Rapid Rehabilitation or Replacement of Bridge Decks Under Concurrent Traffic Conditions

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The Alabama Department of Transportation (ALDOT) has more than 4.8 km (3 mi) of major Interstate bridges near downtown Birmingham with significant levels of deck cracking and deterioration. The bridges are part of the I-65 and I-59/20 Interstate highway system through the city and are approximately 30 years old. About 5 to 7 years ago, ALDOT bridge inspectors began to see longitudinal cracks in the top of the deck above the edges of the support girders. These cracks are continuing to grow in length and width and are beginning to combine with older transverse cracks to form surface spalls. ALDOT must make decisions on rehabilitation actions for the Birmingham decks in the near future. Toward this end, ALDOT is looking closely into what other states and highway agencies are doing, traffic demands and the need for additional lanes, the remaining fatigue and service life of the steel girder superstructures, punching shear load testing, delamination and deterioration of the existing decks, and placement of deck test sections using different rehabilitation strategies.

More than 4.8 km (3 mi) of major Interstate bridges [three to five lanes wide, with approximately 55 742 m^2 (600,000 ft^2) of deck] near downtown Birmingham, Alabama, have significant levels of deck cracking and deterioration. The bridges are part of the I-65 and I-59/20 Interstate highway system through the city and are approximately 30 years old. Typical photographs showing the state of cracking and deterioration of the I-65 and I-59/20 bridges are presented in Figures 1 through 4. Obviously, the decks are showing significant cracking. Alabama Department of Transportation (ALDOT) bridge inspectors indicate that about 5 to 7 years ago they began to see longitudinal cracks in the top of the deck above the edges of the support girders. These cracks are continuing to grow in length and width and are beginning to combine with older transverse cracks (which are almost everywhere) to form surface spalls, as shown in Figure 4.

ALDOT's primary concerns about the Birmingham I-65 and I-59/20 decks are as follows:

- Inadequate traffic lanes and traffic capacity, on I-65 and on I-59/20 from the I-59/20 juncture to the I-65 interchange in particular;
- Significant levels of live load deflections and out-of-plane movement of the deck superstructure system; in turn, these are probably the major contributors to the distresses indicated below;
- Significant level and rate of increase of deck cracking and deterioration, requiring ever-increasing maintenance attendance in the form of surface spall and pothole repairs (which generally require full-depth patches); these probably are reducing the bending stiffness in both the longitudinal and the transverse directions, are leading to greater deflections and cracking, and will eventually lead to deck-punching shear failures;
- Extensive fine cracking on the deck undersides, with a concern for future underside spalling problems, which would create a safety hazard and additional maintenance requirements; and

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FIGURE 1 Close-up of transverse cracking on I-65 bridge.

- Past history of fatigue problems with diaphragms, diaphragm-to-girder connections, and support girders (at locations of transverse diaphragms) and a concern that the girders may be approaching their fatigue limit and will need to be replaced.

ALDOT must make decisions on rehabilitation actions for the Birmingham decks in the near future. Toward this end, ALDOT is looking closely into the following:

- What other states and highway agencies do in similar cases;
- Traffic demands and planning to identify the need for additional lanes on these bridges in the near future (if additional lanes are justified, they will be added first to ease the traffic congestion during later staged-construction deck rehabilitation);
- An assessment of remaining fatigue and service life of the steel girder superstructures through field strain gage measurements and analytical analysis;
- Developing the capabilities to perform punching shear load testing within ALDOT's bridge load testing section to allow the assessment of punching shear capacity and the imminence of deck structural failure via punching shear;

FIGURE 2 Underside of I-65 bridge.

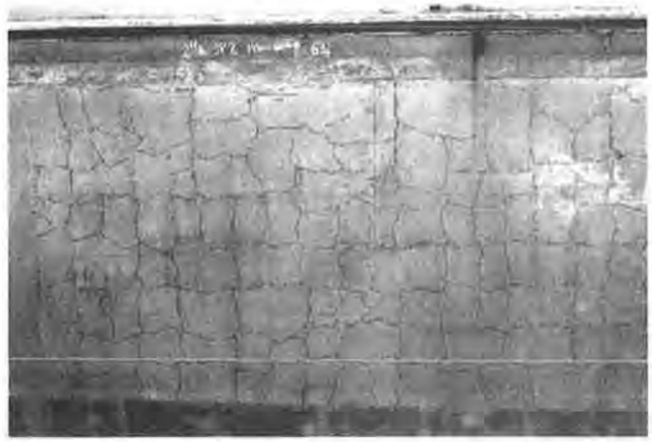

FIGURE 3 Close-up of underside of I-65 bridge at midspan with hairline cracks highlighted.

- Assessing the state of delaminations and deterioration of the existing decks to determine the viability of employing deck overlays as an effective rehabilitation strategy; and
- Placement of deck test sections employing different rehabilitation strategies (deck replacements and deck overlays) to evaluate their construction friendliness, requirements for traffic constraints, costs, and performance and estimated longevity when placed in a staged and rapid construction manner.

The research described below is part of ALDOT's investigative work on the Birmingham bridge deck problem.

Phase 1 Research Work

Before ALDOT could decide on the appropriate rehabilitation actions for the Birmingham bridge deck, several questions had to be answered:

FIGURE 4 I-65 deck surface spall.

• What are the causes of the deck cracking and deterioration?
• What is the present state of structural adequacy of the bridge decks?
• What is the remaining service life of the bridge superstructure girder?
• What are the most viable deck rehabilitation and deck replacement options?
• What are the construction friendliness, required traffic disruption, and costs of the most viable deck rehabilitation and deck replacement options?

The objectives of the Phase 1 research were to answer some of these questions, namely, to

• Identify the causes and failure chronology for the Birmingham bridge decks,
• Survey other state DOTs to determine how they are addressing this problem, and
• Identify effective and efficient deck rehabilitation and replacement procedures that are workable for Alabama operating conditions and under staged construction and concurrent traffic conditions.

From the Phase 1 work, it appears that the deck cracking is primarily the result of early drying and thermal shrinkage, early concrete obstructed settlement, thin and flexible deck [approximately 16.5 cm (6.5 in.) thickness], light and flexible superstructure, and heavy traffic volume and truck loading (80,000 one-way average daily traffic in 1998).

The typical failure chronology for bridge decks in Alabama appears to be as follows:

• A significant level of early transverse shrinkage cracking;
• Growth in width of transverse cracks due to crack movement and abrasion from traffic and environment loadings;
• Development of longitudinal cracks at girder edges due to poor longitudinal distribution of truck tire loadings (in part because of extensive transverse cracking);
• Reduced bending stiffness in both the transverse and the longitudinal direction due to crack growth, which in turn leads to increased deck cracking;
• Local surface spalling requiring ever-increasing maintenance attendance; and
• Eventual deck punching shear failures.

The most viable rehabilitation options for the Birmingham Interstate bridge decks identified in the Phase 1 work were to rehabilitate the bridge decks by using overlays (for 10- to 20-year life extension), replace the decks, add longitudinal girders to strengthen and stiffen the existing deck and superstructure, and replace the bridge superstructures.

Which rehabilitation strategy would be the most cost-effective depends on the structural adequacy of the existing concrete decks and their estimated remaining service life, along with the remaining service life of the bridge girders. Table 1 shows a matrix of rehabilitation strategies for various estimates of remaining life for the deck and support girders. Work is under way to make best estimates of these remaining lives.

To determine how other states address their deck deterioration problems, a short survey questionnaire was mailed out. Forty-one state DOTs responded. Some results of the survey are shown in Figures 5 and 6. The principal investigator (PI) also visited several states that were performing deck rehabilitation at the time. Georgia was using rapid setting Type III cement concrete structural overlay. Kentucky was using 3.17-cm (1.25-in.) rapid setting latex modified concrete overlay. California was using 19-mm (0.75-in.) polyester polymer concrete overlay. And New York was using exodermic precast deck panel deck replacement.

Select photographs of these rehabilitations in progress are shown in Figures 7 through 14.

TABLE 1 Rehabilitation Strategies for Various Combinations of Estimated Remaining Life for Support Girders and Deck

Deck Estimated Remaining Life	Support Girders Estimated Remaining Life		
	15 Years	30 Years	50+ Years
8 years	Overlay in 7 years	Replace deck in 7 years	Replace deck in 7 years
16 years	Replace superstructure in 14 years	Overlay in 15 years	Replace deck in 15 years
24 years	Replace superstructure in 14 years	Replace superstructure in 23 years	Replace deck in 23 years

NOTE: An alternate strategy to those indicated is to add a support girder between each existing girder. This is felt to be a viable option for situations where the estimated remaining life of the girders and the deck is 15 years or greater.

Phase 2 Research Work

On the basis of the Phase 1 work, four bridge deck replacement test sections will be placed in Birmingham in Phase 2. The replacement systems will be as follows:

- A continuous precast prestressed stay-in-place (SIP) form system with a cast-in-place (CIP) concrete topping (Nebraska University deck design);
- An exodermic steel panel system with a CIP concrete topping;

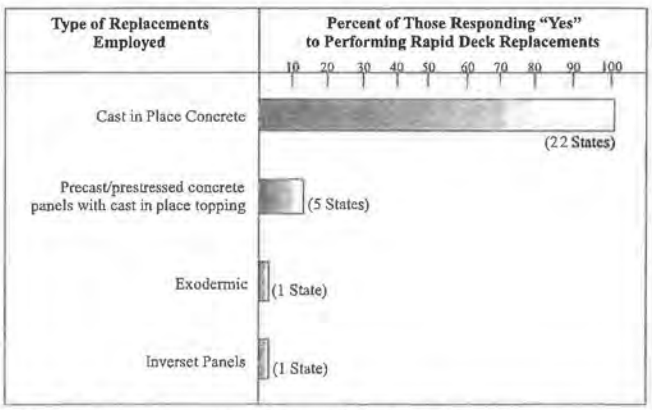

FIGURE 5 Summary of type of deck replacements employed by other states in urban setting with staged construction and concurrent traffic (22 states).

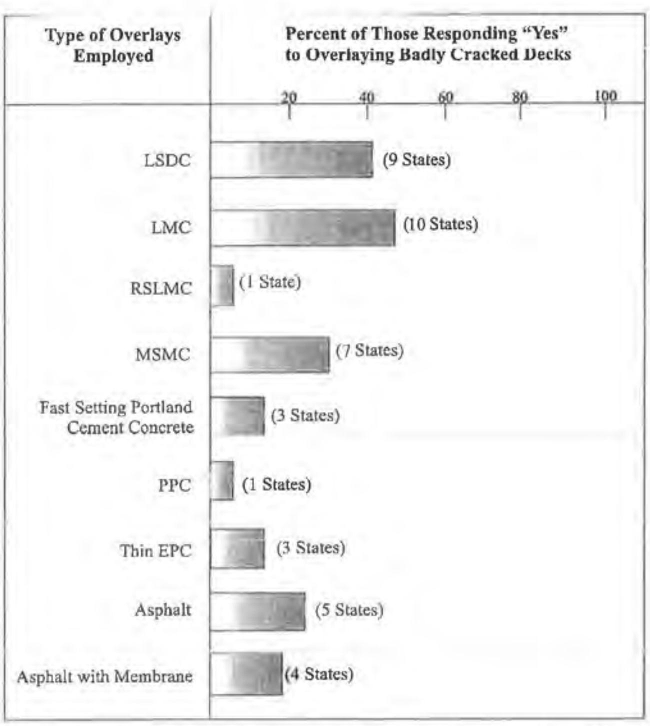

FIGURE 6 Summary of type of deck overlays employed by other states on badly cracked decks (23 states).

FIGURE 7 Hydrodemolition portion of deck near an expansion joint with two sizable blow-outs—I-285 bridge, Georgia.

FIGURE 8 Strip to be overlaid just after completion of hydrodemolition looking south on I-285 bridge, Georgia.

FIGURE 9 Typical deck damage at joints, Kentucky bridge.

FIGURE 10 Typical deck damage away from joints, Kentucky bridge.

FIGURE 11 Applying deck primer—Caltrans's PPC overlay.

FIGURE 12 Screeding Caltrans's PPC overlay.

FIGURE 13 Exodermic panels in off-bridge staging area, Tappan Zee Bridge.

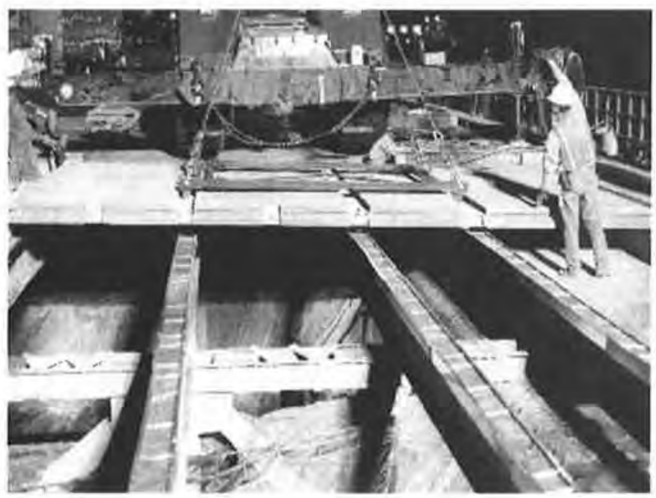

FIGURE 14 Setting of first exodermic panel, Tappan Zee Bridge.

- A conventional steel grid panel system with a CIP concrete topping; and
- A SIP metal form system with a CIP concrete topping.

Additionally, a superstructure stiffening and strengthening system, consisting of adding a girder line (from the underside) between the existing girders, will be placed for one bridge span. A major advantage of this rehabilitation strategy is that most of the work can be performed from the underside of the bridges with little disruption in traffic. Two other significant attractions of this strategy are that it will significantly stiffen and strengthen the deck-superstructure system, and it will reduce fatigue-inducing live-load stresses in the existing girders and deck. Sketches of these replacement and stiffening systems are shown in Figures 15 through 18.

Each of the five systems will be placed for one span of the bridge in a staged construction manner so that traffic, although restricted, will be able to continue. Each system will be monitored to document its construction "friendliness," required lane closure time, costs, and first-year performance.

In addition, four bridge deck overlay test sections will be placed and monitored in Birmingham in Phase 2 in the same manner. The overlay systems will be a 12.7-mm to 19-mm (0.75-in.) asphaltic based with polymer-modified asphalt emulsion binder NOVACHIP overlay; a 9.5-mm (⅜-in.) Polycarb-Flexogrid epoxy polymer concrete overlay; a 12.7-mm Thermo-Chem epoxy polymer concrete with glass fiber grid reinforcement overlay; and a 19-mm polyester polymer concrete overlay [California Department of Transportation (Caltrans) overlay].

In the Phase 2 work, the project PI will work with ALDOT's bridge load testing section to add bridge deck punching shear load testing to its abilities. In turn, the PI and the testing section will perform punching shear field tests on an AL-79 bridge north of Birmingham (after it is taken out of service in 2000) to assess punching shear capacity at cracked and uncracked deck locations. In addition to measuring the punching shear failure loads, the tests will measure vertical deflections at the load point to assess the deck P-Δ behavior and signature.

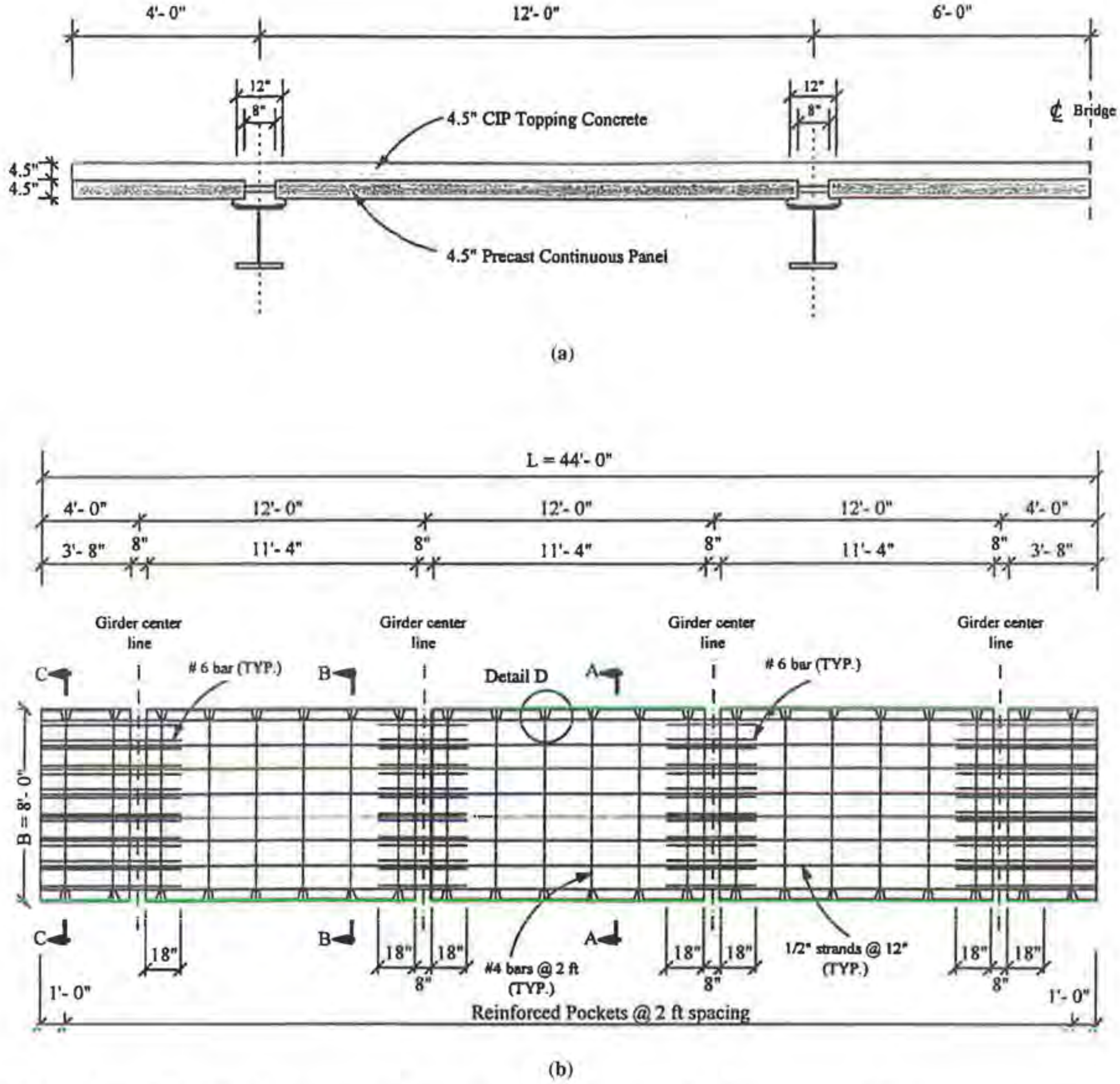

FIGURE 15 Nebraska University continuous prestressed concrete SIP form system: (*a*) cross section and (*b*) plan view. (From report on NCHRP Project 12-41 by M. K. Tadros.)

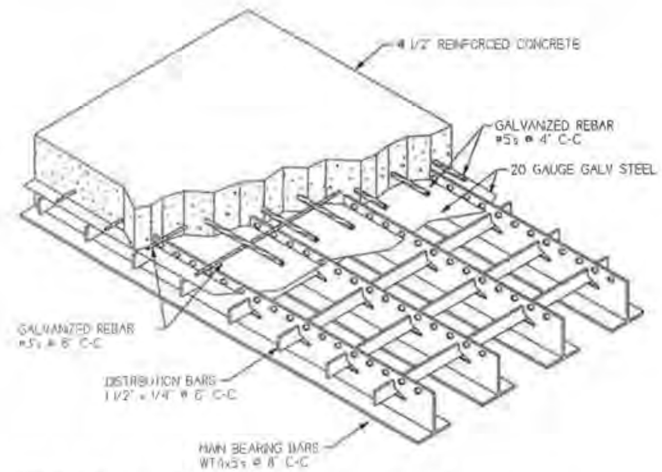

FIGURE 16 New (1998) exodermic deck panel.

Observing the punching shear P-Δ curves for the AL-79 bridge will provide insight on the expected service load, first slip load, and failure load versus deflection behavior, which in turn will be helpful when the results of punching shear proof load testing are analyzed. Additionally, punching shear load testing of some longitudinal deck crack repair and deck patching schemes will be performed to assess their performances. It should be noted that the current punching shear deck repair procedure usually results in fairly early new cracking at each longitudinal end of the repair, and later spalling or punching shear failures at these locations. Lastly, punching shear proof load tests on I-65 and I-59/20 bridges will be conducted at select locations to assess adequacy of the deck capacity via proof loading to three to four times the anticipated maximum truck wheel load.

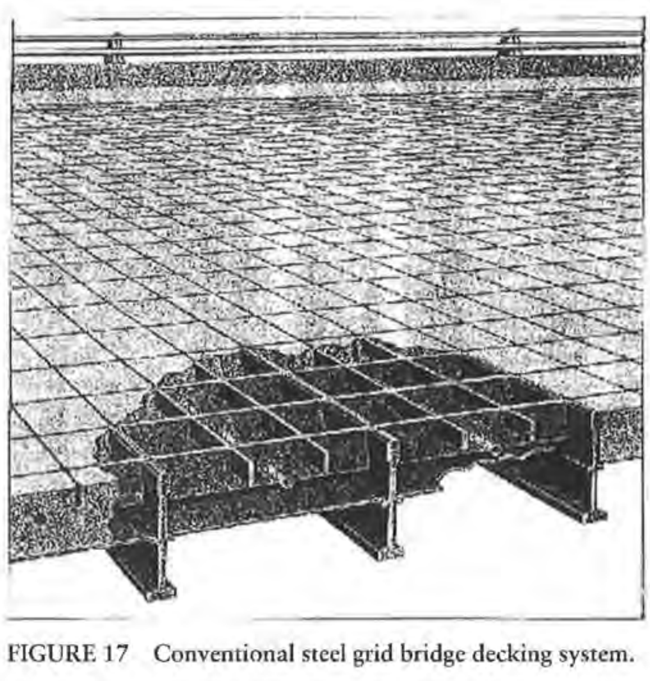

FIGURE 17 Conventional steel grid bridge decking system.

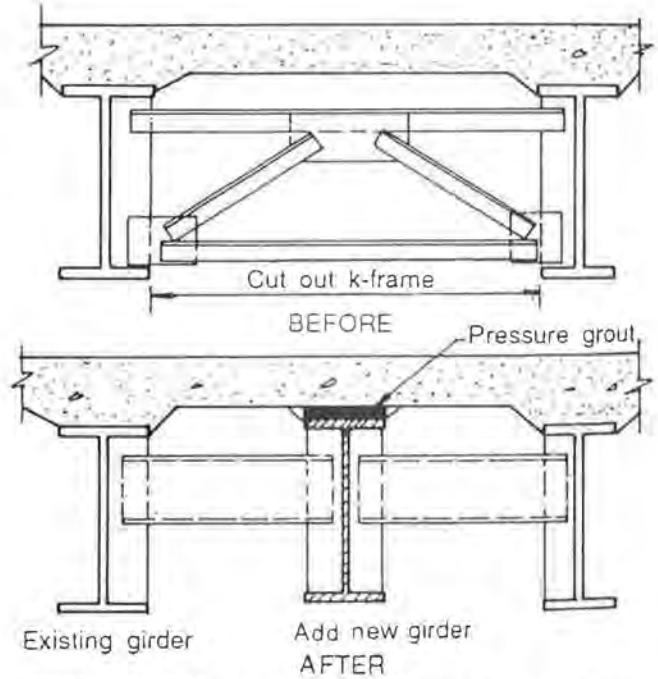

FIGURE 18 Adding girders. (From *Concrete Bridges*, by V.K. Raina.)

In addition to the I-20/59 and I-65 bridges through Birmingham showing considerable deck cracking and deterioration, these same steel girder bridges have experienced significant fatigue cracking, especially at cross-framing and diaphragms. Thus, an evaluation of the remaining life of the steel girders on the Birmingham Interstate highway bridges is needed before a good decision about how to handle the bridge decks can be made.

Mike Stallings of Auburn University is working with ALDOT to evaluate the remaining life of the steel girders of the Birmingham Interstate bridges. A brief outline summary of Stallings' work is as follows:

1. Determine the common bridge types, span lengths, and types and locations of fatigue-prone details such as coverplate ends, transverse stiffener welds, and diaphragms. This information will be determined from the structural drawings and field inspections, and it will be used to identify locations where strain measurements are needed and to provide information for fatigue life calculations.
2. Determine past traffic histories for the roadway and bridges from ALDOT records to estimate how much of the total fatigue life has already been used.
3. Estimate traffic-induced stress ranges at the fatigue-prone locations for calculating remaining fatigue life. These will be estimated first by analytical analysis and later by field measurement, because accurate estimates of

the stress ranges are critical to successfully predicting remaining fatigue life.

4. Field strain gauging and strain measurements will be made at all fatigue-prone locations in four to six typical bridge spans. These data will be reduced and analyzed.

5. Results from the current literature will be used to determine best estimates of the fatigue resistance of the various types of fatigue-prone details found on the Birmingham bridges. Fatigue-resistance relationships given in *NCHRP Report 299* (*1*) appear to be the best currently available.

6. Project future traffic volumes for the Birmingham roadways and bridges. Remaining fatigue-life calculations provide a number of fatigue cycles or truck crossings until failure. Thus, projected future traffic volumes are needed to convert the remaining fatigue cycles into numbers of remaining years of service life.

7. Calculate the remaining fatigue life for each of the fatigue-prone locations for which field strain measurements were made. The number of years until failure predicted at a significant fraction of these locations will be considered the best estimate of remaining fatigue life.

Closure

The Phase 1 and Phase 2 work described, in conjunction with the work on support-girder remaining fatigue and service life, will provide ALDOT with the information needed to make informed and good decisions on the best ways to rehabilitate the Birmingham Interstate bridge decks. That is, Should ALDOT overlay the decks? with what type of overlay? Should ALDOT replace the decks? in what manner? Or should ALDOT replace the whole bridge superstructure?

Acknowledgments

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Reference

1. Moses, F., C. G. Schilling, and K. S. Raju. *NCHRP Report 299: Fatigue Evaluation Procedures for Steel Bridges*. TRB, National Research Council, Washington, D.C., 1987.