world evaluation. Therefore, a more measured assessment can be made in the suitability of a rigid SFRC deck.

Furthermore, it must be noted that the flexible HMAC deck, which is nearly the same age as the SFRC test section and comprises the majority of the Luling Bridge deck, is performing satisfactory and in excellent condition apart from one short beginning/transition area that has some cracking and minor rutting. This further emphasizes the recommendation to extend the evaluation period for these test sections and material types for a better informed comparison.

ACRONYMS, ABBREVIATIONS, & SYMBOLS

ASTM	American Society for Testing and Materials
FHWA	Federal Highway Administration
HMAC	Hot Mix Asphalt Cement
LADOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center
PCC	Portland Cement Concrete
SFRC	Steel Fiber Reinforced Concrete
psi	pounds per square inch
mm	millimeters
lb/yd^3	pounds per cubic yard
in.	inch(es)
MPa	mega Pascals