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United States General Accounting Office

GAO

Report to the Honorable
Bill Schuette, House of Representatives

March 1988

BRIDGE SAFETY

Structural Soundness of the Zilwaukee Bridge



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Detroit Regional Office**Room 865
Patrick V. McNamara Federal
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477 Michigan Avenue
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March 29, 1988

The Honorable Bill Schuette
House of Representatives

Dear Mr. Schuette:

This report responds to your request of April 9, 1987, regarding construction problems encountered on the Zilwaukee Bridge, a large concrete bridge on Interstate 75 near Saginaw, Michigan. This report summarizes the information we presented to you and your staff during briefings on August 5, November 24, and December 22, 1987.

As agreed with you, the specific objectives of our review were to

- review the testing program implemented by the Michigan Department of Transportation (MDOT) to confirm that the Zilwaukee Bridge was structurally sound;
- identify the construction problems causing concerns about the bridge and determine whether these problems affected its ability to perform as designed; and
- review MDOT's draft Zilwaukee Bridge maintenance manual.

Also as agreed with you, to provide technical advice and expertise, we convened an independent panel of professional engineers experienced in the design, construction, and materials of concrete bridges. This panel assessed the adequacy of our work to identify construction problems and determine their significance; evaluated the adequacy of MDOT's bridge testing program and draft bridge maintenance manual; and provided written comments on this report. A detailed discussion of our objectives, scope, and methodology is presented in appendix I.

In brief, our review and the independent panel's evaluation showed that:

- The results of MDOT's comprehensive testing program indicated that the Zilwaukee Bridge was structurally sound and that concrete strength and durability met or exceeded design requirements.

- Construction problems, such as concrete spalling¹ and cracking, did not affect the bridge's ability to perform as designed.
- MDOT's draft bridge maintenance manual was generally well prepared and, when revised to include the panel's recommendations, will provide for adequate maintenance in the future.

Background

The Zilwaukee Bridge is a 1.5-mile-long segmental concrete box girder bridge, built of 1,592 reinforced concrete segments held together by high-strength steel tendons (cables) under tension. (See fig. 1.) Construction of the bridge began in October 1979 and is scheduled to be completed by the summer of 1988. It will replace an outdated four-lane drawbridge over the Saginaw River, reducing highway traffic congestion and removing an obstacle to ship navigation on the river. MDOT currently estimates that the total cost of the bridge will be about \$135 million, more than \$52 million over the initial cost estimated for its construction. The federal government is paying for 90 percent of the cost of constructing the Zilwaukee Bridge through the Department of Transportation's Federal Highway Administration (FHWA).

On August 28, 1982, a construction accident caused a 300-foot section of the bridge balanced on top of a pier² to sag 5 feet on one end and rise 3.5 feet at the other. The accident occurred because too much weight was allowed on one side of the pier while a heavy concrete segment was being added to the structure.

After the accident, we reviewed the decision to build the Zilwaukee Bridge, the circumstances that led to the accident, and the actions taken to repair the bridge. We reported our findings and conclusions in two reports, issued in 1983 and 1984.³ Repairs on the damaged section of the bridge were completed in 1984, and construction resumed under a new contractor in 1985.

Since 1985, a number of concerns have been raised about the Zilwaukee Bridge's strength and durability. An independent engineering report

¹A type of cracking where the concrete breaks or chips away in circular fragments or slabs.

²The vertical supports for bridge spans.

³Early Decisions and Delays on the Zilwaukee, Michigan, Bridge Project (GAO/RCED-83-165, Aug. 17, 1983), and Delays and Increased Cost Result From the Zilwaukee, Michigan, Bridge Project Mishap (GAO/RCED-84-144, June 27, 1984).

Figure 1: The Zilwaukee Bridge



prepared for the Detroit News in 1985 raised questions about the adequacy of the repairs made after the 1982 accident. Other concerns were raised because of construction problems encountered during the project.

These problems included concrete spalling and cracking. Another independent engineering report prepared for the Detroit News in 1987 suggested that the spalling on the bridge resulted from uneven pressure along the joints between concrete bridge segments and low-strength concrete, and could indicate structural weakness.

In addition, an independent engineering report prepared in 1987 for a Michigan Senate committee investigating the bridge suggested that concrete cracking on the bridge was a sign of low-strength, deteriorating concrete and raised questions about the bridge's long-term durability. Other problems causing concern were the incomplete bonding of the concrete overlay to the bridge deck and differences between the bridge's actual and design profiles (the shape of the bridge viewed from the side).

Zilwaukee Bridge Testing Program

In response to these concerns and to gather baseline information for possible future testing, MDOT developed and implemented a testing program for the Zilwaukee Bridge to confirm that it was structurally sound. This program included load tests⁴ of selected spans of the bridge and laboratory tests on concrete samples taken from the structure. The load tests were conducted to assess the actual performance of the bridge as compared to predictions about its performance based on design calculations. The laboratory tests were conducted to determine whether the concrete samples met design requirements for strength and durability.

MDOT's Materials and Technology Division conducted the load tests during late summer of 1987. According to MDOT's final report on the testing program, the test results showed that the tested bridge spans performed as designed during the load tests. Both deflections (the downward bending of a span under a load) and stresses (the intensity of forces or pressure in a span) were less at the mid-points of the tested spans than predicted using design calculations. In addition, laboratory tests on concrete samples taken from the bridge showed that the concrete strength and durability exceeded design requirements.

MDOT retained Construction Technology Laboratories, Inc. (CTL), an independent engineering laboratory, to review the testing program, witness the load tests, and evaluate the test results and MDOT's conclusions. CTL reviewed the test results and the report on the testing program and

⁴Load tests measure the actual response of the bridge to a heavy load and compare the results with the theoretical response based on design calculations.

agreed with MDOT's conclusions that the bridge performed as designed during the tests and that the concrete samples exceeded design requirements for strength. In addition, CTL stated that the testing program was one of the most comprehensive it had ever been involved with on this type of bridge in North America.

We observed the load tests to ensure that MDOT conducted them in accordance with the announced testing program. Moreover, as a separate check on the validity of MDOT's testing program, we discussed it with federal and state (California, Oregon, and Washington) highway officials and engineers as well as with officials from national organizations responsible for setting standards and specifications for concrete bridges.

According to these experts, MDOT's testing program was comprehensive and would provide a greater level of assurance about the bridge's performance than normally obtained in the construction of new bridges in the United States. The load tests would demonstrate whether the bridge was constructed and performing as designed, and the laboratory tests on concrete samples would show whether the concrete used in the bridge met design requirements.

The independent panel also evaluated MDOT's testing program and concluded that it was properly designed and conducted. In addition, the panel reviewed the test results and the final report on the testing program and concluded that they indicated that the Zilwaukee Bridge had performed as designed during the load tests and that the concrete in the bridge exceeded design requirements for strength and durability. (For further discussion of the testing program, see app. II.)

Review of Construction Problems

Based on our review of engineering test results and other evidence cited by engineering experts, together with our own analysis of construction problems, we concluded that the problems encountered on the Zilwaukee Bridge did not affect its ability to perform as designed. For example, we found that:

- Repairs made after the 1982 construction accident fully restored the damaged areas of the bridge.
- Concrete spalling was not caused by uneven pressure along the segment joints or low-strength concrete and was not an indication of structural weakness (most spalling was caused by freezing water trapped in the bridge).

- Most concrete cracking occurred as the segments cured and was not an indication of structural problems or the result of low-strength concrete.
- Some areas of the concrete overlay were not bonded to the bridge deck, but MDOT took corrective action to ensure proper bonding.
- Minor differences between the bridge's actual and design profiles are common on large bridges and do not affect its strength.

The independent panel reviewed these findings and agreed with our assessments. (See app. III for further discussion of our review of these construction problems.)

Zilwaukee Bridge Maintenance Manual

To comply with FHWA requirements, MDOT prepared a draft maintenance manual for the Zilwaukee Bridge. This manual outlines the frequency and scope of periodic bridge inspections; special maintenance precautions; procedures for dealing with accidents and other potential traffic-related mishaps on the bridge; and record-keeping requirements. MDOT plans to complete the manual by March 1988.

The FHWA Michigan Division Bridge Engineer reviewed and tentatively approved the draft manual. However, in his written evaluation, this official had some specific suggestions for improving it (see app. IV).

We compared MDOT's draft manual with similar manuals written by several other states and found that it was generally comparable with these manuals, both in the level of detail included and the nature and frequency of inspections.

The independent panel also reviewed the draft maintenance manual. It concluded that the manual was generally well prepared and, if followed, was adequate to keep the bridge properly maintained in the future. However, the panel recommended several changes to the manual and the overall bridge maintenance program that would improve MDOT's ability to monitor the bridge and ensure that it will remain functional over the many years of anticipated service. These recommendations included

- surveying the bridge's actual profile and repeating the survey at periodic intervals to monitor changes in the shape of the bridge over time (a means of assessing the condition of the steel tendons that hold the bridge together);
- monitoring for corrosion in the bridge on an annual basis (another means of assessing the condition of the steel tendons that hold the bridge together); and

- performing dynamic testing⁵ of the bridge to provide a baseline in possible future testing.

We brought the panel's recommendations to the attention of senior MDOT officials and they agreed to revise the draft maintenance manual and implement the panel's recommendations. These officials noted that MDOT was already in the process of surveying the bridge's actual profile to provide a baseline for monitoring changes in the shape of the bridge over time. (See app. IV for further discussion of the draft bridge maintenance manual.)

Independent Panel's Report

The independent panel's report is presented in appendix V, and the professional background of each panel member is in appendix VI. In addition, the panel provided written comments on this report that were incorporated where appropriate.

Agency Comments

We also requested comments on a draft of this report from the U.S. Department of Transportation and MDOT. The Department of Transportation concurred with our findings and stated that the report supports FHWA's position that MDOT has taken a prudent course of action to ensure that the Zilwaukee Bridge is safe and durable. The Department's comments are presented in appendix VII.

MDOT officials also concurred with our findings and stated that they would implement the recommendations made by the independent panel. MDOT's comments are presented in appendix VIII.

As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 10 days from the date of this letter. At that time we will send copies of this report to interested parties and make copies available to others on request.

⁵Dynamic testing records the bridge's vibration patterns. Changes in these patterns over time can be analyzed to assess the bridge's condition in the event there are future concerns about its strength or durability.

Major contributors to this report are listed in appendix IX.

Sincerely yours,

A handwritten signature in cursive script that reads "Walter C. Herrmann Jr".

Walter C. Herrmann, Jr.
Regional Manager

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Abbreviations

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| CTL | Construction Technology Laboratories, Inc. |
| FHWA | Federal Highway Administration |
| GAO | U.S. General Accounting Office |
| HNTB | Howard Needles Tammen and Bergendoff |
| MDOT | Michigan Department of Transportation |
| psi | pounds per square inch |
| RCED | Resources, Community, and Economic Development Division |

Introduction

The Zilwaukee Bridge is a precast segmental concrete box girder bridge located on Interstate 75 near Saginaw, Michigan. It is built of 1,592 high-strength, reinforced concrete segments held together by high-strength steel tendons (cables) under tension. It is about 1.5 miles long and about 142 feet high at its mid-point. The bridge is actually two separate four-lane bridges, one for northbound and one for southbound traffic. The northbound bridge has 25 spans, and the southbound bridge has 26 spans. Span lengths vary from 130 feet to 392 feet. Each span consists of varying numbers of precast concrete segments. The Zilwaukee Bridge will replace an outdated four-lane drawbridge over the Saginaw River, reducing highway traffic congestion and removing an obstacle to ship navigation. (See fig. 1.)

Construction of the bridge began in 1979 and was scheduled to be completed by 1983. However, the near collapse of a 300-foot section of the northbound bridge during construction on August 28, 1982, delayed the bridge's completion for several years. The section, which was balanced on top of a pier, sagged 5 feet on one end and rose 3.5 feet at the other. In addition, the pier's footing cracked. The accident occurred because too much weight was placed on one side of the pier while a heavy concrete segment was being added to the structure.

The Michigan Department of Transportation (MDOT) developed repair procedures for the areas of the northbound bridge involved in the 1982 construction accident in conjunction with its engineering consultant, Howard Needles Tammen and Bergendoff (HNTB). The repairs included constructing a new pier footing to replace the one damaged during the accident. This new footing was constructed in place around the existing footing. Once the pier footing was repaired, the 300-foot section of the bridge was rotated back into proper position. The repairs were completed in March 1984 at a cost of about \$7.8 million. Construction resumed in 1985 under a new contractor, S.J. Groves & Sons of Minneapolis, Minnesota.

Currently, the Zilwaukee Bridge's completion is over 4 years behind schedule. MDOT opened the northbound bridge to highway traffic on December 23, 1987. The contractor erected the last segment of the southbound bridge in late September 1987. The remaining work on the southbound bridge includes pouring concrete barrier rails and the concrete overlay that protects the bridge deck, as well as grading and paving the approaches to the bridge. The southbound bridge is scheduled to open by the summer of 1988. MDOT currently estimates that the total cost of the bridge will be about \$135 million, more than \$52 million over the

initial cost estimated for its construction. The federal government is paying for 90 percent of the cost of constructing the Zilwaukee Bridge through the Department of Transportation's Federal Highway Administration (FHWA).

Concerns About Construction Problems

Throughout its life, the Zilwaukee Bridge has generated considerable public controversy. During its planning and design, there was substantial controversy about the need for such a large bridge to replace a 593-foot drawbridge and the selection of concrete over steel construction. Public criticism increased after the August 1982 construction accident. After the accident, at the request of U.S. Senator Donald W. Riegle, Jr., we reviewed the actions taken by FHWA and MDOT that resulted in the decision to build the Zilwaukee Bridge, the circumstances that led to the accident, and the actions taken to repair the bridge. We reported our findings and conclusions in two reports, issued in 1983 and 1984 (GAO/RCED-83-165 and GAO/RCED-84-144).

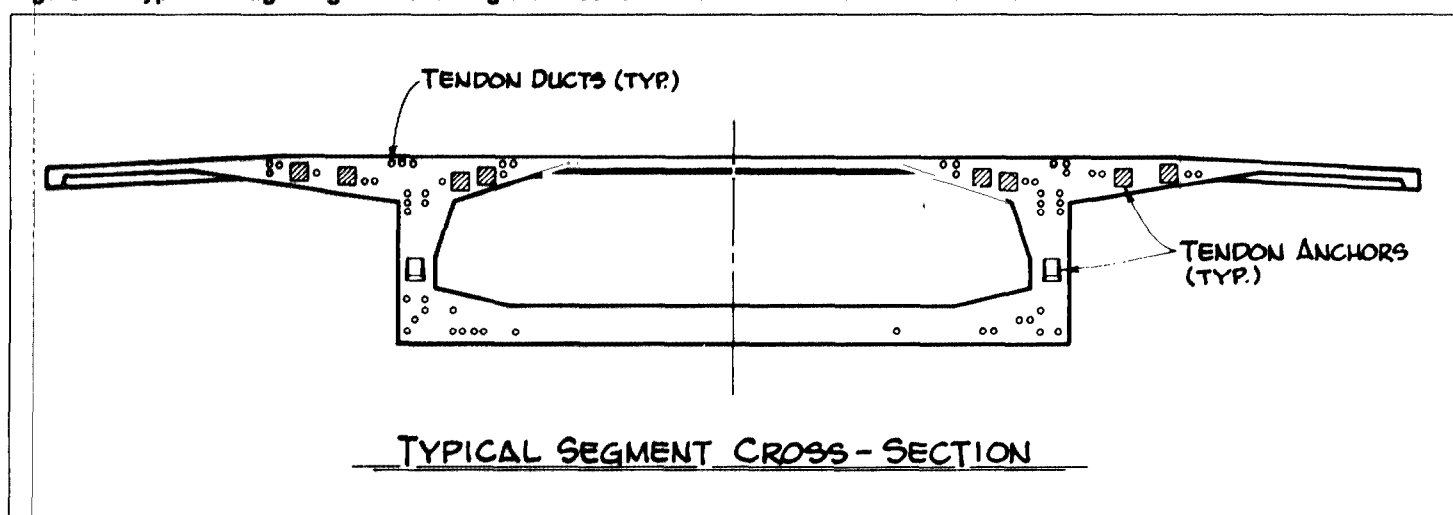
Public controversy surrounding the Zilwaukee Bridge continued after the 1982 accident repairs were completed. An independent engineering report prepared for the Detroit News in 1985 raised questions about the adequacy of the repairs made after the accident. Public controversy increased after some parts of the bridge were damaged by concrete spalling during the winters of 1985-86 and 1986-87. Another independent engineering report prepared for the Detroit News in 1987 suggested that the spalling was caused by point loading (uneven pressure along the joints between the concrete bridge segments) and low-strength concrete, and could indicate structural weakness.

The increasing public controversy surrounding the Zilwaukee Bridge as a result of these construction problems led the Michigan Senate Committee on State Affairs, Tourism, and Transportation to hold hearings and conduct its own investigation of the bridge. An independent engineering report prepared for this committee in 1987 raised further concerns about concrete cracking and apparent concrete deterioration and questioned the Zilwaukee Bridge's long-term durability. Other problems causing concerns were the incomplete bonding of the concrete overlay to the bridge deck on the northbound bridge and differences between the bridge's actual and design profiles (the shape of the bridge viewed from the side).

Throughout the controversy, MDOT held the position that the concerns about the bridge's strength and durability were either unfounded or

based on incorrect information. MDOT stated that the repairs made after the 1982 accident restored the damaged section of the bridge. MDOT also stated that most spalling on the Zilwaukee Bridge was caused by freezing water trapped in tendon ducts¹ and anchor recesses² in the bridge, and that this type of spalling was not an indication of structural weakness as suggested by the 1987 report prepared for the Detroit News.

Figure I.1: Typical Bridge Segment Showing the Location of Tendon Ducts and Anchor Recesses



In addition, MDOT stated that its quality control procedures were adequate to ensure that the concrete used in the bridge met design requirements for strength and durability. With regard to the other construction problems causing concerns, MDOT either took corrective action or maintained that they had no impact on the bridge's strength or durability.

However, despite MDOT's assurances that the Zilwaukee Bridge was safe, the public controversy about it continued unabated. Finally, in response to the concerns about its strength and durability, MDOT developed and implemented a testing program to confirm that the Zilwaukee Bridge was structurally sound. The program included load tests of selected spans of the bridge and laboratory tests on concrete samples taken from the structure.

¹Galvanized steel tubes placed in the concrete segments to provide a pathway for the tendons that hold the bridge together and help protect them from corrosion.

²Recesses in the segment joint where the tendons that hold the bridge together are anchored.

Objectives, Scope, and Methodology

In view of the concerns raised about its construction, Congressman Bill Schuette requested that we conduct an independent review of the Zilwaukee Bridge. As agreed with the Congressman, the specific objectives of our review were to

- review the testing program implemented by MDOT to confirm that the Zilwaukee Bridge was structurally sound;
- identify the construction problems causing concerns about the bridge and determine whether these problems affected its ability to perform as designed; and
- review the draft Zilwaukee Bridge maintenance manual.

To provide technical advice and expertise, we convened an independent panel of professional engineers experienced in the design, construction, and materials of segmental concrete box girder bridges. (See app. VI.) This panel assessed the adequacy of our work to identify and determine the significance of construction problems; evaluated the adequacy and results of MDOT's bridge testing program; and evaluated the adequacy of the draft bridge maintenance manual. In addition, the panel provided written comments on this report. These comments have been incorporated into our report where appropriate.

We discussed construction problems and possible ways to determine their significance, as well as bridge maintenance, with the various officials and engineers at

- FHWA headquarters in Washington, D.C., FHWA Regional Offices in Chicago, Illinois, and FHWA Division Offices in Lansing, Michigan;
- MDOT headquarters in Lansing, Michigan, MDOT District Offices in Saginaw, Michigan, and the Zilwaukee Bridge construction site;
- MDOT's engineering consultant, HNTB, in Kansas City, Missouri, and at the Zilwaukee Bridge construction site;
- the current contractor, S.J. Groves & Sons, in Minneapolis, Minnesota; and
- the current contractor's engineering consultant, T.Y. Lin International, in San Francisco, California.

We reviewed the independent engineering reports prepared for the Detroit News in 1985 and 1987, as well as the report prepared for the Michigan Senate Committee on State Affairs, Tourism, and Transportation in 1987. In addition, we discussed these reports and other issues related to our review with their authors in West Palm Beach, Florida, and Sanford, Michigan.

We also attended the Michigan Senate Committee on State Affairs, Tourism, and Transportation hearings on the Zilwaukee Bridge in Lansing and Romulus, Michigan, and reviewed the committee's preliminary report.

We reviewed FHWA's answers to questions about the strength and durability of the Zilwaukee Bridge contained in Congressman Schuette's April 22, 1987, letter to the FHWA Administrator.

We reviewed MDOT's construction records and notes and evaluated its quality control procedures for materials used to construct the bridge and cast and erect segments. We also reviewed MDOT's bridge testing program and its draft bridge maintenance manual and compared them to those used by other states.

To help confirm or refute possible explanations for the spalling that occurred on the Zilwaukee Bridge, we mapped the location and timing of all concrete spalling on drawings of the entire bridge. We also performed statistical analyses of the relationships between spalling and construction variables such as concrete strength, segment casting dates, and segment erection dates. In addition, to assess the relationship between spalling and tendon duct and anchor recess locations, we mapped a random sample of spalls on individual segment drawings.

We interviewed state highway officials and engineers from California, Oregon, and Washington because of their considerable experience in designing, constructing, and maintaining segmental concrete box girder bridges. We also visited several segmental concrete box girder bridges in these states, including the Interstate 205 Bridge in Portland, Oregon, which is similar in design and construction to the Zilwaukee Bridge. In addition, we interviewed FHWA Division Bridge Engineers in California, Oregon, and Washington who were familiar with this type of bridge.

Finally, we interviewed officials from various national organizations responsible for developing standards and specifications for designing, constructing, and maintaining segmental concrete box girder bridges, including the Post-Tensioning Institute and the Prestressed Concrete Institute, which are recognized authorities about these bridges.

This review was performed between May 1987 and February 1988 in accordance with generally accepted government auditing standards.

Zilwaukee Bridge Testing Program

In response to questions about its strength and durability, MDOT developed and implemented a testing program to confirm that the Zilwaukee Bridge was properly constructed and structurally sound. In addition, the testing program would gather baseline information for possible future testing. The testing program consisted of load tests of selected spans of the bridge and laboratory tests on concrete samples taken from the bridge. The load tests were conducted to assess the actual performance of the bridge as compared with predictions about its performance based on design calculations. The laboratory tests on concrete samples were conducted to determine the chemical and physical properties of the concrete and provide insights into the strength and durability of the segments used to construct the bridge.

MDOT's Materials and Technology Division conducted the load testing during late summer 1987. According to MDOT's final report on the testing program (dated November 1987), the test results showed that the performance of the tested bridge spans was equal or superior to predicted performance based on design calculations. Both deflections (the downward bending of a span under a load) and stresses (the intensity of forces or pressure in a span) were less at the mid-points of the tested spans than predicted using design calculations. In addition, the laboratory tests on concrete samples taken from the bridge showed that the concrete strength and durability exceeded design requirements.

MDOT retained Construction Technology Laboratories, Inc. (CTL), an independent engineering laboratory experienced in the testing and evaluation of concrete bridges, to review the testing program, witness the load tests, and evaluate the test results and MDOT's conclusions. CTL reviewed the test results and the report on the testing program and agreed with MDOT's conclusions that the bridge performed as designed during the load tests and that the concrete samples exceeded design requirements for strength. In addition, CTL stated that the testing program was one of the most comprehensive programs it had ever been involved with on this type of bridge in North America.

We observed the load tests to ensure that MDOT conducted them in accordance with the announced testing program. Moreover, as a separate check on the validity of MDOT's testing program, we discussed it with federal and state (California, Oregon, and Washington) highway officials and engineers as well as with officials from national organizations responsible for setting standards and specifications for concrete bridges.

According to these experts, MDOT's testing program was comprehensive and would provide a greater level of assurance about the bridge's performance than normally obtained in the construction of new bridges in the United States. The load tests would demonstrate whether the bridge was constructed and performing as designed, and the laboratory tests on concrete samples would show whether the concrete used in the bridge met design requirements. They advised us that new bridges are not normally load-tested and that the industry's accepted method for determining concrete strength and durability is to test samples taken from the concrete as it is poured rather than to test samples taken from a completed structure.

The independent panel reviewed the bridge testing program and concluded that it was properly designed and conducted. In its opinion, the program was comprehensive and provided adequate assurance as to the adequacy of the design, strength, and durability of the bridge. In addition, the panel reviewed the test results and the final report on the testing program and concluded that they indicated that the bridge had performed as designed during the load tests and that the concrete in the bridge exceeded design requirements for strength and durability. The panel stated that the test results demonstrated that the Zilwaukee Bridge's performance exceeded the requirements of the American Association of State Highway and Transportation Officials' Standard Specifications for Highway Bridges.

Load Tests

The Zilwaukee Bridge has 51 spans, 25 on the northbound bridge and 26 on the southbound bridge. Five of these spans were load-tested, four from the northbound bridge and one from the southbound bridge. The spans were selected to represent spans constructed by both contractors, spans damaged by spalling, and undamaged spans. In addition, the span involved in the 1982 construction accident was selected. Three spans were constructed by the first contractor; two spans were constructed by the second contractor. Two of the spans constructed by the first contractor contained expansion joints.¹ One of these spans was involved in the August 1982 construction accident; the other was not.

MDOT's Materials and Technology Division conducted the load tests during late summer 1987. The same test load was used on each span. The test load consisted of a specialized truck and trailer, normally used to

¹ An expansion joint is a mechanical coupling designed to allow the bridge to move horizontally to compensate for the expansion and contraction of the concrete because of temperature changes.

haul concrete segments to the bridge for erection, carrying a bridge segment. Combined, the truck, trailer, and concrete segment weighed about 258 tons. This is about three times the maximum legal weight limit for a single vehicle in Michigan.

The load tests measured the deflections (downward bending) and stresses (the intensity of force or pressure) in selected spans of the bridge under the test load. The deflections were compared with predicted deflections for those spans computed using design calculations. The stresses in those spans were calculated by measuring the strains (the amount of shortening or stretching) and multiplying the test results by a property of concrete known as the modulus of elasticity.² This property was determined from concrete samples taken from the tested spans. These stresses were compared with predicted stresses.

Deflections were measured by surveying the elevations of reference points on top of the segments in the test spans with and without the test load placed at the mid-point of each span. MDOT determined the amount of deflection in the span by calculating the difference between the surveyed elevations. The measurements were taken with precision surveying instruments accurate to one-thousandth of a foot.

Strains were measured using strain gauges as the test load traveled slowly along a test span. A minimum of seven strain gauges, accurate to one-millionth of an inch per inch, were placed in the test spans at segments adjacent to the piers and at mid-span. These gauges were glued to the concrete on the bridge deck and inside the segments on the ceiling and floor. They were connected to an electronic amplifier and recorder.

MDOT's engineering consultant, HNTB, calculated the predicted deflections and stresses using a structural analysis computer model of the bridge based on design calculations. These predictions were calculated before the load tests took place to avoid any appearance of manipulation of the test results.

The deflections measured during the load tests were less than the deflections predicted using design calculations. Table II.1 shows the span length and the measured and predicted deflections at the mid-point of each test span.

²The ratio of stress in an object to the corresponding strain.

Table II.1: Measured and Predicted Deflections

| Length of span tested (feet) | Measured deflection (inches) | Predicted deflection (inches) |
|-------------------------------------|-------------------------------------|--------------------------------------|
| 325 | 2.0 | 2.6 |
| 377 | 1.8 | 2.5 |
| 368 | 1.9 | 2.2 |
| 326 | 2.0 | 2.6 |
| 329 | 1.8 | 2.6 |

The stresses in the concrete segments during load tests were less at the mid-point of the tested spans than predicted using design calculations. The stresses were reasonably close to the predicted stresses at locations adjacent to the piers.

Laboratory Tests

MDOT conducted laboratory tests on concrete samples taken from the Zilwaukee Bridge. Some of the laboratory tests were conducted as part of the load tests. However, others were conducted in response to specific concerns raised about the strength and durability of the concrete near spalls and cracks.

As part of the load-testing program, MDOT took concrete samples from segments where strain gauges were placed during the testing. These samples were analyzed to determine their compressive strength³ and modulus of elasticity.

MDOT determined the compressive strength of the concrete samples using American Society for Testing and Materials procedures. Design specifications require that concrete used in the Zilwaukee Bridge have a minimum compressive strength of 5,500 or 6,000 pounds per square inch (psi), depending on where the segment is placed in the bridge. Average compressive strength for the samples taken from the load-tested spans was 7,800 psi.

MDOT determined the modulus of elasticity of the concrete samples using American Association of State Highway and Transportation Officials and American Society for Testing and Materials procedures. The design modulus of elasticity was 4.7 million psi. The average measured modulus

³The maximum compressive force, gradually applied, that a given material will bear before fracturing.

of elasticity for the concrete samples taken from the bridge was 4.9 million psi. As indicated in the prior section, MDOT used this value to convert the strains measured during the load test into stresses.

MDOT also took concrete samples from the bridge and tested them to address questions about concrete strength and durability raised by the independent engineering report prepared for the Michigan Senate Committee on State Affairs, Tourism, and Transportation in 1987. This report suggested that spalled and cracked areas of the bridge deck could be evidence of concrete deterioration and lack of durability. In response, MDOT took concrete samples from the southbound bridge near some spalled and cracked areas and tested them for compressive strength, air content,⁴ and water soluble chloride ion content,⁵ which are generally accepted indicators of concrete strength and durability.

According to MDOT, test results indicate that the concrete strength and durability around these spalled and cracked areas of the bridge exceeded design requirements and industry standards. We confirmed MDOT's conclusion by comparing the test results with the appropriate design requirements and industry standards. Average compressive strength of the samples was 6,824 psi, exceeding the design requirements for compressive strength (5,500 or 6,000 psi). Average air content was 6.24 percent, within both design requirements (5.5 percent plus or minus 1.5 percent) and American Concrete Institute standards (5 percent plus or minus 1.5 percent). Average water soluble chloride ion content was less than 0.02 percent by weight of cement, which is below the Institute's standard for water soluble chloride ion content in bridges of this type—0.06 percent by weight of cement.

⁴The amount of air in the concrete, an important indicator of concrete's ability to resist the effects of weather.

⁵The amount of water soluble chloride ions (the corrosive element in salt) in the concrete, an accepted indicator of concrete's potential for corrosion.

Review of Construction Problems

In recent years, a number of concerns have been raised about the Zilwaukee Bridge's overall strength and durability. Initially, some concerns were raised about the adequacy of repairs made after the 1982 construction accident. Later, other concerns were raised about construction problems encountered during the project. These construction problems included concrete spalling; concrete cracking; incomplete bonding of the concrete overlay to the bridge deck; and differences between the bridge's actual and design profiles. This appendix presents our assessment of these problems and concerns.

1982 Accident Repairs

An independent engineering report prepared for the Detroit News in 1985 raised some concerns about whether the repairs made after the 1982 construction accident fully restored the strength and durability of the damaged section of the northbound bridge. These concerns focused on whether the bridge had sustained serious structural damage during the accident or the subsequent repairs. The key concern expressed in the report was whether the tendons that hold the bridge together had been damaged either when the 300-foot section of the bridge sagged 5 feet on one end and rose 3.5 feet on the other, or when this section of the bridge was rotated back into position.

In addition, others raised concerns about the possibility that some of the tendons may have started corroding because the tendon ducts in the damaged section of the bridge were not sealed with grout for over 3 years, until the repairs had been completed. Damage from corrosion could weaken the tendons and reduce the northbound bridge's service life.

An HNTB analysis of accident stresses concluded that no structural damage occurred during the accident, while the northbound bridge sat idle, or during repairs. This analysis was confirmed during the load tests. (See app. II.) Test results showed that the span involved in the accident performed the same as a similar span not involved in the accident. In addition, the contractor removed and replaced those tendons subject to the greatest stresses during the accident and the subsequent repairs. Construction records showed that MDOT tested these tendons and found that they had not been damaged and were not corroded. Nevertheless, these tendons were not reused in the bridge.

Concrete Spalling

Some spans of the Zilwaukee Bridge were damaged by concrete spalling during the winters of 1985-86 and 1986-87. This damage caused considerable public controversy and debate over the bridge's strength and durability. An independent engineering report prepared for the Detroit News in 1987 suggested that the concrete spalling might be the result of point loading (uneven pressure along the joints between the concrete bridge segments) or low-strength concrete, and could indicate structural weakness. However, MDOT, HNTB, the contractor, the contractor's engineering consultant, and FHWA maintained that the spalling was caused by freezing water trapped in tendon ducts and anchor recesses in the bridge and did not affect the bridge's strength or durability. (See fig. I.1.)

As discussed below, we found no evidence to support the suggestion that the spalling was the result of point loading or low-strength concrete. However, the evidence does strongly support the position that the spalling was caused by freezing water trapped in tendon ducts and anchor recesses.

The independent engineering report prepared for the Detroit News in 1987 suggested that the point loading was caused by poor match casting¹ of the concrete segments used to construct the bridge. Under this scenario, the spalling would have occurred because the mismatched segment faces could not evenly distribute the high pressures created by the tendons holding the bridge together, causing the "high spots" to spall and crack. The report also suggested that low-strength concrete contributed to the spalling that occurred on the Zilwaukee Bridge. Under this scenario, concrete in the segments spalled and cracked because it was too weak to withstand the high pressures created by the tendons holding the bridge together.

FHWA engineers responsible for observing and monitoring the bridge's construction reported that the match casting quality of the concrete segments was good. In addition, other engineers not associated with the project who had observed the bridge's construction also advised us that the match casting was good. According to MDOT officials, the segments were closely examined for quality after they were cast. We noted that a number of segments were rejected as a result of these inspections and later destroyed because they did not meet MDOT's specifications.

¹Match casting is a process in which each succeeding segment is cast against the previous segment, ensuring that the adjoining segment faces are perfectly matched to each other.

Moreover, as discussed in appendix II and later in this appendix, laboratory tests showed that the concrete used in the bridge met or exceeded design requirements for strength. In addition, to determine whether segments with lower concrete strength spalled more frequently than those with higher strength, we analyzed the relationship between spalling and concrete strength. We found no relationship between spalling and the concrete strength of a segment.

Federal and state highway officials and engineers as well as other experts advised us that, if point loading or low-strength concrete were the cause, the spalling would have taken place during or soon after the segments were erected. It would not have occurred after that time because the pressures in the segments decrease rapidly over the first few months after they are tensioned together, leveling off at about 80 percent of the original force. However, the timing of the spalling did not coincide with what would be expected if it had been caused by point loading or low-strength concrete. We found that most of the spalling occurred during the winters of 1985-86 and 1986-87, months after most of the segments were erected.

The fact that most of the spalling occurred during winter months does support the position that water became trapped in tendon ducts and anchor recesses and froze, building up pressure (water expands in volume as it freezes) that caused the concrete around these locations to spall. These ducts and anchor recesses were supposed to be sealed with grout within 30 days after the construction of a span was completed.² However, because grout cannot be used during cold weather, tendon ducts and anchor recesses in spans of the northbound bridge were not sealed on time when the contractor elected to continue construction into the winter of 1985-86. Similarly, tendon ducts and anchor recesses in partly completed spans of the southbound bridge could not be sealed with grout when the contractor ceased construction during the winter of 1986-87. According to MDOT, the tendon ducts and anchor recesses in the unsealed spans of the bridge were not properly protected, and water trapped in these spaces froze and expanded, causing the surrounding concrete to spall.

We found that most spalling was located in spans of the bridge that were not sealed with grout during winter months when the weather was cold

²Grout is a mixture of cement and water, used to fill the empty space between the tendon and duct to prevent water and moisture from accumulating and to develop a bond between the tendon and the surrounding segment.

enough to freeze any water trapped in tendon ducts and anchor recesses. In addition, we found that most of the spalling was located around unsealed tendon ducts and anchor recesses where water was most likely to become trapped. In fact, MDOT inspectors' reports noted that water was present in the anchor recesses in some cases when repair crews removed the loose concrete in the spalled areas prior to making repairs. Often the anchor recesses were clearly visible near the center of the spalls once the loose concrete was removed.

In addition, we observed tendon ducts that had ruptured in spalls on the bridge deck away from the segment joints. The damage to these tendon ducts was consistent with the argument that the spalling was caused by freezing water. Moreover, the fact that these spalls were not located at segment joints was further evidence that the damage was not caused by point loading or low-strength concrete.

Other segmental concrete box girder bridges, such as the Interstate 205 Columbia River Bridge near Portland, Oregon, have experienced various degrees of spalling caused by freezing water trapped in the bridge. Moreover, during the construction of the Islington Avenue Bridge in Toronto, Ontario, spalling was only narrowly averted when inspectors found water trapped in tendon anchor recesses (the water was drained from the bridge before it could freeze).

Although undesirable, spalling does not threaten the Zilwaukee Bridge's strength or, if properly repaired, durability. According to federal and state highway officials and engineers, spalling does not result in structural damage and therefore does not affect the bridge's ability to perform as designed. In addition, an HNTB engineering analysis of the spalling damage showed that its effect on the bridge's strength was insignificant. These experts also told us that the spalling should not threaten the Zilwaukee Bridge's durability if properly repaired. FHWA and HNTB engineers examined MDOT's repair procedure and concluded that the spalls were being properly repaired.

In addition to the spalling discussed in the independent engineering report prepared for the Detroit News in 1987, we observed some minor concrete spalling near the alignment keys (male and female guides that help align the segments) located on the segment wings (overhang). This spalling was the result of the temporary misalignment of some segments as they were positioned and drawn together during erection. According to federal and state highway engineers, this type of spalling is common on segmental concrete box girder bridges with large, heavy segments,

such as the Zilwaukee and Columbia River Bridges, and does not weaken the structure.

After observing some spalls firsthand and reviewing our analysis and other information, the independent panel reached similar conclusions about the causes of concrete spalling on the Zilwaukee Bridge and its effect on the bridge's strength and durability. It concluded that most of the reported and observed spalling was caused by freezing water trapped in the bridge and some by temporary misalignment of segments during erection. The panel did not observe any spalling caused by poor match casting or low-strength concrete. Finally, it concluded that the spalling did not affect the bridge's strength and that MDOT's current repair procedures are adequate to ensure a normal service life for the bridge.

Concrete Cracking

The 1987 independent engineering reports prepared for the Detroit News and the Michigan Senate Committee investigating the Zilwaukee Bridge noted that concrete bridge segments were cracking and suggested that this could indicate concrete deterioration. These reports raised concerns about the strength and durability of the segments used to construct the bridge. In addition, they raised concerns about the potential for corrosion of the bridge's steel tendons and reinforcing steel³ if moisture, salt, or other corrosives were able to seep into the bridge through these cracks.

In our 1983 report on the Zilwaukee Bridge, we also noted that there was some concrete cracking on the bridge. However, we further noted that most of these cracks occurred as the concrete cured, and were narrow and closed as the segments were tensioned. We were advised by federal and state highway officials and engineers as well as other experts that some cracking was expected in any concrete structure.

To protect the bridge's reinforcing steel and steel tendons from corrosion, MDOT has implemented a repair program for the cracks in the concrete on the bridge. To reduce the potential for moisture or salt intrusion, MDOT specifications require that cracks wider than 0.004 inches be injected with epoxy. MDOT's 0.004-inch standard is much more stringent than the industry's recommended practice of injecting cracks

³Steel bars placed in the concrete to add strength.

wider than 0.007 inches. Federal and state highway officials and engineers advised us that this program should adequately protect the bridge's reinforcing steel and steel tendons.

To further address continuing concerns about the strength and durability of concrete used in the bridge's construction, we (1) talked to bridge engineers who monitored concrete quality and reviewed their reports; (2) reviewed the standards used by MDOT to assess the quality of materials and concrete; (3) reviewed reports of the tests made on materials and concrete during the bridge's construction; and (4) reviewed the laboratory tests conducted on concrete samples taken from the structure.

In discussing the quality of the segments used in the Zilwaukee Bridge's construction, FHWA bridge engineers responsible for monitoring its construction reported that the strength and durability of the concrete in these segments was good. They also noted that the quality of the Zilwaukee Bridge segment casting plant was above average in comparison to typical casting plants for large bridge projects of this type.

In the area of standards, we found that MDOT had a comprehensive quality control program in place to ensure that the materials and concrete used to construct the Zilwaukee Bridge met industry and design specifications. The standards applied were those established by the American Association of State Highway and Transportation Officials and the American Society for Testing and Materials, supplemented by standards established in MDOT's Standard Specifications for Construction and the Zilwaukee Bridge construction specifications.

To determine how these standards were applied, we reviewed the quality control procedures MDOT used to test the materials used to construct the bridge. These procedures called for testing all materials used to construct the bridge. The materials tested included the sand, stone, cement, cement additives, and water used to make the concrete in the segments, as well as the concrete itself. The tested materials also included reinforcing steel, steel tendons, tendon ducts, tendon anchors, the epoxy used to join and seal the segments together, and the latex emulsion used to modify the concrete used to overlay the bridge deck.

MDOT maintains records for each of these tests. Our selective review of these records showed that they support MDOT's contention that no substandard (poor-quality or low-strength) materials or concrete were used in the bridge's construction. Our analysis of the test results for concrete compressive strength for all 1,592 precast bridge segments showed that

the average strength exceeded the 6,000 psi design requirement by 18 percent. In addition, our analysis of the minimum and average concrete compressive strength using American Concrete Institute recommended practices showed that the concrete in the bridge was strong enough to meet the Zilwaukee Bridge's design requirements. Further, as discussed in appendix II, laboratory tests conducted on concrete samples taken from the completed structure showed that concrete strength and durability met or exceeded design requirements.

The independent panel also concluded that segment quality and strength were adequate. Specifically, the panel concluded that most concrete cracking occurred as the concrete cured. Moreover, the panel also concluded that the quality of segments used to construct the bridge was average or above average. The panel did not observe any evidence of low-strength concrete or concrete deterioration. The panel concluded that the concrete used in the bridge met design requirements for strength and durability.

During its visit to the bridge, the panel observed a limited number of small cracks near some tendon anchors that probably were the result of tensile stresses induced by the tendons that hold the bridge together. According to the panel and other experts, this type of crack is expected and even predictable on concrete box girder bridges. The panel concluded that MDOT can protect the bridge adequately by monitoring the cracks over time as part of its maintenance program and injecting epoxy into those that pose a potential corrosion problem.

Concrete Overlay

The Zilwaukee Bridge deck is covered with a latex-modified concrete overlay.⁴ The overlay extends the bridge's service life by sealing the bridge deck with a dense layer of concrete, protecting its reinforcing steel and steel tendons from corrosives. The overlay also provides a smooth, seamless, and durable road surface.

Two concerns were raised about the overlay. First, because the overlay was applied more thickly on some parts of the bridge than specified by the bridge design specifications, some concerns were raised about whether the resulting extra weight could affect the bridge's strength. Second, concerns were raised that some areas of the overlay were not

⁴Concrete made dense and impenetrable to salt and other environmental contaminants by adding a latex emulsion.

bonded to the bridge deck, which could allow water and corrosives to reach the bridge's reinforcing steel and steel tendons.

We found that the overlay was applied more thickly on some parts of the bridge than the 1.5 inches specified in the design to even out small irregularities in the underlying bridge deck and provide a smoother road surface. The northbound bridge overlay's average thickness was about 1.8 inches. When completed, the southbound bridge overlay's average thickness will be about 2 inches.

According to design specifications, the Zilwaukee Bridge was designed to support an additional 3 inches of overlay on top of the initial 1.5 inches. This would allow MDOT to apply an additional overlay when the initial overlay becomes worn. However, since MDOT officials have decided not to apply an additional overlay—deciding instead to remove and replace the initial overlay when it becomes worn—the increased thickness of the existing overlay should have no effect on the bridge's strength.

With regard to overlay bonding, some areas of the overlay were not bonded to the bridge deck. This problem was confined to one part of the northbound bridge where the overlay was applied by the first contractor.

FHWA and MDOT engineers determined that the bonding problem was caused by inadequate preparation of the bridge deck before the overlay was applied. For the overlay to bond properly, the bridge deck must be free of oil and other contaminants that accumulate during construction. Prior to applying the overlay to some parts of the northbound bridge, the first contractor sandblasted the bridge deck to remove oil and other contaminants. This procedure was not completely effective, and the remaining oil and other contaminants prevented proper bonding between the overlay and the bridge deck in some areas.

The second contractor used a different procedure, called scarifying, to prepare the bridge deck before applying the overlay. Scarifying involves cutting or scraping away the top quarter inch of the deck surface, ensuring that oil and other contaminants are removed. This procedure was used to repair the incompletely bonded areas on the parts of the northbound bridge where the overlay was applied by the first contractor.

MDOT officials are confident the bonding problem will not recur because the current contractor is scarifying the deck before applying the overlay. Even so, they plan to have the overlay on the southbound bridge

inspected when it is completed to ensure that it is completely bonded to the bridge deck. If warranted, the current contractor will repair any improperly bonded areas. Federal and state highway officials and engineers advised us that scarifying is a common and effective method for preparing concrete bridge decks before applying an overlay. The independent panel examined this problem and concluded that scarifying the bridge deck before applying the overlay should eliminate bonding problems.

While investigating the bonding problem, the independent panel observed some "plastic cracking"—a type of cracking that extends down only about one-quarter to one-half inch below the surface of the overlay (and not through to the underlying bridge deck). Plastic cracking results when the top surface of the overlay shrinks more than the remainder of the overlay, causing a pattern of hairline cracks. The panel concluded that the plastic cracking should not significantly reduce the overlay's ability to protect the underlying bridge deck from water and corrosives.

Bridge Profile

Some concerns have been raised about the Zilwaukee Bridge's strength and durability because the bridge's actual profile (the shape of the bridge viewed from the side) differs in some places from its design profile. These differences, visible as waves or "dips" in the bridge's profile when sighting along the side of the bridge, raised concerns that sections of the bridge were settling or sagging.

Our review of MDOT construction records and design drawings, together with survey measurements of the existing structure, showed that the bridge's actual profile differed from design by a maximum of about 8 inches at the piers and about 8.5 inches near the mid-point of some spans.

Federal and state highway officials and engineers as well as other experts consider such differences between the actual and design profiles to be minor and advised us that such differences are common on bridges this large and would not affect the bridge's strength or durability. These experts pointed out that these minor differences make it important that MDOT survey the entire Zilwaukee Bridge after it is completed so that MDOT will have accurate elevations of the actual structure to use as a baseline for assessing any future changes in the shape of the bridge. MDOT officials advised us that they were in the process of surveying the bridge to provide a baseline for such monitoring.

Zilwaukee Bridge Maintenance Manual

FHWA recognizes that some types of bridges require special attention during inspection and maintenance because of their size or unusual design. Accordingly, since 1984 FHWA has required states to prepare a special maintenance manual for major or unusual bridges. These are bridges that have an unsupported length greater than 500 feet or an unusual or innovative design. This definition includes segmental concrete box girder bridges such as the Zilwaukee Bridge.

To comply with this FHWA requirement, MDOT prepared a draft maintenance manual outlining its plans for inspecting and maintaining the Zilwaukee Bridge. This draft manual was written by the MDOT Segmental Bridge Maintenance Committee, which was established after the 1982 construction accident. The committee consists of engineers from MDOT's Design, Construction, Materials and Technology, and Maintenance Divisions who are familiar with the Zilwaukee Bridge. MDOT plans to complete the manual by March 1988.

The draft manual outlines the frequency and scope of bridge inspections; special maintenance precautions; procedures for dealing with traffic-related accidents on the bridge; and record-keeping requirements. Bridge inspections and maintenance will be performed by specially trained MDOT teams. In addition, the manual provides for inspections at least every 2 years by an engineering consulting firm experienced with precast segmental concrete box girder bridges.

The draft manual recognizes that any unusual movement or cracking of the bridge would be a special maintenance concern because it might signal a serious structural problem. As discussed in our 1984 report, the key to the strength and safety of segmental concrete bridges is the steel tendons that hold them together. However, since these tendons are sealed in their ducts with grout, they cannot be inspected during the life of the bridge. Federal and state highway officials and engineers and other experts advised us that the condition of the tendons can be assessed by monitoring any unusual movement (sagging) or cracking of the bridge. According to these experts, if the tendons were damaged, the bridge would exhibit these visible signs of distress years before there was any real danger to the public.

Accordingly, the manual emphasizes the need to monitor closely any unusual movement or cracking. It requires that MDOT establish a standard method to record the location and size of cracks. This would allow MDOT maintenance personnel to monitor the progress of these cracks over time. The manual also outlines "typical" cracking that should be

expected on the bridge and requires MDOT maintenance personnel to alert MDOT design engineers to any unexpected cracking or other evidence of unusual movement of the bridge.

The draft manual also recognizes that to ensure the durability of segmental concrete bridges, the steel tendons that hold them together must be protected. Bridge experts have found that corrosion of these tendons occurs when chlorides and other corrosive materials, such as those contained in de-icing salt, migrate through the concrete and attack them. The draft manual addresses this problem by requiring that

- noncorrosive de-icers are used on the bridge and for some distance before it;
- concrete cracks larger than 0.004 inches are sealed by injecting them with epoxy; and
- cracks in the latex-modified concrete overlay are treated with a sealer.

The FHWA Michigan Division Bridge Engineer reviewed and tentatively approved the draft bridge maintenance manual. However, in his written evaluation of the manual, the Division Bridge Engineer did have some suggestions for improving it. These suggestions included adding specific procedures to be followed to inspect or repair the bridge and adding the results of the bridge testing program conducted in 1987. (See app. II.)

We compared the draft maintenance manual with similar manuals written by two other states and found that it was generally comparable with these manuals, both in the level of detail included and the nature and frequency of inspections.

The independent panel also reviewed the draft maintenance manual. It concluded that the draft manual was generally well prepared and, if followed, is adequate to keep the bridge properly maintained in the future. The panel also concluded that the draft manual was more comprehensive than would normally be expected for a bridge of this size and type. However, the panel recommended several changes to the draft manual and the overall bridge maintenance program to improve MDOT's ability to monitor the bridge and ensure that it will remain functional over the many years of anticipated service. These recommendations included

- surveying the bridge's actual profile and repeating the survey at periodic intervals to monitor changes in the shape of the bridge over time (to assess the condition of the steel tendons that hold the bridge together);

- monitoring for corrosion of the bridge's steel tendons and reinforcing steel on an annual basis; and
- performing dynamic testing of the bridge to provide a baseline in possible future testing.

The panel also recommended that MDOT reassess the objectives and results of the maintenance program at regular intervals. (A more detailed discussion of these and other recommendations made by the independent panel is contained in its report in app. V.)

We brought the panel's recommendations to the attention of senior MDOT officials and they agreed to revise the draft maintenance manual and implement the panel's recommendations. These officials noted that MDOT was already in the process of surveying the bridge's actual profile to provide a baseline for monitoring changes in the bridge's shape over time.

The Independent Panel's Report

January 11, 1988

**REPORT OF THE INDEPENDENT PANEL
ON THE SAFETY
OF THE
ZILWAUKEE BRIDGE**

INTRODUCTION. In September 1987, the U.S. General Accounting Office (GAO) assembled a panel of engineers experienced in the design, materials, and construction of prestressed concrete segmental bridges to aid in its review of the Zilwaukee Bridge, located on Interstate 75 near Saginaw, Michigan. The purpose of the Panel was to (1) assess the adequacy of GAO's work to isolate key safety issues concerning the bridge; (2) evaluate the adequacy of the Michigan Department of Transportation's (MDOT's) load testing program for the structure; (3) evaluate the adequacy of MDOT's proposed bridge inspection and maintenance program; and (4) provide comments on GAO's draft report on the bridge.

The Panel met in Michigan on September 22-25, 1987, to visit the Zilwaukee Bridge and observe the structure and the construction methods firsthand; review the information collected by GAO; discuss the bridge's design and construction with MDOT officials; review documents related to the bridge's construction; and formulate preliminary opinions. The Panel met again on December 10, 1987, in San Diego, California, to finalize its opinions and finish drafting this report.

The opinions expressed in this report are based upon the information obtained during the site visit as well as information received subsequently. The Panel will provide comments on GAO's draft report at a later date.

BASIS OF THE PANEL'S REPORT. The Panel considered numerous items specifically related to the Zilwaukee Bridge in reaching its findings and making the recommendations contained in this report. Following is a list of the more important documents, interviews, and discussions the Panel considered in reaching the opinions contained in this report:

1. GAO Report RCED-83-165, entitled Early Decisions And Delays On The Zilwaukee, Michigan, Bridge Project, dated August 17, 1983.

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2. GAO Report RCED-84-144, entitled Delays And Increased Cost Result From The Zilwaukee, Michigan, Bridge Project Mishap, dated June 27, 1984.
3. MDOT publication entitled The Zilwaukee Bridge: From The Beginning, May 11, 1987.
4. Report entitled Zilwaukee Bridge, prepared by Dr. Lev Zetlin, Consulting Engineer, Zetlin-Argo Structural Investigations, Inc., West Palm Beach, Florida, dated January 29, 1987.
5. Article from the Detroit News, entitled "Engineer Warns Of Bridge Flaws," dated May 7, 1987.
6. Statement of James P. Pitz, MDOT Director, in response to the report prepared by Dr. Lev Zetlin (undated).
7. Report entitled HNTB Review Of Lev Zetlin's Zilwaukee Bridge Report, dated March, 1987.
8. Report entitled The Zilwaukee Bridge: Some Pertinent Facts, Observations, and Recommendations, prepared by Gale L. Emig, P.E., of Anatek, Inc., dated May 1, 1987.
9. Proposal copy of the Agreement And Appendices between MDOT and Construction Technology Laboratories, Inc. (CTL) for testing and inspection services (undated).
10. Draft of the MDOT Maintenance Manual For The Zilwaukee Bridge, Saginaw County, Michigan, prepared by the MDOT Bridge Maintenance Team, dated August 14, 1987.
11. Observations of the members of the panel made at the bridge site on September 22-24, 1987.
12. Discussions with officials from MDOT, Howard, Needles, Tammen and Bergendoff, the Federal Highway Administration, CTL, and GAO during the period of September 23-25, 1987.
13. Detailed information about the spalls, cracks, materials used in the construction, and construction methods employed in the first and second contracts, as assembled by GAO.
14. Portions of the contract documents.
15. Drawings, sketches, photographs, and narrative prepared by GAO and assembled in two workpaper bundles, identified as E-1, Spalling Analysis, and H-1, Engineering Reports.
16. MDOT draft and final reports on the load testing of the Zilwaukee Bridge, dated October 1987 and November 1987, respectively.

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17. CTL comments on the MDOT draft report on the load test of the structure, dated November 6, 1987.
18. MDOT report on tests made on concrete core samples taken from the structure in September 1987.

LIMITATIONS OF THE REVIEW. The Panel did not comprehensively review the Zilwaukee Bridge's structural design calculations nor the contract documents for construction. The Panel also did not inspect in depth every concrete spall and crack reported to exist or to have been repaired in the structure. Tests to determine the physical properties of the materials used in construction were not performed by or for the Panel. The Panel reviewed the general methods used in construction but did not examine them in detail.

DISCUSSION OF SPECIFIC ITEMS OF CONCERN. GAO called the Panel's attention to certain concerns expressed in recent years about the Zilwaukee Bridge's construction. GAO asked the Panel to review these concerns and express its opinion about their cause and seriousness. The Panel's opinions are presented in the following paragraphs.

Concrete Spalling. Spalling of several types at various locations was observed and can be categorized into the following types:

1. Deck overhang alignment keys.
2. Longitudinal tendon anchorage pockets in deck-web fillets at segment joints.
3. Longitudinal tendon anchorage pockets in webs at segment joints.
4. Top and bottom slab delamination.
5. Others.

The spalling was caused, in the most part, by water freezing in some post-tensioning ducts and anchorage pockets. Other spalling was caused by misalignment of some segments as they were positioned and drawn together during erection. The great majority of the spalling would not have occurred if proper precautions had been taken to guard against water freezing in the bridge. The Panel did not observe any spalling that was the result of deficiencies in the concrete used in the bridge.

Concrete Cracks. Several types of cracks were observed in the segments and can be categorized as follows:

1. Longitudinal cracks near joints connecting top slabs and webs.
2. Longitudinal cracks at other locations.
3. Transverse cracks.
4. Others.

The majority of the cracks were caused by temperature changes and concrete shrinkage during the curing of the concrete rather than applied loads. Some of the cracks were caused by tensile stresses resulting from the post-tensioning forces. The cracks observed were not unusual and not important from the standpoint of structural strength. MDOT's policy of injecting cracks wider than 0.004 inches should render the cracks completely unimportant from a structural point of view.

Durability of Segment Concrete. The durability of the concrete in the segments is of utmost importance with respect to the useful life of the bridge. The Panel observed no evidence of deterioration of the concrete that can be associated with a concrete having low durability. The entrained air content test results reported by MDOT lead to the conclusion that the concrete should be expected to be resistant to deterioration due to the effects of freeze-thaw. The chloride ion content test results reported by MDOT, together with the maturity of the concrete in the bridge at the time it will be put into service, lead to the conclusion that the concrete should be durable with respect to chloride-related deterioration.

Corrosion of Reinforcement. Corrosion of the prestressed and non-prestressed permanent reinforcement is of great importance in the evaluation of the safety and useful life of a concrete bridge. No evidence of detrimental corrosion in the permanent prestressing tendons is known to exist. Corrosion in an amount that would be unacceptable in the completed structure was observed in the temporary prestressing tendons used to lock the expansion joints during construction. However, these temporary tendons have been removed. There is no evidence any unacceptable amount of corrosion exists on any of the permanent reinforcing steel in the bridge. Recommendations for monitoring corrosion of the reinforcement in the structure are included in this report.

Concrete Overlay. Concern has been expressed about cracking in the latex-modified concrete overlay as well as with its bonding to the bridge deck. The cracking in the overlay is of the type known as plastic cracking--a type of cracking that normally extends downward only a fraction of an inch below the surface and not

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through the entire depth of the overlay. Although undesirable, plastic cracking should not significantly affect the ability of the overlay to prevent the intrusion of chloride ions and water into the bridge deck below. Current procedures for preparing the bridge deck before applying the overlay (scarifying rather than sandblasting) should eliminate future bonding problems. Areas of the existing overlay not bonded to the deck surface are to be removed and replaced.

Maintenance Manual. The Panel reviewed the draft maintenance manual prepared by MDOT and found it to be generally well-prepared. Some suggestions for revision are contained in the recommendations included in this report.

FINDINGS. The Panel has reached the following unanimous conclusions:

1. The load testing of the completed structure, conducted by MDOT and reviewed by CTL, demonstrated that the Zilwaukee Bridge's structural performance exceeded the requirements of the Standard Specifications for Highways Bridges, prepared by the American Association of State Highway and Transportation Officials (AASHTO).
2. Based on site observations, plus MDOT quality control procedures and test results assembled and reported by GAO, the materials incorporated in the structure meet the performance requirements of the structure.
3. The spalling, cracking, etc., observed on the Zilwaukee Bridge are physical damage of types that do not affect its structural strength. Procedures employed to repair this damage are adequate to assure a normal service life for the structure.
4. No evidence of concrete deterioration on the structure was observed nor found in the information assembled by GAO.
5. No evidence of damage that could be attributed to corrosion of reinforcement, such as concrete splitting or spalling, was observed or found in the information assembled by GAO. There is no evidence nor reason to believe corrosion will be a problem in the future.
6. The procedures included in the draft of the Maintenance Manual prepared by MDOT are more comprehensive than would normally be expected for a bridge of this type and size.
7. The Panel's review of the information assembled by GAO, together with the observations made at the site, led to the conclusion that the bridge is safe as constructed.

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RECOMMENDATIONS. The Panel offers the following recommendations in the interest of assisting MDOT in monitoring the bridge and helping to guarantee that it will remain functional for the many years of service anticipated.

Geometric Changes. Changes in geometry of all prestressed concrete bridges must be anticipated and provided for in the design. Some geometric changes are due to the various loadings and forces imposed on the bridge, including live load, dead load, and prestress forces. Other changes in geometry result from creep and shrinkage of the concrete, relaxation of the prestressed steel, and thermal effects.

Distress in a bridge of this type may manifest itself through unanticipated changes in geometry. Excessive loss of prestress or settlement of a support, for example, could be noticeable as a change in the geometric configuration of the structure. Therefore, any unusual or unanticipated changes in the geometry of the bridge should be examined by a qualified engineer. To establish a reference for monitoring the behavior of the bridge with the passage of time, the Panel recommends that MDOT make the following initial measurements as soon as possible after all dead load is in place:

1. Expansion joint openings.
2. Position of moveable bearings.
3. Elevations at midpoint of each span.
4. Elevations on each side of each expansion joint.
5. Elevations at each pier and at each abutment.

The elevations should be measured over the webs and in each gutter at each location. Elevations, bearing movements and joint openings should be measured with an accuracy of 0.005 feet. Permanent reference points should be established such that they will not be disturbed or affected by traffic.

Differences in concrete temperature or the thermal gradient through the depth of the superstructure will affect deck elevations and the position of the bearings and joint openings. Measurements should be timed to minimize the thermal effects. The Panel recommends that the initial measurements be taken on several different days so the effect of temperature can be assessed and to provide information for comparing subsequent measurements with the initial measurements. Continuous monitoring of weather conditions for several days prior to making the measurements is necessary.

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The Panel also recommends that MDOT perform geometric monitoring in conjunction with the routine inspections of the structure. The frequency may be reduced to every two to four years if unanticipated changes in geometry are not detected in the first year or two and if visual observations do not indicate other unanticipated behavior.

The most significant objectives in monitoring the geometry are the detection of changes in dimension and deflection as well as how the changes at one location compare with those at another. With this in mind, MDOT can make adjustments in measurements to account for temperature effects to eliminate the need for identical thermal conditions at the time of each of the measurements.

Corrosion of Reinforcement. Corrosion of reinforcement in the bridge deck is a major concern when considering the long-term structural adequacy of this type of bridge. MDOT's provisions for a latex-modified concrete overlay and the use of Calcium Magnesium Acetate (CMA) as a deicer rather than salt (which contains chloride) will greatly reduce the amount of chloride available to penetrate into the bridge deck concrete. Additional chloride will, however, fall on the deck from the undercarriage of vehicles crossing the bridge.

In order to take timely corrective action, should the level of free chloride ions reach the threshold for corrosion, the Panel recommends monitoring the bridge for corrosion activity on a regular basis. A valid method of measuring the presence of corrosion activity is to determine voltage potentials using a half-cell as described in ASTM C-876. Testing points should be established in several spans of both the northbound and southbound bridges. We recommend that MDOT take readings at the following locations:

1. For the northbound bridge, the span adjacent to abutment AN and in a span at the top of the vertical curve.
2. For the southbound bridge, the span adjacent to Abutment BS and in a span at the top of the vertical curve.
3. For each span place test points in the right and left shoulder area at the quarter points of the span, for a total of four test points per span.
4. At each test point establish an electrical connection to a transverse prestressing duct and a reinforcing bar.

Locations chosen will provide readings in areas where a vehicle first reaches the bridge and where salts are most apt to remain on the deck surface. Benchmark readings should be taken as soon as possible, preferably before traffic is on the bridge. They should be followed by a series of annual readings.

Appendix V
The Independent Panel's Report

Maintenance Program. The key to assuring a durable structure is a program of regularly scheduled inspections of critical bridge elements. MDOT's Maintenance Manual for the Zilwaukee Bridge provides the basis for this process. To assure the program is accomplishing its intended purpose, MDOT should make periodic evaluations of the program as well as the people responsible for its execution.

MDOT should make periodic random checks in the following areas of the inspection program and staffing:

1. Observe salting crews to confirm that they are using CMA on the bridge deck and that they are not applying roadway salt beyond the appropriate cut-off points.
2. Review maintenance crew staffing for changes and provide additional training as needed.
3. Check deck wearing surface for timely application of overlay sealer.
4. Observe bridge crews during overlay patching to assure they conform to proper procedures and materials requirements.
5. Review the total maintenance program every five years to assure its objectives are met. Re-evaluate the maintenance program to determine whether it is accomplishing its objectives or should be revised.

In addition, the Panel recommends the following revisions to the Maintenance Manual:

1. Section I. GENERAL. As this is the definitive guide for maintenance of the Zilwaukee Bridge, change all references to activities with the use of "should" to "will" or "shall."
2. Section II. INSPECTION. If serious deficiencies do exist in the bridge, they will manifest themselves early in its service life. The Panel therefore recommends the first inspection be done six months after the bridge is opened to traffic, followed by a second inspection six months later. Subsequent inspection frequency would then conform to the procedures set out in the Manual.
3. Section XI. DECK DEICING AND SNOW REMOVAL. Since MDOT intends to use CMA to deice the Zilwaukee Bridge, the primary source of salt on the bridge will be from vehicles traveling across it. To minimize this effect, the Maintenance Manual should be revised to stop salt application one mile before the bridge and apply CMA from that point to just past the end of the bridge for both the northbound and southbound

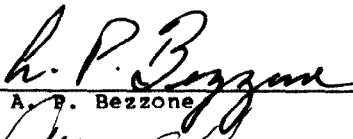

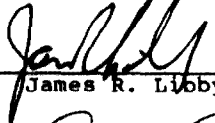
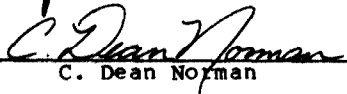
Appendix V
The Independent Panel's Report

roadways. This will allow as much time as practical for salt to drip off the undercarriages of vehicles before they cross the bridge without increasing the use of CMA.

4. Appendix C. This special provision provides for flushing cracks prior to repair with a mild solution of muriatic (hydrochloric) acid. A major emphasis of the Manual is minimizing the entrance of chloride ions into the structure. The Panel has serious doubts that all acid can be removed after flushing and for the value of an acid flush. As it is not possible to determine where the acid may eventually penetrate into the structure, the Panel recommends that MDOT eliminate acid flushing from the crack repair procedure in the Manual.

Dynamic Tests. The Panel recommends that MDOT consider conducting dynamic/vibration tests on selected spans of the Zilwaukee Bridge to determine as-built natural frequencies, mode shapes, and damping ratios. These test results would provide a benchmark to compare with future test results to determine and evaluate any changes in the bridge's structural response characteristics with time. Measured values of the test parameters could be compared with predicted values from a suitable dynamic structural analysis procedure to assure the validity of the measurements obtained during the initial tests. This analysis could also be used to assess the structure's as-built performance further.

This report, which is the only report of this Panel, is the unanimous opinion of the Panel.

| | |
|--|----------------------------|
|  A. P. Bezzone | <u>2/2/88</u> Date |
|  Allan C. Harwood | <u>8 Feb 1988</u> Date |
|  James R. Lloby | <u>4 Feb. 1988</u> Date |
|  C. Dean Norman | <u>11 Jan 88</u> Date |

Professional Background of the Independent Panel Members

Albert Bezzone

Mr. Bezzone, currently Chief of Structure Construction for the California Department of Transportation, has been assigned to increasingly more responsible positions in the design, construction, and maintenance of highway bridges since joining the Department in 1953.

While progressing from Project Engineer; Bridge Design Engineer; Deputy Chief Engineer, Maintenance, State-owned Toll Bridges; Executive Assistant to the Chief Engineer, California Department of Transportation; to his present position, Mr. Bezzone was responsible for activities such as

- designing the first cast-in-place segmental concrete box girder bridge built in the United States using the balanced cantilever method of construction;
- initiating and directing the investigation of suspected problems in a 50-year-old toll bridge and directing the resulting rehabilitation and strengthening;
- developing policy and applications for prestressed concrete bridge design;
- managing the maintenance program for all state-owned toll bridges; and
- managing the California Department of Transportation's \$300 million annual bridge construction program.

In 1970, Mr. Bezzone was sent to Europe to study the design and construction of segmental concrete box girder bridges constructed by the balanced cantilever method (the same method employed on the Zilwaukee Bridge). He visited bridge design offices and construction sites in France, Germany, Austria, and Italy.

Mr. Bezzone is a registered Professional Engineer and has authored many papers and articles about the design, construction, and maintenance of highway bridges and has received a number of national awards for bridge design.

Allan Harwood

Mr. Harwood, currently Region Operations Engineer for the Oregon Department of Transportation, has been involved in highway bridge construction and maintenance continuously for more than 31 years. During that time he has held positions ranging from Structural Inspector, Resident Engineer, and Project Manager on bridge construction projects, as well as State Bridge Construction Engineer and his current position with responsibility for bridge maintenance and construction.

Mr. Harwood was Project Manager for the states of Oregon and Washington on the \$150 million Interstate 205 Columbia River Bridge near Portland, Oregon, which is similar in design and construction to the Zilwaukee Bridge. Other notable projects which Mr. Harwood was involved with include the Willamette River Bridge at West Linn; the Oregon Channel Bridge; the Interstate 5 Bridges across the Columbia River; the Fremont Bridge across the Willamette River at Portland; the Young's Bay Bridge at Astoria; and the Interstate 205 South Channel Bridges.

Mr. Harwood is a registered Professional Structural Engineer. He received a Bachelor of Science in Civil Engineering from Oregon State College in 1954 and has completed graduate work in public administration, engineering, and related subjects.

Mr. Harwood is a member of a number of professional organizations, including the American Society of Civil Engineers, the American Concrete Institute, the Transportation Research Board, and the National Cooperative Highway Research Project and serves on several committees that set policy and standards for bridge design, construction, and maintenance. Mr. Harwood also has authored papers on segmental bridge construction that have been published in various professional journals.

James Libby

Mr. Libby, currently the president, James R. Libby & Associates in San Diego, California, has over 37 years of experience as a civil engineer specializing in structural engineering. He has been active in the design and construction of highway bridges, buildings, and waterfront structures.

Mr. Libby has worked as a civil engineer in dam construction in Oregon; an Instructor in Civil Engineering at Oregon State College; a Structural Engineer in concrete research at the U.S. Navy Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California; and Chief Engineer and West Coast Representative of the Freyssinet Company, Inc. In 1956, Mr. Libby entered private practice in structural engineering in New York City. In 1960, he relocated his practice to San Diego, California.

Mr. Libby is a registered Professional Engineer in 11 states and the District of Columbia. He received a Bachelor of Science in Civil Engineering from Oregon State College in 1949.

**Appendix VI
Professional Background of the Independent
Panel Members**

Mr. Libby is the author of professional reference books on prestressed concrete and bridge design and has written numerous articles published in various technical journals. He has received a number of national awards for his work.

Mr. Libby is a member of a number of professional organizations, including the American Society of Civil Engineers, the American Concrete Institute, the American Society for Testing and Materials, the Prestressed Concrete Institute, and the International Conference of Building Officials and serves on several committees that set policy and standards for bridge design, construction, and maintenance.

C. Dean Norman

Mr. Norman is a Research Civil Engineer in the Research Group of the Concrete Technology Division of the U.S. Army Corps of Engineers' Waterways Experiment Station in Vicksburg, Mississippi. Mr. Norman is responsible for research in the areas of concrete response to three-dimensional stresses, thermal stress analysis of concrete, and concrete cracking and fracturing.

Mr. Norman received a Bachelor and Masters of Science in Civil Engineering from Mississippi State University in 1968 and 1971, respectively. He has also completed additional study at the University of Texas, Austin.

Mr. Norman is an instructor in the Waterways Experiment Station Graduate Institute, teaching courses in the analysis and design of concrete structures and materials.

Mr. Norman is a member of a number of professional organizations, including the American Society of Civil Engineers, the American Concrete Institute, and the Society of American Military Engineers and serves on several committees in these organizations.

Mr. Norman has authored a number of papers on concrete behavior and design.

Comments From the Department of Transportation



U.S. Department of
Transportation

Assistant Secretary
for Administration

400 Seventh St., S.W.
Washington, D.C. 20590

MAR 1 1988

Mr. J. Dexter Peach
Assistant Comptroller General
Resources, Community, and Economic
Development Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Peach:

Enclosed are two copies of the Department of Transportation's comments concerning the U.S. General Accounting Office report entitled, "Bridge Safety: Structural Soundness of the Zilwaukee Bridge."

Thank you for the opportunity to review this report. If you have any questions concerning our reply, please call Bill Wood on 366-5145.

Sincerely,

Meussa J. Allen jr
Jon H. Seymour

Enclosures

DEPARTMENT OF TRANSPORTATION REPLY TO
GAO DRAFT REPORT OF FEBRUARY 8, 1988
ON
BRIDGE SAFETY: STRUCTURAL SOUNDNESS OF THE
ZILWAUKEE BRIDGE (GAO/RCED-88-96)

SUMMARY OF GAO FINDINGS

The GAO found that:

- o Michigan's Department of Transportation's (MDOT) testing program was comprehensive and the test results indicated that the Zilwaukee Bridge was structurally sound and that concrete in it exceeded design specifications for strength and durability;
- o construction problems, such as concrete spalling and cracking did not affect the bridge's ability to perform as designed; and
- o MDOT's draft bridge maintenance manual for the Zilwaukee Bridge was generally well-prepared and when revised to include the recommendations of the GAO's independent panel of professional engineers, will provide for adequate maintenance in the future.

DEPARTMENT OF TRANSPORTATION'S POSITION

The Department concurs in the GAO's findings. The report bears out the Federal Highway Administration's experience with this bridge project in that the State has taken a very prudent course of action to ensure that the Zilwaukee Bridge is safe and durable.

Specific comments on the report are as follows:

1. Appendix II, page 25, last sentence: A more meaningful measure of the corrosive potential of concrete is the amount of water soluble chloride contained in the mix in lieu of the total chloride ion content. The MDOT test report for determination of chloride content, dated October 8, 1987, reports less than 0.1 pounds of chlorides per cubic yard of concrete for the twelve samples taken. The American Concrete Institute Committee 201, Guide to Durable Concrete, suggests that prestressed concrete contain a limit of 0.06 percent chloride ion by weight of cement (see attachment). This translates, for the particular mix used, to 0.4 pounds of chloride per cubic yard of concrete.
2. Appendix III, page 37, first full paragraph, second sentence: The plastic cracking described occurs when the top surface of the overlay shrinks more than the remainder of the overlay.
3. Glossary, page 48: Compressive strength is the maximum compressive stress that a given material will bear before fracturing.

Now on p. 21.

Now on p. 30

Now on p. 51

Comments From the Michigan Department of Transportation

STATE OF MICHIGAN

TRANSPORTATION
COMMISSION
WILLIAM C. MARSHALL
RODGER D. YOUNG
HANNES MEYERS, JR.
STEPHEN F. ADAMINI
SHIRLEY E. ZELLER
WILLIAM J. BECKHAM, JR.
LH 0-0 (4/87)



JAMES J. BLANCHARD, GOVERNOR
DEPARTMENT OF TRANSPORTATION
TRANSPORTATION BUILDING, 425 WEST OTTAWA, PHONE (517) 373-2090
POST OFFICE BOX 30050, LANSING, MICHIGAN 48909

JAMES P. PITZ, DIRECTOR

March 2, 1988

Mr. Walter C. Herrmann, Jr.
Regional Manager
General Accounting Office
477 Michigan Ave., Room 865
Detroit, MI 48226

Dear Mr. Herrmann:

Thank you for the opportunity to review and offer comments on the draft letter report, Bridge Report: Structural Soundness of the Zilwaukee Bridge. It is a thorough and professional examination of the construction project at Zilwaukee.

This project was initiated to replace an outdated drawbridge at the Saginaw River which represented a problem to both highway and river traffic. Since the drawbridge has only two lanes in each direction, while I-75 is three lanes wide, the bridge became a bottleneck during peak traffic periods, causing significant traffic delays. In addition, when the bridge opened to allow ships to pass, traffic would often be backed up for miles. Also, the drawbridge has been struck repeatedly by large ships, once causing serious and costly damage.

Three years after construction began on the new bridge, an accident occurred on the northbound structure. There was no loss of life or personal injury, but construction progress was dealt a major blow while the causes of the accident were examined and repairs were planned and implemented. Many studies of the accident were undertaken; among them was the definitive work done by the U. S. General Accounting Office in a report prepared for Senator Donald W. Riegle, Jr. All of the studies agreed that the August 1982 accident was due to an error in the construction process. There was no problem with the basic design of the structure.

When I became director of MDOT in 1983, I had to decide whether to complete the structure or to stop the project and dismantle the completed portions which would have cost about \$35 million. Had the choice to dismantle the bridge been made, MDOT also would

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Appendix VIII
Comments From the Michigan Department
of Transportation

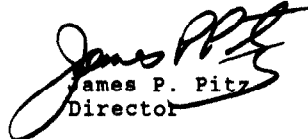
Mr. Walter C. Herrmann, Jr.
Page 2
March 2, 1988

have been required to return more than \$80 million to the U.S. Federal Highway Administration, its 90 percent participation in project costs. A new bridge still would have been required to replace the drawbridge. I made the decision to complete the Zilwaukee Bridge because it was the best decision and the least expensive alternative for the people of Michigan.

There has been concern expressed regarding the final costs of this project. Those costs were directly related to the accident that occurred in 1982. The original contract, including the final settlement, came to \$82,203,682. The repair contract was \$7,768,557. The completion contract for the Zilwaukee Bridge is estimated to be \$45,097,842. As you can see, 66.6 percent of the costs were incurred in the original contract and the repair. With the increased effort and vigilance on the part of all connected with this project, the northbound bridge was completed and opened to traffic in December 1987. The southbound bridge is structurally complete and will be opened to traffic in the second half of 1988.

We have carefully reviewed your report to Representative Schuette and concur with the findings.

Sincerely,



James P. Fitz
Director

Major Contributors to This Report

**Resources,
Community, and
Economic
Development Division,
Washington, D.C.**

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James R. Hunt, Group Director

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Michael D. Rohrback, Site Senior
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Lawrence M. Kubiak, Evaluator
Mark D. Ulanowicz, Evaluator
Kathleen A. Kerchinsky, Evaluator

Glossary

| | |
|--------------------------------|--|
| Air Content | The amount of air in the concrete, an important indicator of its ability to resist the effects of weather. |
| Alignment Keys | Male and female guides cast on the segment face that help align the segments. |
| Chloride Ion Content | The amount of chloride ions (the corrosive element in salt) in the concrete, an accepted indicator of its potential for corrosion. |
| Compressive Strength | The maximum compressive force, gradually applied, that a given material will bear before fracturing. |
| Deflections | The downward bending or sagging of a bridge span under a load. |
| Dynamic Testing | A process that records the bridge's vibration patterns. Changes in these patterns over time can be analyzed to assess the bridge's condition in the event of future concerns about its strength or durability. |
| Expansion Joint | A mechanical coupling designed to allow the bridge to move horizontally to compensate for the expansion and contraction of the concrete because of temperature changes. |
| Grout | A mixture of cement and water, used to fill the empty space between the tendon and duct to prevent water and moisture from accumulating and to develop a bond between the tendon and the surrounding segment. |
| Latex-Modified Concrete | Concrete made dense and impenetrable to salt and other environmental contaminants by adding a latex emulsion. |
| Load Test | A measurement of the actual response of the bridge to a heavy load. The results of the test are compared with the theoretical response based on design calculations. |

Glossary

| | |
|-----------------------|---|
| Match Casting | A process in which each succeeding segment is cast against the previous segment, ensuring that the adjoining segment faces are perfectly matched to each other. |
| Modulus of Elasticity | The ratio of stress in an object to the corresponding strain. |
| Pier | The vertical supports for bridge spans. |
| Plastic Cracking | A type of cracking that extends down to about one-quarter to one-half inch below the surface of the latex-modified concrete overlay. It results when the top surface of the overlay shrinks more than the remainder of the overlay, causing a pattern of hairline cracks. |
| Point Loading | Uneven pressure along the joints between the concrete bridge segments resulting from high points or projections from one or both adjoining segment faces. |
| Profile | The shape of the bridge viewed from the side. |
| Reinforcing Steel | Steel bars placed in the concrete to add strength. |
| Scarifying | The process of cutting or scrapping away the top quarter-inch of the bridge deck surface to remove oil and other contaminants. |
| Spalling | A type of cracking where the concrete breaks or chips away in circular fragments or slabs. |
| Strain | The amount of stretching or shortening of a span under a load. |
| Stress | The intensity of forces in a span. |

Glossary

Tendons

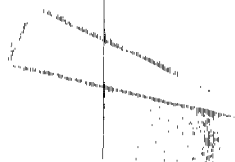
The steel cables that hold the bridge together under tension.

Tendon Anchor Recess

Recesses in the segment joint where the tendons that hold the bridge together are anchored.

Tendon Duct

Galvanized steel tubes placed in the concrete segments to provide a pathway for the tendons that hold the bridge together.



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10/10/00

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