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BY THE U.S. GENERAL ACCOUNTING OFFICE

Report To Senator Donald W. Riegle, Jr.

Delays And Increased Cost Result From The Zilwaukee, Michigan, Bridge Project Mishap

In August 1982 the Zilwaukee Bridge under construction on Interstate 75 near Saginaw, Michigan, experienced a near collapse caused by the failure of an expansion joint to withstand the loading stresses imposed by construction activities just prior to the mishap

A contract to repair the damaged portion of the bridge was signed in May 1983 and repair work was completed in March 1984 The mishap will extend the bridge's completion by more than 3 years to 1987 and increase costs by at least $38 million to a total estimated cost of $119 million.

The state of Michigan is taking steps to assure the future safety, maintenance, and durability of the bridge.

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UNITED STATES GENERAL ACCOUNTING OFFICE
WASHINGTON, D.C. 20548

RESOURCES COMMUNITY,
AND ECONOMIC DEVELOPMENT
DIVISION

B-215223

The Honorable Donald W. Riegle, Jr.
United States Senate

Dear Senator Riegle:

This is the second of two reports on the Zilwaukee, Michigan, bridge construction mishap prepared at your request. It discusses the results of our review of the construction mishap and subsequent events which have increased the bridge's cost by at least $38 million and extended its completion by more than 3 years.

The report also discusses the mishap's impact on the bridge's maintenance and safety once completed.

As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 7 days from the date of the report. At that time, we will send copies to the Secretary of Transportation; the Administrator, Federal Highway Administration; and other interested parties and make copies available to others upon request.

Sincerely yours,

J. Dexter Peach
Director

GENERAL ACCOUNTING OFFICE
REPORT TO THE HONORABLE
DONALD W. RIEGLE, JR.
UNITED STATES SENATE

DELAYS AND INCREASED COST RESULT FROM THE ZILWAUKEE, MICHIGAN, BRIDGE PROJECT MISHAP

D I G E S T

On August 28, 1982, the Zilwaukee Bridge project experienced a construction mishap that resulted in a near collapse when one end of a 300-foot-long section of the bridge resting atop a pier column sagged over 5 feet while the opposite end rose about 3.5 feet. The bridge, being built near Saginaw, Michigan, consists of twin 1.5-mile-long structures (one for northbound and one for southbound traffic) designed to replace an obsolete drawbridge on Interstate 75 where it crosses the Saginaw River. The mishap occurred on the northbound bridge.

This is the second of two GAO reports on the Zilwaukee Bridge prepared at the request of Senator Donald W. Riegle, Jr., of Michigan. The initial report, Early Decision and Delays on the Zilwaukee, Michigan, Bridge Project (GAO/RCED-83-165, Aug. 17, 1983), covered the period from the decision to replace the existing drawbridge to the August 28, 1982, mishap. This report covers activities subsequent to the mishap.

Senator Riegle requested GAO to examine the facts surrounding the bridge mishap; actions taken by the Michigan Department of Transportation (MDOT) and the Federal Highway Administration (FHWA) following the mishap; subsequent repairs made to the bridge; and the impact of the mishap on the bridge's future safety, maintenance, and service life.

GAO found that:

--Bridge repairs encountered delays and were not completed until March 1984 at a cost of $5.5 million.

--The mishap extended the completion date to 1987, a delay of more than 3 years.

--The original construction contract was terminated because the state and the contractor reached an impasse on completing the bridge under the original contract.

--The federal government will provide 90 percent of the current estimated cost of $119 million for the bridge.

--Engineering experts agree that a failed expansion joint caused the mishap.

--Both federal and state governments believe the bridge, when completed, will serve its original design life of 50 years.

DELAY IN STARTING REPAIRS

In October 1982, the Michigan Department of Transportation adopted a repair approach estimated to cost up to $3 million which it hoped to carry out over the winter so that bridge construction could resume in the spring of 1983. MDOT and the contractor building the bridge negotiated unsuccessfully in an effort to reach agreement on the repairs and on completing the project as specified in the original construction contract. The impasse centered around the adequacy of MDOT's repair plan and claims and liability for the mishap. In April 1983, with the construction season fast approaching, MDOT, with the contractor's and FHWA's concurrence, decided to hire a second contractor to perform the repair work as a way of resolving the impasse and allowing construction to resume. (See pp. 9 and 10.)

To expedite the repair, MDOT, with FHWA's concurrence, invited three contractors to bid rather than advertising for bids. In May 1983, a contract was awarded to the low bidder in the amount of $5.5 million. The $2.5 million increase over the original estimate was due to changes in the repair plan designed to provide a greater margin of safety for the workers during the repairs and to the cost of obtaining extensive insurance. Work started immediately, but in July 1983 a problem in building a framework to support the bridge during the repair caused delays. The repair was completed on March 23, 1984, 4 months behind the repair contract's schedule and more than 1-1/2 years after the mishap. It is now estimated that the bridge will be completed in 1987, more than 3 years later than the original date. FHWA monitored the repair but took no active role. (See p. 10.)

TERMINATION AGREEMENT ON ORIGINAL CONSTRUCTION CONTRACT

In July 1983, MDOT decided, with the contractor's and FHWA's concurrence, to terminate the original construction contract. The decision was made after MDOT had studied several options to complete the bridge and concluded, along with FHWA, that terminating the contract was the most economical solution because the state and the contractor had reached an impasse on completing the bridge under the original contract. The termination agreement consisted of a $13-million payment to the contractor--about $5 million for settling the contractor's claims and about $8 million for the purchase of his equipment and the on-site concrete segment casting plant. The intent of the termination agreement was to pay the contractor up to $61.9 million for construction actually completed and materials purchased for use in the bridge. Currently, $500,000 of the total of $74.9 million paid the contractor is being retained to assure that the contractor fulfills its obligations under the termination agreement. (See pp. 12 to 14.)

The Federal Highway Administration, which is providing 90 percent of the project's costs under the federal-aid highway program, concurred with the decision to terminate the contract with the original contractor. FHWA also agreed to participate in the repair and bridge completion costs. The mishap escalated the project cost estimate, including repairs, to $119 million from a prefailure-adjusted contract amount of $81 million. (See pp. 12 to 14.)

FAILED EXPANSION JOINT LED TO THE MISHAP

Investigations by three engineering consulting firms with experience in the type of construction being used to build the Zilwaukee Bridge all concluded that the mishap occurred when an expansion joint (which permits temperature-related expansions and contractions) did not withstand the loading stresses imposed by construction activities just prior to the mishap. While there was general agreement among the three firms, FHWA, and MDOT that the immediate cause of the mishap was the failed expansion joint, they differed in assessing the cause of the joint failure. (See pp. 15 to 20.)

THE BRIDGE'S FUTURE SERVICE LIFE

Highway officials in several states with bridge expertise contacted by GAO stated that there are problems in protecting and preserving the service life of all bridges, and improvements in these areas is an evolving science. They further stated that bridges built with concrete segments like the Zilwaukee bridge can provide as lengthy a service life as other bridges if properly designed, constructed, and maintained. (See pp. 21 to 23.)

Both FHWA and MDOT believe the bridge, when completed, will serve its original design life of 50 years. State, local, academic, and private experts with bridge expertise that GAO contacted agree that a major factor in ensuring the bridge's long-term durability and safety is adequately protecting from corrosion the steel used in the bridge to strengthen the concrete and hold the bridge together. At Zilwaukee, MDOT has taken steps to provide corrosion protection to ensure the integrity of both the reinforcing steel and the steel tendons which hold the bridge together. (See pp. 23 and 24.)

FEDERAL AND STATE AGENCY COMMENTS

The U.S. Department of Transportation stated that the GAO report was substantially accurate and comprehensive. The Department and FHWA will take appropriate steps in the future to assure that each state has the capability to adequately oversee the construction of complex and innovative bridges. (See pp. 5 and 20.)

MDOT stated that the report does not appear to have any major errors or omissions. (See p. 5.)

Contents

ABBREVIATIONS

BVN/STS	Bouvy, van der Vlugt, and van der Niet/ Segmental Technology Services, Incorporated
FHWA	Federal Highway Administration
GAO	General Accounting Office
HNTB	Howard, Needles, Tammen and Bergendoff
MDOT	Michigan Department of Transportation
TYLI	T.Y. Lin International
ZCE	Zilwaukee Construction Engineering, Inc.

GLOSSARY

Bridge deck	The roadway of a bridge.
Cantilever	Either of two beams projecting toward each other from piers to be joined to form the span of a cantilever bridge.
Expansion joint	A coupling designed to permit an endwise movement of its parts to compensate for expansion and contraction.
Footing	The base on which a pier rests.
Grout	Mixture of cement and water used to fill the voids in and around post-tensioning tendons to provide corrosion protection and to develop a bond between the steel and surrounding concrete.
Joint venture	A partnership or cooperative agreement between two or more contractors which is usually restricted to one specific undertaking.
Moment	The physical force exerted on any given point of an object which is a function of the weight affecting that point and the distance of that weight from the point.
Pier	The vertical supports for bridge spans.
Pile	A long slender piece of timber, steel, or reinforced concrete driven into the ground to carry a vertical load on which a footing rests.
Piling	Piles collectively.

CHAPTER 1

INTRODUCTION

Shortly after midnight on August 28, 1982, a section of the Zilwaukee Bridge, under construction near Saginaw, Michigan, suffered a construction failure which resulted in its near collapse. Although no one was injured, the structure was damaged extensively when one end of an approximately 300-foot-long section of the bridge, balanced atop a concrete pier, sagged over 5 feet while the opposite end rose about 3.5 feet.

The bridge will replace the existing four-lane drawbridge, where Interstate 75 crosses the Saginaw River, with two side-by-side, high-level bridges that will allow the free flow of vehicles on the bridges and ship traffic on the Saginaw River. One bridge will carry vehicles northbound, the other will carry them southbound. The bridge employs a relatively new design and construction technique that uses precast concrete segments held together by steel tendons stretched between the segments. Construction started in 1979 with an original completion date of November 1983. When construction was suspended following the mishap, the bridge was about two-thirds to three-fourths complete.

The State of Michigan owns the bridge and the Michigan Department of Transportation (MDOT) is administering its construction. The U.S. Department of Transportation through its Federal Highway Administration (FHWA) is providing 90 percent of the project's cost under the federal-aid highway program, and Michigan is providing the remaining 10 percent. The current estimated construction cost is $119 million. This is $38 million more than the $81 million construction estimate before the mishap.

MDOT originally planned to build a steel bridge. However, FHWA strongly encouraged MDOT to offer an alternate concrete design for bidding purposes to take advantage of price competition between steel and concrete and between alternate construction techniques. Because it lacked experience and expertise in designing a long-span concrete bridge, MDOT contracted with a Dutch firm, Bouvy, van der Vlugt, and van der Niet, and its associated company, Bouvy, van der Vlugt, and van der Niet/Segmental Technology Services, Incorporated (BVN/STS), of Indianapolis, Indiana, in November 1977 for the bridge design and related engineering.[1] In March 1980, following a construction contract award to the low bidder, which had selected the concrete alternate, MDOT contracted with BVN/STS to provide engineering services during construction. At the time of the near collapse, Zilwaukee Construction Engineering, Incorporated (ZCE), also of Indianapolis, Indiana, was providing these engineering services under a July 1982 contract with

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[1] In commenting on a draft of this report, the Department of Transportation noted that the practice of hiring consultants is not unique to the state of Michigan and has been widely used in the past on major, complex structures.

MDOT. An officer of BVN/STS had formed ZCE when BVN/STS assets were about to be purchased by another firm. The ZCE staff consists of two former BVN/STS engineers. Another former BVN/STS engineer, who had been the chief design engineer for the Zilwaukee project, provided continued engineering input to the project as a consultant to ZCE.

A joint venture of Stevin Construction, Incorporated, a Dutch firm, and Walter Toebe Construction Company of Wixom, Michigan, was awarded the contract for building the bridge. Toebe, which was responsible for the substructure (pilings, footings, abutments, and piers), had substantially completed its share of the project prior to the mishap. Stevin, which was responsible for fabricating and erecting the segments comprising the bridge superstructure, was involved in the construction associated with the mishap.

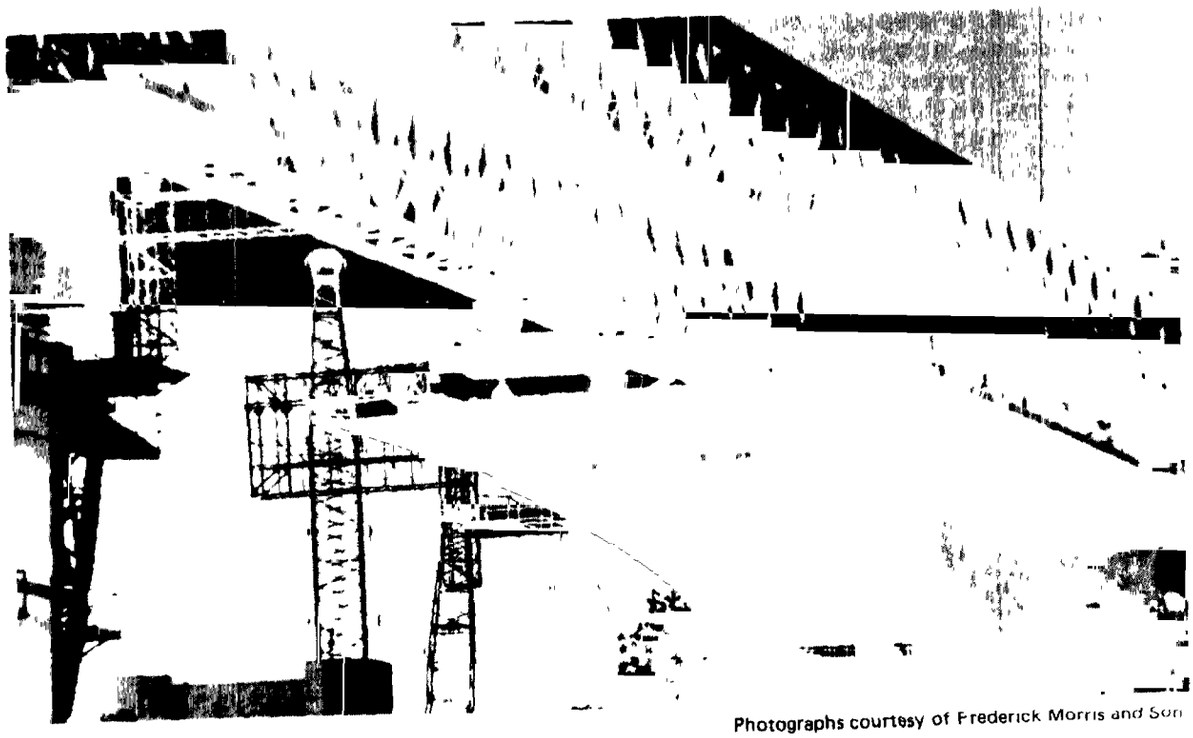
ZILWAUKEE PROJECT USES RECENTLY DEVELOPED BRIDGE BUILDING TECHNOLOGY

In the early 1960's, a French company developed technology for precast segmental box girder bridges. These bridges consist of a series of precast segments, hollow and shaped like a box with wings, which are fastened together to form the bridge roadway. The technology gained rapid acceptance and subsequently spread to other countries, including Canada in 1967 and the United States in 1973. In 1983, the United States had over 20 precast, prestressed concrete segmental box girder bridges either completed or under construction, including the Zilwaukee project.

When completed, the Zilwaukee twin bridges will be about 1.5 miles long. The northbound bridge will have 25 spans, and the southbound bridge will have 26 spans. Span lengths vary from 130 feet to 392 feet. Each span consists of varying numbers of precast concrete segments joined together by steel tendons. To assemble the two bridges and one entrance ramp, 1,656 segments are needed, joined to each other by more than 325 miles of steel tendons threaded through galvanized steel ducts. Figure 1 on page 3 is a photograph of the bridge under construction and illustrates a bridge segment.

Of the various prestressed, concrete segmental bridges either completed, under construction, or in design in the United States, few have been or will be constructed in exactly the same manner. The multitude of choices available to contractors allows them to tailor each project to their personnel and equipment in the interest of maximum efficiency. At Zilwaukee the assembly method being used is a balanced cantilever. The precast concrete segments that form the bridge are set in place by a crane that moves along a 940-foot launching girder. Appendix I contains a description of the construction method used for the Zilwaukee project. Figure 2 on page 3 is a photograph illustrating the construction method.

Figure 1



Photographs courtesy of Frederick Morris and Son

The Zilwaukee bridge under construction, revealing the end of a bridge segment.

Figure 2

Photographs courtesy of Frederick Morris and Son

Two spans of the Zilwaukee bridge under construction, with the launching girder atop the spans.

OBJECTIVES, SCOPE, AND METHODOLOGY

On September 30, 1982, Senator Donald W. Riegle, Jr., of Michigan, as a result of the mishap, requested that we evaluate the Zilwaukee project. In subsequent discussions with his office, we agreed to provide (1) an initial report covering the project period from the decision to replace the existing drawbridge to the August 28, 1982, near collapse and (2) a second report covering activities subsequent to the mishap.

In the first report,[2] we drew several conclusions as follows:

--The decisions to replace the drawbridge and to build a high-level bridge were reasonable based on estimates and conditions at the time of the decisions.

--FHWA's requirement for an alternate design and MDOT's subsequent rejection of the first low bid delayed the project. However, these actions apparently increased competition and may have reduced initial estimates of costs to build the bridge. The delay resulting from the alternate design requirement could have been avoided if MDOT had coordinated its initial decision not to develop an alternate design with FHWA.

--If MDOT had used value engineering or obtained broader input during design development, it may have improved the design and reduced costs. FHWA currently encourages value engineering, but the concept had not been widely accepted and applied at the time the Zilwaukee bridge design was developed.

We have focused this review on

--the August 28, 1982, construction mishap;

--the MDOT and FHWA actions following the mishap;

--the repair solution; and

--the impact of the mishap on project schedules and costs as well as future maintenance, safety, and service life.

We conducted our review between June 1983 and February 1984. To address the subjects listed above, we held discussions with appropriate FHWA officials and reviewed pertinent documents at its Washington, D.C., headquarters; Homewood, Illinois, region; and Lansing, Michigan, division offices. At the state level, we held

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[2]Early Decision and Delays on the Zilwaukee, Michigan, Bridge Project (GAO/RCED-83-165, Aug. 17, 1983).

discussions on these subjects with appropriate MDOT officials and reviewed pertinent documents at its Lansing, Michigan, headquarters. We visited the Zilwaukee, Michigan, construction site and talked with MDOT's project engineer and staff. We reviewed pertinent correspondence prepared by MDOT's internal audit group. We also discussed the legal implications of the mishap with an assistant attorney general from the Michigan Attorney General's Office and with an attorney from FHWA's Office of Chief Counsel.

In assessing the construction mishap, we discussed the Zilwaukee project with spokespersons for the contractor. We also reviewed the reports prepared by the three engineering firms which investigated the cause of the near collapse: T. Y. Lin International for the contractor; Howard, Needles, Tammen, and Bergendoff for MDOT; and Zilwaukee Construction Engineering, Incorporated, on its own behalf. We discussed the reports and the investigations with representatives of each firm. We did not, however, make any independent judgments of engineering matters related to the cause of the mishap.

We discussed the maintenance requirements and durability of prestressed concrete segmental bridges with highway officials from the states of Michigan, California, Colorado, Florida, Indiana, Pennsylvania, Texas, and Washington and the Province of Ontario, Canada, and officials of the city of Seattle, Washington, because of their experience with these types of bridges. We also discussed this subject with a chemist from the National Bureau of Standards, Structures Division, spokespersons from the Prestressed Concrete Institute, the Post-Tensioning Institute, the American Concrete Institute, and two professors at the University of Texas-Austin with several years involvement in prestressed concrete segmental bridge construction.

Except as noted above, this review was performed in accordance with generally accepted government auditing standards.

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The Department of Transportation and MDOT comments on our report are contained in appendixes IV and V, respectively. The Department of Transportation stated that our report was substantially accurate and comprehensive. MDOT stated the report appeared to have no major errors or omissions. MDOT did, however, raise some minor matters for our attention. These matters are addressed, where appropriate, in the following chapters.

CHAPTER 2

TIMELY ACTIONS STABILIZED STRUCTURE, BUT PROLONGED NEGOTIATIONS DELAYED START OF REPAIRS

Immediately following the mishap, MDOT and the contractor took various actions to reduce the danger of additional movement and/or the collapse of the structure. However, concerns for the safety of workers working atop a possibly unstable structure prevented the bridge from being protected from the winter weather until mid-November 1982. This delay resulted in the bridge tendons' being exposed to the elements without corrosion protection beyond the 30 days specified in the construction contract. FHWA and MDOT officials believe that this delay will have no impact on bridge safety and service life.

MDOT originally hoped to complete the repair over the winter of 1982-83 so that bridge construction could resume in the spring of 1983 at the start of the next construction season. However, safety concerns and prolonged negotiations concerning the repair between MDOT and the construction contractor delayed the repair. Finally, in April 1983, with the construction season fast approaching and the repair negotiations still at an impasse, MDOT decided, in order to avoid further delays in completing the bridge,.to hire another contractor to repair the bridge. The original contractor agreed to this approach. FHWA agreed to have the repair work done by another contractor and approved MDOT's repair plans, including estimated costs. To expedite the repair, MDOT, with FHWA's approval, invited three contractors to bid rather than advertising for bids. In May 1983, MDOT awarded a $5 million repair contract to the low bidder--Walter Toebe Construction Company, the joint venture partner which had done the original substructure work. Work started immediately; however, a fabrication/design problem delayed the repair's completion by more than 4 months. The repair was completed on March 23, 1984.

FOLLOWING MISHAP, STRUCTURE STABILIZED AND INVESTIGATIONS INITIATED

Shortly after midnight on August 28, 1982, the near collapse of a section of the northbound bridge produced or resulted in considerable physical damage to the structure. One end of an approximately 300-foot-long section of the bridge deck situated atop pier column 11 sagged over 5 feet while the opposite end rose about 3.5 feet. No personal injuries resulted. The mishap occurred moments after a large crane lifted a 157-ton concrete bridge segment from a transport truck located on the bridge. The pier columns are numbered consecutively south to north; pier 11, where the mishap occurred, is next to the river's south shore. Figure 3 on page 8 illustrates the movements and damage.

Within hours of the mishap, contractor employees returned to the bridge and took various actions to stabilize the structure. This included strengthening the expansion joint, post-tensioning

additional steel tendons in the span section north of the expansion joint to strengthen that portion of the span against the stress being imposed on it by the tilted section, and placing a pier frame (a temporary framework) with hydraulic jacks on pier 11 to support the tilted section.

Ten days after the mishap, the contractor began moving two 30-ton pieces of equipment used in the erection process from the lower end of the tilted section. Next, the soil surrounding the footing was removed revealing the shattered condition of the footing. Following this discovery, MDOT decided that neither the 1,200-ton launching girder nor its crane which still held the 157-ton segment were to be moved until the structure was better stabilized. MDOT suspended work on the northbound bridge; however, work continued on the southbound bridge until the end of the construction season late in 1982. The contractor continued operation of its on-site segment casting plant until February 1983.

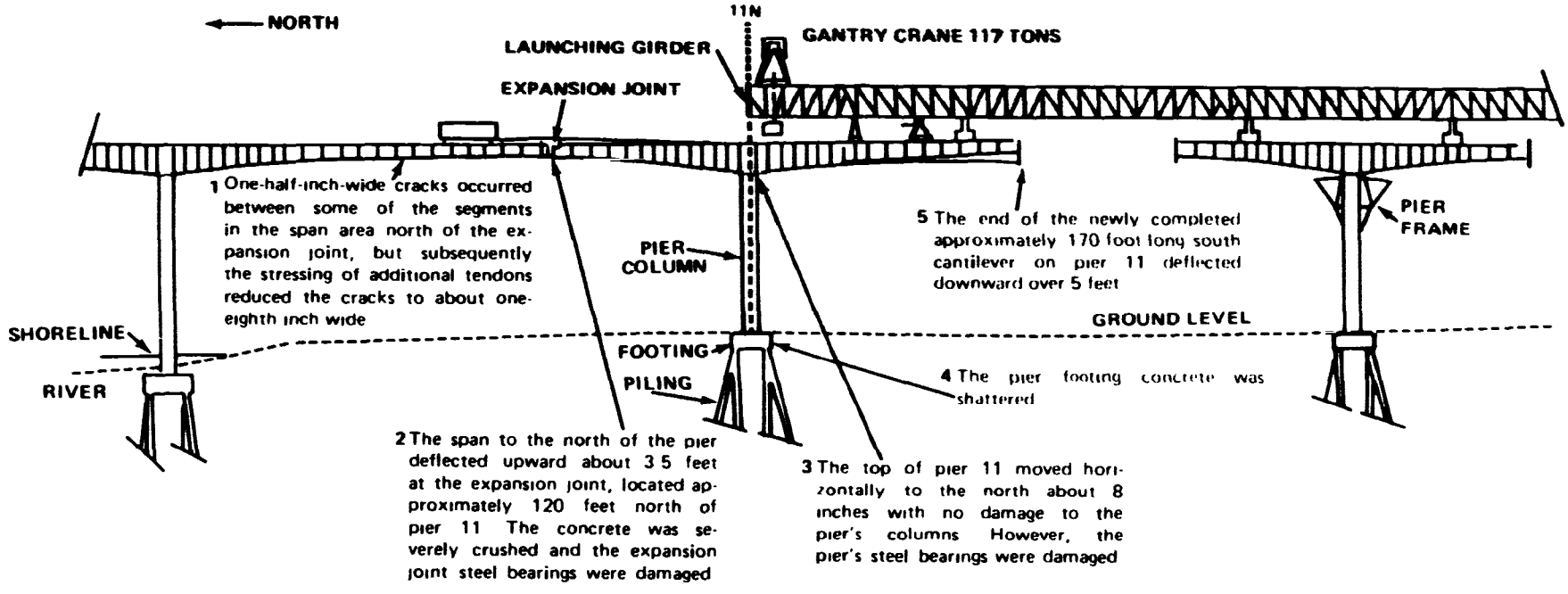
The MDOT Testing and Research Division began monitoring--visually and with equipment sensitive to movements--the damaged footing, the cracks in the bottom of the damaged span, and the sagged section of the bridge to assure that there was no movement other than what might be expected to result from temperature changes.

During the 2 weeks following the mishap, both the contractor and MDOT hired expert consultant design engineering firms to investigate the cause of the mishap. The contractor engaged T.Y. Lin International (TYLI) of San Francisco, California. MDOT worked with Zilwaukee Construction Engineering, Incorporated (ZCE), of Indianapolis, Indiana, already under contract to provide construction engineering services during the building of the bridge. In mid-September 1982, because of concerns about potential criticism of ZCE's objectivity due to its involvement with the project, MDOT also retained Howard, Needles, Tammen, and Bergendoff (HNTB), a Kansas City, Missouri, firm with no previous association with the project. The results of the consultant investigations were formalized in early calendar year 1983 and are discussed in chapter 4.

Following the activities to stabilize and monitor the damaged structure and the hiring of the consultants, MDOT took action to winterize the bridge (protect it from the elements when construction is normally suspended for the winter). The main concern was to protect the steel tendons from corrosion. However, concerns for worker safety delayed the start of winterization at Zilwaukee for about 2 months. This delay resulted in the tendons, which are steel cables, being exposed to the elements without corrosion protection longer than the 30 days specified in the construction contract. The winterization was completed on December 7, 1982. FHWA and MDOT officials believe that the delay will not affect bridge safety and service life.

Figure 3

DAMAGE TO THE ZILWAUKEE BRIDGE



Source Prepared by GAO from information provided by FHWA and MDOT

REPAIR WORK DONE UNDER SEPARATE CONTRACT

On October 19, 1982, MDOT announced a repair approach for the damaged bridge. At that time, MDOT intended to start the repair work, estimated to cost up to $3 million, within a month, work through the winter, and complete it by spring 1983. Bridge construction would then resume. However, finalizing and implementing the repair plan was delayed by safety concerns and by the inability of the contractor and MDOT to reach agreement on how the repair would be made and paid for, how much time was needed for completing the repair, concerns related to the contractor's claims for costs incurred before and after the mishap, and the question of liability for the mishap. MDOT did not finalize its plan until after it decided to have another contractor do the repair work. The delay put off the start of repair work until the spring of 1983, the resumption of bridge erection until at least the spring of 1984, and the bridge completion until 1987.

The subject of a separate repair contract was first discussed at an April 13, 1983, meeting between MDOT and the contractor. FHWA was in attendance but did not take an active role in the negotiations. In a written summary of that meeting, FHWA stated:

--MDOT suggested that the preferred option would have the contractor make the repair while a less desirable second option would be to contract with another contractor.

--The contractor stated that a second contractor might be preferable and implied that if it did the work under the original contract, it would require MDOT to provide an extremely detailed set of plans and procedures for making the repair.

--The contractor suggested that an outside contractor do the repair, making it possible to separate the repair work from the other issues under discussion.

After receiving the contractor's approval for having a second contractor do the repair, MDOT submitted the finalized plans, contract proposal, and estimated costs to FHWA on April 21, 1983. The estimated cost was $4.4 million, with $500,000 and $300,000 allocated for the superstructure repair and work insurance,[1] respectively. However, the contractor was allowed reimbursement for actual costs on the above two items because of MDOT's inability to estimate their cost. The increase from MDOT's earlier $3 million estimate was due to revisions in the repair procedure which would be used.

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[1]Because the mishap was not covered by insurance, MDOT's repair proposal required the contractor who did the repair work to obtain $134 million in insurance coverage not normally required for bridge projects.

To expedite the contracting process, MDOT asked FHWA's approval to forego advertising for bids and allow MDOT to invite selected contractors to bid. MDOT believed that this would speed up the contracting process and would allow the repair to be completed during the 1983 construction season, thus permitting construction work to resume on the northbound structure in 1984. On April 22, 1983, FHWA authorized the repair work to proceed and approved MDOT's contracting procedures to expedite the start of repairs. FHWA was aware of the identity of the three contractors, but only approved the procedure, not the choice of contractors. This choice was an MDOT, not an FHWA, responsibility.

On May 6, 1983, MDOT solicited bids from three Michigan-based firms. One of the firms--Walter Toebe Construction Company of Wixom, Michigan--was a partner in the joint venture responsible for building the bridge under the original construction contract. Toebe was responsible for the bridge's substructure (pilings, footings, abutments, and piers) and had substantially completed its share of the project prior to the mishap. Toebe was included because both FHWA and MDOT said Toebe had done quality work on the bridge substructure and had completed work ahead of schedule. Toebe submitted the low bid of $5 million for the repair. On May 11, 1983, FHWA authorized MDOT to award the contract, which it did 2 days later on May 13, 1983. Under the contract, Toebe had to begin work within 10 days of the award and complete the work by November 15, 1983. The contract amount was increased from $5 million to $5.5 million because of the actual cost of the required insurance.

REPAIRS NOW COMPLETE

Toebe began work under the repair contract on May 16, 1983. MDOT's contract required completion of the repair by November 15, 1983. The repair, however, was not completed until March 23, 1984. The repair delay resulted when a problem arose in July 1983 in the design and fabrication of the temporary framework, temporarily halting further repair efforts for over 3 months. The framework was subsequently put in place and the repair resumed in December 1983. FHWA, in addition to approving the repair contract, monitored the repair but took no active role.

MDOT officials told us that part of the repair work on the damaged span originally scheduled as part of the repair contract but which could not be done over the winter months, has been deleted from the repair contract with an accompanying reduction in the repair contract cost. This work includes repairing the cracks, identifying and replacing damaged tendons, and repairing the damaged concrete in the expansion joint segments. This work will be included as part of the bridge completion contract.

CONCLUSIONS

The contractor and MDOT took emergency actions immediately following the mishap to stabilize the structure and prevent further damage. Although actions to protect the steel tendons

holding the bridge together were not as timely as prescribed in the construction contract, they seem to have been taken in a manner as timely as circumstances permitted.

MDOT had a repair approach 2 months after the mishap. However, MDOT could not obtain the contractor's agreement to go ahead with the repair work because of safety concerns, the inability of the contractor and MDOT to reach agreement on the repair plan details, the contractor's claims for additional costs, and the question of liability. These matters had not been resolved after 6 months of negotiations. With the advent of warmer weather and the approach of the construction season, MDOT and the contractor agreed to have another contractor proceed with the repair work. FHWA authorized the repair work to proceed and approved MDOT's contracting procedures to expedite the start of repairs.

Repair work began May 16, 1983, under a separate $5.5 million contract with the Walter Toebe Construction Company, a partner in the original construction contract. The repairs, originally required by the repair contract to be completed by November 15, 1983, were not completed until March 23, 1984. FHWA, in addition to approving the repair contract, monitored the repair but took no active role.

CHAPTER 3

CONTRACTUAL ARRANGEMENTS WITH CONSTRUCTION CONTRACTOR TERMINATED

In July 1983, MDOT and the contractor entered into an agreement, approved by FHWA, terminating the original bridge construction contract. MDOT agreed to termination after studying several options and concluding that this course of action would allow it to complete the bridge in early 1986 at an estimated cost of $119 million. MDOT reasoned that the only alternative to resolving the contractor's claims for delays and other items and the question of who was liable for the mishap would have been a lengthy litigation, an increase in the project cost to as much as $159 million, and an uncertain completion date. MDOT will solicit bids for completing the bridge which it estimates will cost $42 million.

FHWA concluded that termination was the most appropriate option and concurred with MDOT's request to terminate following its analysis of MDOT's estimated costs for the various options. FHWA agreed to participate in the settlement after concluding that participation need not be denied for reasons of law and upon consideration of the federal-state relationship, the need for a bridge, the need for advancing new technologies, and the public benefit.

AGREEMENT REACHED TO TERMINATE CONTRACT; FHWA TO PARTICIPATE IN COST

In early April 1983, MDOT and FHWA still expected the contractor to carry out the repair and then complete the bridge. However, later that month, as discussed in chapter 2, MDOT, with the contractor's concurrence, decided to have another contractor do the repair work. A month later MDOT and the contractor agreed to terminate the original construction contract after over 8 months of negotiations on completing the project under the original contract.

At a May 16, 1983, meeting with MDOT, the contractor proposed terminating the contract and letting MDOT purchase the contractor's equipment, including the casting plant, as a possible solution to resolving the questions of how claims for delays and other items would be settled, the responsibility and liability for the mishap, and the basis for carrying out the remaining construction work. In a written summary of that meeting, FHWA's Michigan Administrator stated that termination might be the least costly solution from the State of Michigan's and FHWA's point of view.

In a June 3, 1983, letter, MDOT formally advised FHWA's Michigan Administrator of the proposed termination, including the purchase of the contractor's equipment and concrete segment casting plant. FHWA, in a June 24, 1983, letter, requested MDOT to provide additional information including an analysis of possible alternatives and costs involved, an explanation of why termination

was necessary, and reasons why the federal government should share in the costs. MDOT responded on July 15, 1983. MDOT's and FHWA's analysis is contained in appendix II.

On July 25, 1983, FHWA's Chief Counsel, based on a review of the Zilwaukee project, recommended that the Administrator, FHWA, participate in the cost of the MDOT settlement negotiated with the contractor. As a general rule, FHWA participates in the cost of correcting design errors but bases participation in construction errors on the merits of the individual case. FHWA also generally participates where the failure was caused by a design change during the construction when normal federal-aid policies and procedures are followed.

In this instance, the Chief Counsel found that it could be argued that the cause of the mishap was closely related to the design as well as construction engineering errors and that it would be harder to argue that the mishap was entirely caused by the contractor in the course of construction. The Chief Counsel further stated that it was less clear as to whether federal participation should be denied based on the state's failure to adequately administer the construction contract but noted that the state's errors occurred in part with the implicit approval or knowledge of FHWA. In addition, the Chief Counsel noted that the state's decision to proceed with a design with which it had no experience, was not comfortable with, and felt inadequate to administer properly without expert technical help, was the result of strong encouragement from FHWA. As a result of his analysis, the Chief Counsel recommended that FHWA participate in the settlement. Contributing factors included the conclusion that participation need not be denied for reasons of law as well as consideration of the federal-state relationship, the need for a bridge, the need for advancing new technologies, and the public benefit.

Consequently, in a July 25, 1983, letter to MDOT, FHWA approved the mutual termination concept and agreed to participate in the costs of the settlement. At the same time, FHWA advised MDOT to investigate the responsibility and liability of the design consultant, ZCE, concerning the project's problems. An assistant attorney general in the Michigan Attorney General's Office said that MDOT is considering whether to pursue the matter of ZCE's liability for the mishap. He advised us that the decision will be greatly influenced by results of a current review to determine whether ZCE has enough assets to make it worthwhile for MDOT to seek damages. MDOT advised FHWA on May 7, 1984, that it had determined that ZCE lacked the assets to justify seeking recovery.

MDOT finalized the termination agreement and publicly announced it on July 27, 1983. The final agreement had four basic elements:

--The contractor and MDOT agreed to drop all potential claims against each other.

--The contractor and MDOT agreed to forego any litigation against each other on the project.

--The state acquired the contractor's complete inventory of equipment used on the project, including the concrete segment casting plant.

--The contractor and MDOT agreed to terminate the contract with MDOT paying $13 million, about $5 million for settling all claims and $8 million for the equipment and the plant.

The contractor also agreed to make available to MDOT on a temporary basis some of its skilled staff when MDOT is ready to resume construction. These people would be paid by MDOT or the new contractor hired to complete the bridge. MDOT held back $500,000 earned under the original construction contract to assure the contractor's fulfillment of this and other obligations under the termination agreement.

As a result of the termination agreement, the contractor has been paid a total of $74.9 million--$13 million under the termination agreement and $61.9 million of the adjusted construction contract price of $81 million. MDOT told us that the $61.9 million represented payment for construction actually completed and the contractor's purchase of material for use in the bridge. At the time of the mishap, MDOT told us that the bridge was about two-thirds to three-fourths complete.

The termination agreement resulted in the contractor's being paid the bulk of the $81 million adjusted contract price for a bridge no more than three-fourths complete. Several factors should be considered in viewing the $74.9 million paid the contractor. First, both MDOT and FHWA's Michigan Division verified that the contractor's alleged claims, which were valued at $29 million and could escalate to $40 million with delay costs resulting from any litigation, were valid. The $13 million settlement agreement included the contractor's withdrawal of all claims against the state. Second, while the revised contract price at the time of the mishap was $81 million, MDOT estimates that the actual completion cost would have been $105 million. It is possible that some of this additional amount could have ultimately been paid by MDOT and FHWA in settling contractor claims. Third, MDOT expects to sell the purchased equipment for $3.4 million. When the equipment is sold, FHWA will receive 90 percent of the purchase price.

Both MDOT and FHWA believed recourse to the courts would have been an unsatisfactory solution. As previously discussed, both MDOT and FHWA verified the contractor's claims to be valid. Furthermore, once the mishap occurred, FHWA contract administration officials said that it is no longer appropriate to compare the construction cost before the mishap with the amount ultimately paid the contractor because of the claims generated by the mishap. A detailed audit of the contract and extensive engineering and legal analysis of the parties' positions would be necessary to independently judge the settlement's reasonableness.

CHAPTER 4

VARIETY OF FACTORS ASSOCIATED WITH THE CAUSE OF THE MISHAP

Investigations by three design engineering firms with segmental bridge experience all concluded that the mishap occurred when an expansion joint, which permits temperature-related expansions and contractions, failed to withstand the loading stresses imposed by construction activities just prior to the mishap. The firms, however, differed in assessing the cause of the joint failure. The construction contractor's consultant (TYLI) stated that a deficient expansion joint design by MDOT's design/construction engineer (ZCE) caused the failure. MDOT's consultant (HNTB) concluded that the failure was caused by construction loads and conditions exceeding the expansion joint's capacity. ZCE attributed the failure to contractor actions which resulted in an excessive load on the expansion joint.

FHWA and MDOT concur in the conclusion that the immediate cause of the mishap was the failed expansion joint. FHWA, however, believes the primary cause of the failure was ZCE's failure to recognize the capacity of the expansion joint, coupled with errors in calculating the load that the joint would experience during construction.

Because it lacked the technical expertise, MDOT had hired ZCE to be integrally involved in the construction process. However, over time, ZCE also acquired dual, but conflicting, roles of advising the contractor on construction loadings and then approving those loads as MDOT's agent. Consequently, there was no independent check of the construction procedure.

SEVERAL FACTORS CONTRIBUTED TO THE MISHAP

HNTB, TYLI, and ZCE issued reports early in calendar year 1983. All three reports agreed that the mishap occurred when an expansion joint failed. FHWA concurred in this conclusion. However, TYLI concluded that the failure was the result of a design deficiency, HNTB said that it was the result of construction loads and conditions exceeding the expansion joint's capacity, and ZCE concluded that it was largely the result of contractor errors which overloaded the joint.

TYLI and HNTB believe that the lack of an adequate safety factor, necessary to allow for errors in calculating loads during construction, was a primary factor in the expansion joint failure. Contributing factors, including improper assumptions about what materials would remain on the bridge and misplacement of equipment, reduced the margin of safety. In addition, the procedure for approving construction loading developed into a situation in which there was no independent check of construction loadings because MDOT's agent was both advising the contractor on construction loadings and then approving those loadings for MDOT.

Nature of tendons and the redesign

Both the HNTB and TYLI reports cite insufficient temporary tendons crossing the expansion joint as the cause of the failure and suggest that more tendons would have prevented it. TYLI stated that MDOT had approved the handling manual (a document detailing construction procedures) in which (1) the loads planned during construction were about equal to the loads that would cause failure and (2) 40 rather than 24 tendons would have been needed to provide an adequate safety factor of 1.5. However, ZCE, which actually approved the manuals for MDOT, does not agree and takes the position that rather than there being an insufficient number of tendons to prevent the failure, the failure resulted from the contractor placing a greater load on the tendons than ZCE had approved.

To handle expected construction loads, the original design required 30 temporary tendons for the failed expansion joint. During the casting of the first few concrete expansion joint segments, the contractor had difficulty in fabricating these segments to accommodate the number of tendons called for in the original design. The contractor discussed the problem with MDOT and its consultant, which at that time was BVN/STS, and, in an August 13, 1981, letter to MDOT, formally requested the deletion of some of the tendons. MDOT, under advisement from BVN/STS, agreed to a design change reducing the number of tendons in each expansion joint segment to 24 tendons. FHWA was advised of this and approved it on a conceptual basis, but it did not review the design change details nor was it required to do so. In a March 1983 report, ZCE defended the approval of the revised expansion joint design, stating it believed that the erection method was sufficiently flexible to allow safe operation, even with the reduction from 30 to 24 tendons.

Loadings left little margin for error

The American Association of State Highway and Transportation Officials, comprised of public agency officials responsible for highway design, construction, and maintenance, has specifications for highway bridges but does not establish specific safety factors for bridges during construction. Both FHWA and HNTB believed that 1.3 was an adequate safety factor. TYLI representatives told us they believed a safety factor of at least 1.5 is necessary to take care of anticipated minor overloads and inaccuracies in material properties and dimensions and to allow for inacccuracies in assumptions. A TYLI representative told us that the construction loading that ZCE had approved was too close to the failure point of the expansion joint as it was designed.

The ZCE consultant, in commenting on TYLI's report, took exception to the need for a 1.5 safety factor. He believes that if loads and frequency of loads are known, it is possible to work with a safety factor close to unity. He further stated that it is possible, and necessary, to get very accurate determinations of loads when working in critical situations such as the construction of the span in question.

Five factors identified by FHWA and/or MDOT as contributing to the failure

FHWA concurs in the conclusion that the immediate cause of the mishap was the failed expansion joint. FHWA, however, stated that the insufficiency of the expansion joint does not necessarily indicate any impropriety in its design or construction. Rather, the primary cause of the failure, according to FHWA, was the failure to recognize or adequately consider the effective load-bearing capacity of the expansion joint as designed. The error of not recognizing the true capacity of the expansion joint, in FHWA's view, was compounded by additional factors of lesser importance which worked to reduce the margin of safety. While ZCE felt it was approving a load of 63,700 kip/feet (a kip is 1,000 pounds), MDOT said the moment[1] on the expansion joint at the time of the mishap was 80,200 kip/feet.

MDOT said five major items contributed to the difference in the force applied to the expansion joint. These are, with the exception of the last item, the additional factors identified by FHWA. They are as follows.

--ZCE did not take into account the fact that the cast-in-place forms had been removed in the span involved in the mishap (span 11/12). It was standard practice to remove the forms, and ZCE's calculations prior to the work done on span 11/12 were reportedly based on this procedure. Stress calculations on span 11/12, however, were based on the forms remaining in place. Had the forms remained in place, their presence would have reduced critical moments at the expansion joint. According to FHWA, ZCE never informed the contractor of this assumption and the handling manual was approved without specifically requiring the forms to remain. ZCE's on-site representative was either unaware of the assumption upon which the approval calculations were based, or neglected to assure that the handling manual conformed to the assumed procedure. MDOT said this action added 5,000 kip/feet to the load. (Cited by FHWA and MDOT.)

--A similar error was made by ZCE with respect to the work platform at the south end of the span. Calculations did not account for the presence of the platform, but handling manual procedures were approved which did not specifically require the platform's removal. (Reportedly, this error occurred at other spans as the retention of the work platform was standard contractor practice and common knowledge on the work site.) ZCE failed to recognize the potential importance of the platform's load, made calculations based on assumptions that did not represent standard practice,

[1]Moment, in engineering, is the physical force exerted on any given point of an object, which is a function of the weight affecting that point and the distance of that weight from the point.

and then did not follow up in order to assure that the assumptions they did make were put into practice. In FHWA's view, these actions are an indication of negligence. MDOT said this added 5,700 kip/feet to the load. (Cited by FHWA and MDOT.)

--The contractor misplaced a leg (the C-leg) of the launching girder by approximately 4 feet. MDOT said this added 2,600 kip/feet to the load. FHWA believes this to be the only error directly attributable to the contractor. However, FHWA, MDOT, HNTB, and TYLI believe that if the other factors had not been present, this error alone would not have caused the failure. (Cited by FHWA and MDOT.)

--MDOT supplied the contractor with the wrong sequence for stressing tendons in span 11/12. FHWA's Michigan Division Bridge Engineer believes that ZCE developed the desired stressing sequence for span 11/12. However, the individual involved had left the stressing sequence in his office and gone on vacation. His replacement was apparently not aware that MDOT had not received it or that he should provide it. MDOT personnel apparently assumed that because new data for span 11/12 were not provided, the sequence for the previous span was to be used. MDOT said this added 1,500 kip/feet to the load. (Cited by FHWA and MDOT.)

--An incorrect assumption by ZCE about the effect of the launching girder at an earlier stage of erection added 3,400 kip feet to the load, according to MDOT. ZCE assumed the effect of the launching girder would reduce the force on the bridge. In actuality, however, ZCE overestimated the favorable effect of the launching girder, thus underestimating the load on the expansion joint by 3,400 kip/feet. (Cited by MDOT.)

MDOT said these five items do not add up to the difference between the approved force on the joint and the actual force because other minor factors were involved.

ZCE cited the mispositioning of the launching girder's support legs and the work platform by the contractor as major elements in the overload that caused the failure. TYLI and HNTB stated that the mispositionings were not a major factor in causing the failure.

HNTB in its January 1983 report stated that the actual erection procedure was in general agreement with the handling manual except for the placement of the support legs for the launching girder and the fact that the work platform was not to have remained on the structure. The report further stated that these items contributed to the joint failure, but the failure would have occurred even if the support legs and the work platform had been placed as outlined in the handling manual.

Regarding the work platform, as previously noted, the handling manual in use at the time of the mishap, developed by the

contractor and approved by MDOT/ZCE, did not specifically require its removal. ZCE maintains that this is a contractor error. However, ZCE admitted that the ZCE engineer (a replacement for the vacationing ZCE resident engineer) on site at the time of the accident misinterpreted a handling manual step and assumed the work platform was to be removed. According to the contractor and the TYLI report, the work platform normally was left in place until it was needed elsewhere.

NO INDEPENDENT CHECK EXISTED ON KEY CONTRACTOR ACTIVITIES

In FHWA's view, during the course of construction a situation developed in which ZCE was advising the contractor on construction loadings on the one hand and then approving those loadings as MDOT's agent. MDOT, unfamiliar with the type of construction at Zilwaukee, had hired ZCE as its engineering consultant and authorized ZCE to perform the approval function. Consequently, there was no independent check of the construction procedure. MDOT's actions, in hiring ZCE, took place with the approval or knowledge of FHWA, but FHWA was not aware of the contractor's subsequent dependence on ZCE until after the mishap.

MDOT lacked familiarity with concrete segmental bridges

MDOT is responsible for developing the bridge design, approving any design modifications, and assuring that construction is consistent with the design. The Zilwaukee design involved a construction technology with which MDOT had no in-house expertise and with which FHWA had only limited experience. MDOT had no experience with concrete segmental design, was not comfortable with it, and felt inadequate to administer it properly without expert technical help. Because MDOT lacked expertise in concrete segmental bridge design, it contracted with a design engineering consultant firm to develop the bridge design and provide engineering services during the construction period. FHWA approved these contracts.

Neither MDOT nor FHWA made a detailed review of the bridge design in the sense of checking all the details and verifying the calculations. They relied on self-assurance by the design consultant to provide a quality design. The reason for this is best explained by the complexity of the concrete bridge design which necessitates a computer program to provide a detailed analysis of the structure. Although MDOT did not have staff experienced in concrete bridge design and construction, FHWA did have some staff with concrete design/construction experience. However, neither entity had the computer program to verify the design. Furthermore, the Director, Office of Structures, FHWA Region 5, which encompasses Michigan, told us that this was not FHWA's role. He stated that FHWA's role is to look for obvious errors or items that appear questionable and seek clarification or correction.

No independent check was made on the bridge's load-bearing capability

According to FHWA, over time a situation developed where the contractor became dependent on ZCE and no independent check was made of the capability of the structure to accommodate the imposed erection loads. ZCE, as MDOT's consultant, served in the dual capacity of advising the contractor how to carry out the contract and advising MDOT whether to approve the procedures of the contractor. ZCE provided the contractor with the calculations for stresses and then approved construction loadings producing such stresses. Since MDOT had no previous experience with this engineering technique, MDOT felt it necessary to rely on ZCE to approve the contractor's procedures.

All of the activities involved in the complicated erection procedure are outlined in a series of handling manuals. However, information on the magnitude of the loads was prepared by the contractor and submitted separately from the handling manuals to MDOT/ZCE. After receiving the information from the contractor, ZCE calculated the effects of the submitted loads on the structure. Upon completing its review, ZCE as MDOT's agent could reject the procedures, recommend alternative actions, or approve what the contractor had submitted. ZCE indicated its approval by stamping the document "Approved" with a MDOT stamp that included the signature of a MDOT Design Division official.

FHWA concluded, based on discussions with MDOT, that MDOT's eventual interpretation of contract plans/proposal was that the contractor was not responsible for calculating structural stresses resulting from construction loadings. The contractor was, therefore, dependent on MDOT/ZCE to make the calculations for it. FHWA approved the agreement between MDOT and ZCE and was aware of MDOT's inexperience and dependence on ZCE.

While FHWA was aware of MDOT's dependence on ZCE, it was not aware of the contractor's dependence on ZCE. In retrospect, FHWA believes it probably should have been aware of some problem. FHWA believes MDOT was aware of the contractor's dependence on ZCE by the time of the mishap but that this situation had developed over the life of the contract. It was apparently not intended by MDOT or FHWA. This development occurred for the most part as both MDOT and the contractor became aware of the complexity of the erection procedures and the analyses required to evaluate and accommodate the contractor's launching girder. FHWA concluded, however, that MDOT's overreliance on ZCE was nearly inevitable, given its inexperience in this kind of design and construction.

AGENCY COMMENTS

In commenting on a draft of this report, the U.S. Department of Transportation stated that the Department and FHWA will take appropriate steps in the future to assure that each state has the capability to adequately oversee the construction of complex and innovative bridges and that consultants filling this role as the state's agent do not have a conflict of interest.

CHAPTER 5

SAFETY, MAINTENANCE, AND DURABILITY OF THE BRIDGE WHEN COMPLETE

MDOT has completed the repair and is developing a proposal for the bridge completion contract. As part of this effort, MDOT is addressing concerns affecting the completion, safety, and maintenance of the Zilwaukee Bridge project and is especially taking steps to prevent corrosion.

THE COMPLETION CONTRACT IS BEING DEVELOPED

MDOT has developed the bid package for completion of the bridge and has provided it to FHWA for review. FHWA is reviewing the package but had not approved it as of May 30, 1984.

MDOT has contracted with HNTB to perform the engineering services provided by ZCE under the original contract. To prevent a recurrence of the dual working relationship that developed before the mishap, MDOT is planning to review its working relationship with HNTB and then inform FHWA of its selected course of action. To monitor construction under the completion contract, MDOT said it will have a design construction team made up of its own staff and consultant staff and will have more extensive supervision. MDOT will require the contractor to carry the standard performance bond and liability insurance. HNTB will not be required to have any special insurance. Both MDOT and FHWA see the completion contract as a typical construction project.

In commenting on a draft of this report, the U.S. Department of Transportation noted that the special provisions planned for the readvertisement of the bridge's completion have stipulations requiring the contractor to

> "obtain the services of an engineering firm that shall have demonstrated a thorough knowledge of concrete segmental bridges. This knowledge is to be demonstrated by having previously designed and provided construction engineering services for major concrete segmental bridges."

The Department concurs in this action and feels it imperative for proper construction management.

SAFETY, MAINTENANCE, AND DURABILITY CONCERNS

The U.S. experience with concrete segmental bridges has not been long enough to determine their maintenance requirements and service life. Problems exist in protecting and preserving all types of bridges, and the science of doing so is an evolving one. However, the general consensus of bridge experts is that segmental bridges, if designed and constructed properly, can provide years of safe service with maintenance requirements less than those

experienced for the more common steel bridges. Although some states are experiencing problems with their segmental bridges, the state officials we interviewed are generally satisfied with them and will continue building them.

A major factor in ensuring durability of segmental concrete bridges is protecting the tendons which hold them together. Since the tendons are usually bonded (grouted in place), they cannot be removed or repaired should they be damaged by corrosion. Bridge experts are finding that such corrosion is resulting where chlorides and other corrosive materials, such as are contained in deicing salt, migrate through the concrete and attack the reinforcing steel and tendons. MDOT has taken steps to address this problem.

Durability and maintenance concerns of prestressed concrete structures

According to the Chief, Bridge Division, Office of Engineering, FHWA, the maintenance requirements and service life of prestressed concrete segmental bridges are unknown because not enough history exists on them. Long-span, prestressed concrete segmental bridges were first built in the United States in the early 1970's.

The head of the Building Composite Group, Structures and Materials Division, National Bureau of Standards, told us that cracking in concrete always occurs. With segmental bridges the concern is corrosion of the tendons. He said prestressed concrete structures (other than bridges) have developed problems. Corrosion has been occurring in prestressed concrete pipes, buildings, and parking garages. He told us that corrosion is occurring in such structures even when, according to the design engineers, it is not supposed to occur because of the precautions that have been taken.

The Province of Ontario, Canada, has used post-tensioned, prestressed concrete for highway bridges for about 25 years. After the Ontario Ministry of Transportation and Communication demolished two nonsegmental, post-tensioned, prestressed concrete bridges (20 and 25 years old), it examined their tendons to check on their long-term performance against corrosion. According to the Ministry's Head of Material Research, the 20-year-old bridge's tendons were severely corroded while the 25-year-old bridge's tendons had no signs of corrosion. Further study showed that very poor grouting material had been used on the 20-year-old bridge and a very high-quality grout had been used on the 25-year-old bridge. Based on this difference, the Ministry concluded that corrosion protection of post-tensioned, prestressed concrete structures (especially bridges) is an important function of grout quality and the grouting procedures used in constructing these bridges.

According to Colorado and Florida State transportation officials, these states are having problems with some of their recently completed segmental bridges. They attributed the problems, which involved cracking, to improper design and/or construction.

They stated that had the design and construction problem been recognized early enough, the cracking problems would not have occurred.

MDOT's efforts at Zilwaukee

To address the concerns about corrosion, MDOT has used epoxy-coated reinforcing steel near the bridge deck surface and grouted the tendons in galvanized metal ducts to provide further protection. FHWA has reviewed and approved these measures. The Zilwaukee Bridge decks will have a 1.5-inch latex-modified concrete overlay (wearing surface) to provide additional protection to the reinforcing steel and the tendons in the concrete. In addition to providing more distance between migrating corrosives and the reinforcing steel and tendons below, the material is very dense and impedes the movement of corrosives. Further, the overlay can be removed and replaced should the wearing surface deteriorate or should corrosives penetrate to the point of threatening the tendons. Estimates from various experts indicate an overlay life of about 15 years.

MDOT estimates that the bridge will serve the people of Michigan from 50 to 100 years. FHWA believes the bridge will fulfill its design life of 50 years. According to an MDOT Bridge Inspection and Maintenance engineer, Michigan has found that concrete bridges require much less maintenance than steel bridges, which need costly painting on a recurring basis to protect the steel. However, Michigan's existing concrete bridges are of a different design than the Zilwaukee Bridge and a direct comparison cannot be made.

Special concerns about Zilwaukee

As discussed in our first report, before the mishap MDOT had taken measures to resolve a problem with hairline cracking on the wing portions of individual bridge segments. An MDOT study had recommended repair procedures which MDOT implemented. The study also recommended that additional layers of pavement not be placed on top of the original overlay as allowed by the design specifications. Because of the concerns about possible excessive intrusion of corrosive material, MDOT also decided to (1) prohibit vehicles with overload permits from using the bridge and (2) use non-corrosive materials rather than salt for winter ice control.

A further reflection of MDOT's concern for structural maintenance was its August 1982 establishment of a maintenance committee comprised of several appointees from MDOT's Maintenance Division and one member each from its Design, Construction, and Testing and Research Divisions. According to a committee spokesperson, the Zilwaukee twin bridges will not need additional or more frequent inspections because of the mishap. The bridges will be inspected every 2 years, the same as other Michigan bridges.

In addition to the cracking before the accident, numerous cracks resulted from the mishap. The cracks occurred mainly along the joints in the top slab, down the segment walls, and in

the bottom slabs. As discussed earlier, MDOT plans to have these cracks repaired. According to the MDOT Engineer of Design, the mishap will have no effect on the bridge's service life.

Safety of the completed bridge

As noted above, a major factor in ensuring the bridge's durability and ultimately its safety is protecting the tendons which hold the structure together. MDOT has taken steps during bridge design and construction to protect the critical steel, and it is taking steps to ensure that the bridge is properly maintained. FHWA must certify annually that all of a state's federal-aid bridges are being properly maintained, but actual maintenance is wholly a state responsibility.

CONCLUSIONS

Our discussions with federal, state, and other pertinent officials and review of documents indicate that there is not enough history of or experience with concrete segmental bridges to accurately predict their service life and maintenance requirements. However, the consensus is that segmental bridges can provide years of safe service if properly designed, constructed, and maintained.

There are problems in protecting and preserving the service life of all bridges, and the science of doing so is still evolving. To date, FHWA and state officials are satisfied with the performance of segmental concrete bridges; however, they have recognized that the precautions must be taken to deal with cracking concrete and prevent tendon corrosion. The officials said that they would continue building these bridges in the future.

MDOT has taken steps to ensure the integrity of the reinforcing steel and the tendons in the Zilwaukee Bridge. MDOT's establishment of a special maintenance committee indicates an awareness of the importance that inspections and maintenance play in preventing corrosives from reaching the steel tendons. A further indication of this awareness is MDOT's decision to not use salt as an ice control agent on the structure.

PRECAST SEGMENTAL CONSTRUCTION

ON THE ZILWAUKEE PROJECT

At Zilwaukee the concrete bridge segments were precast in a plant built by the contractor at the bridge site. The segments were match cast (precast against each other) to ensure proper fit. The contractor used the balanced cantilever assembly method and a launching girder to position the segments on the bridge.

The balanced cantilever method involves first placing and anchoring a segment atop a support pier. Then, additional segments are alternately placed at each end of the pier segment out to mid-span. Each pier supports projecting segments (cantilevers), like wings, on each side of it. A pier frame (temporary framework) helps support the load on the pier while the cantilevers become unbalanced and then balanced again as segments are added. Where the two cantilevers from adjacent piers meet at mid-span, a concrete segment is cast in place between them to close the gap, forming a completed span. This procedure is repeated until the structure is completed.

Each segment added is attached to the already completed portion of the structure with temporary steel bars. They are joined to each other with permanent tendons (bundles of steel strands) stretched and anchored at each end (post-tensioning) after a segment is erected at the end of each cantilever. Before the segments are aligned and tightened to the already completed portion of a cantilever, their faces are coated with epoxy. This provides additional support, but the epoxy's main purpose is to seal the joint preventing the intrusion of moisture.

At Zilwaukee a typical tendon consisted of twelve 1/2-inch prestressing steel strands. Tendons were installed by being pulled through voids in the concrete segments formed by galvanized ducts. Next, they were tensioned using jack devices. After post-tensioning, the tendons were grouted to provide corrosion protection and to develop a bond between the steel and the surrounding concrete.

Segment manipulation was accomplished with a launching girder. A girder is a special mechanism that travels along the completed deck spans and maintains the work flow at that level. The essential parts of a typical launching girder are a main truss (group of steel beams forming a framework) with a length somewhat greater than the maximum bridge span, leg frames which are attached to the main truss, and a trolley which travels along the girder and is capable of moving a concrete segment in longitudinal, transverse, and vertical directions. During construction, by assuming various positions, the girder can place segments in cantilever, can place segments over piers, and can move to the next span so that the construction process can be repeated. This is the fastest method of cantilever construction, but it is limited to large projects because of the high initial cost of the launching girder.

The girder used at Zilwaukee weighs about 1,200 tons; its 940-foot length allowed the contractor to erect segments on two spans simultaneously. A 117-ton crane on the girder lifted segments from a delivery truck, travelled along the top of the girder, and carried the segments forward to their appropriate location. The girder has four movable legs, one fixed leg, one launching device to move the girder, and one leg to aid in placing pier segments on the next pier. The legs rest on the bridge until needed and are then positioned below the girder as supports. The legs are moved from span to span by the launching girder.

MDOT AND FHWA ANALYSIS OF PROJECT COMPLETION OPTIONS

In its July 15, 1983, response to FHWA, MDOT analyzed five alternatives for resolving the Zilwaukee Bridge project dilemma. These options and associated costs (some of which have already been incurred) are as follows:

Option	Estimated cost (millions)
1. The contractor completes the work under the existing contract at prices negotiated to reflect the changed character of the remaining work due to the mishap. It is assumed that potential claims of $29 million would ultimately be added to the construction contract price.	$137.6
2. The contractor terminates the original construction contract. This assumes payment of potential claims of $29 million as a result of litigation. A new contractor would complete the project, including purchasing the original contractor's production plant and equipment.	158.9
3. MDOT and the contractor mutually agree to terminate the original construction contract. MDOT buys the contractor's plant and equipment. MDOT selects a new contractor to complete the project.	119.2
4. The contractor completes the contract on an actual cost basis. MDOT buys the contractor's plant and equipment.	no less than 119.2
5. The contractor completes the contract at prices negotiated to reflect the changed character of the remaining work. MDOT buys the contractor's plant and equipment.	139.8

MDOT's audit group, with assistance from MDOT's construction division, developed the option cost estimates all of which include two commons costs: $61.9 million earned by the contractor on the original construction contract and $5.5 million for the repair contract. Because FHWA made an intensive review and analysis of the remaining cost elements for the five options prior to approving the termination, we accepted the option cost estimates as stated.

In its July 15, 1983, transmittal of this information to FHWA, MDOT concluded that the months of negotiation had convinced it that all possibilities for options 1, 4, and 5 had been exhausted and that only options 2 and 3 were realistic alternatives. Both options involved readvertising for a new contractor

to complete the bridge. MDOT stated that, under option 2, project costs potentially could reach almost $159 million and, in any comparison, would substantially exceed the cost of option 3. MDOT used the following cost estimates to support its conclusion that mutual termination was the most economical means of resolving the impasse and was in the public interest.

Item	Option 2	Option 3
	(millions)	
Bridge repair	$ 5.5	$ 5.5
Bridge completion[a]	62.5	42.2
Termination payment		13.0
Plant and equipment sale		(3.4)
Current contract earnings	61.9	61.9
Total	129.9	119.2
Maximum potential claims[b]	29.0	-
Total option cost	$158.9	$119.2

[a]The difference in the bridge completion costs between options 2 and 3 represents MDOT's estimated cost for a new contractor to purchase a production plant and equipment. MDOT said this difference was the original cost of the plant and equipment.

[b]Claims include delays, launching girder rental, and costs incurred higher than those provided for in the construction contract.

As shown above, the potential maximum claims of $29 million would be eliminated under option 3. They would be offset by the $13 million termination payment which covers both the claims and the purchase of the contractor's equipment. Also, MDOT reduced the option 3 estimates by $3.4 million, the estimated receipts from the sale of the purchased equipment and plant upon project completion.

FHWA Division staff analyzed the various MDOT cost estimates for the option elements including a rating of the potential claims. Their analysis revealed that the $20.3 million difference between the bridge completion amounts for the two options is the estimated costs to a new contractor for the purchase of the production plant, launching girder, and other associated equipment. FHWA staff concluded that this was a maximum amount and the actual cost might be as low as $8 million. FHWA staff also discounted some of the potential claims and indicated that the total option 2 cost could be as low as $125 million. FHWA's analysis resulted in no adjustments to the $119 million option 3 estimate.

ZILWAUKEE BRIDGE PROJECT

CONSTRUCTION CHRONOLOGY

Month	Year	Event
August	1979	State opened bids--low bidder was Toebe-Stevin (joint venture) with a bid of $76.8 million for a concrete structure.
September	1979	FHWA concurred with state's request to award the contract.
September	1979	Michigan Transportation Commission approved low bid of $76.8 million.
October	1979	Michigan Administrative Board approved contract with Toebe-Stevin with a November 15, 1983, project completion date.
October	1979	Contractor started construction.
March	1980	State contracted with BVN/STS for providing an onsite consultant, training of state staff, and reviewing contractor items (contract amount $393,000) with services commencing on October 15, 1979.
July	1981	State amended March 1980 service contract with BVN/STS for redesign of footings and services related to the launching girder (contract amount $294,000).
February	1982	State notified FHWA Michigan Division that BVN/STS might be acquired by Henningson, Durham, and Richardson, but Zilwaukee Construction Engineering, Inc., will continue the BVN/STS contract work.
July	1982	State contracted with Zilwaukee Construction Engineering, Inc., for work previously contracted to BVN/STS in March 1980 and June 1981 (contract amount $316,000) with services commencing on March 1, 1982.
August	1982	A section of the northbound bridge teetered and almost collapsed during construction, dropping about 5 feet on one end and rising about 3.5 feet on the other end. Material price adjustments and other changes had increased the contract amount to $81 million.

APPENDIX III

September	1982	State hired Howard, Needles, Tammen and Bergendoff to perform construction and inspection services related to the mishap, including determining its cause. The contractor hired T.Y. Lin to investigate the cause. Zilwaukee Construction Engineering also investigated the mishap.
October	1982	State announced repair approach with estimated cost of up to $3 million.
April	1983	Contractor agreed to permit MDOT to have another contractor make the repair.
April	1983	FHWA accepted repair proposal.
May	1983	State opened bids--low bidder was Walter Toebe Construction Company (one of the joint venture partners) with a low bid of $5 million.
May	1983	Michigan Transportation Commission and Michigan Administrative Board approved low bid and contract, respectively.
May	1983	Repair contractor started construction.
May	1983	Contractor proposed terminating the original construction contract and having another contractor complete the project.
June/July	1983	State and FHWA analyzed, considered, and negotiated regarding the proposed termination which would escalate the total project cost, including the repair, to an estimated $119.2 million.
July	1983	FHWA approved the mutual termination concept.
July	1983	State announced the termination agreement, which provided $13 million ($5 million for claims and $8 million for equipment and plant) to the contractor.
March	1984	Repair contractor missed November 15, 1983, completion date because of repair design and fabricating problems. Some deleted repair work will be added to the bridge completion contract. Repair completed March 23, 1984.

APPENDIX IV

U.S. Department of Transportation

Assistant Secretary for Administration

400 Seventh St S W
Washington D C 20590

JUN 1 1984

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

Dear Mr. Peach:

This is in response to your letter requesting Department of Transportation (DOT) comments on the General Accounting Office (GAO) draft report, "Delays and Increased Cost Result from the Zilwaukee, Michigan, Bridge Project Mishap," dated April 23, 1984.

The report states that investigations by the three design engineering firms involved in determining the cause of the mishap concluded that primary failure occurred at the temporarily locked-up expansion joint The reason for that failure, however, was not agreed upon by the three firms. The firms that were retained by the State and the contractor cited insufficient prestressing force across the joint while the third firm, conducting an unsolicited individual review, attributed incorrect contractor erection procedures and loadings as producing the failure due to excessive loads on the joint. The report also states that the consulting firm hired by the State to provide construction engineering services during erection of the structure, was in effect, providing the same services to the contractor. With this method of operation, the report states, no other independent check was made of the capability of the structure to accommodate the erection loads, only those calculations of the State retained consultant were used

In regard to the termination of the original contract by the State with concurrence by Federal Highway Administration (FHWA), the report states that the State and FHWA believe the decision was the best solution under the circumstances.

The maintenance, durability and safety of the structure in the future is addressed in the report with a GAO concluding statement that the State has taken steps to ensure the integrity of the reinforcing steel and the tendons in the bridge by establishment of a special maintenance committee. The report indicates a further awareness by the State of the problem since they do not plan to use salt as an ice control agent on the structure.

The DOT finds the GAO report substantially accurate and comprehensive on the matter. We concur with the reason for the failure being insufficient prestressing force across the failed joint.

It was pointed out in the GAO report that the reason the State hired a consultant to not only design the bridge, but to provide construction engineering services was the lack of experience by the State in designing and constructing this type of structure. It should be noted that the practice of hiring consultants is not unique to the State of Michigan. It is a practice that has been widely used in the past on major, complex structures, including those other than segmental concrete structures. The DOT has accepted this practice in the past and will continue to do so in the future.

The special provisions for the readvertisement of the completion of the structure have stipulations requiring the contractor to "obtain the services of an engineering firm that shall have demonstrated a thorough knowledge of concrete segmental bridges. This knowledge is to be demonstrated by having previously designed and provided construction engineering services for major concrete segmental bridges." We concur in this action and feel it imperative for proper construction management. In addition, the State will retain independent specialty engineering services to review the contractor's work.

In the future DOT and the FHWA will take appropriate steps to assure that each State has the capability to adequately oversee the construction of complex and innovative bridges and that consultants filling this role as the State's agent do not have a conflict of interest.

If we can be of further assistance, please let us know.

Sincerely,

Robert L. Fairman

APPENDIX V

STATE OF MICHIGAN

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

May 25, 1984

Mr. J. Dexter Peach, Director
Resources, Community, and Economic
Development Division
U. S. General Accounting Office
441 G Street, N.W. - Room 4915
Washington, D.C. 20548

Dear Mr. Peach:

You have furnished us with a copy of your draft report entitled, Delays and Increased Cost Result from the Zilwaukee, Michigan, Bridge Project Mishap. We are pleased that you have given us the opportunity to review and comment on the report prior to its publication.

The draft report does not appear to have any major errors or omissions. We do, however, have some minor matters to bring to your attention. We have referenced our comments to the page and paragraph where the item appears.

Page iii, paragraph 1:

We feel this portion of the digest does not accurately relate the facts concerning the payments made and to be made for the following reasons.

A. At the time of the mishap, $61.9 million was not due to the contractor.

B. Several months of work were done after the mishap which the termination agreement recognized, and

C. There is a $500,000 retainage in effect to assure that the contractor performs his obligations under the termination agreement. The entire balance of the retainage is required to be paid with interest to the contractor one year after the termination agreement was entered into unless drawdowns from the fund are appropriately made.

*Page numbers have been changed to correspond to the final report.

APPENDIX V

In order to better summarize the facts discussed on page 15 of the draft report, we believe the final two sentences of that paragraph might read as follows:

"The intent of the termination agreement is to pay the contractor up to $61.9 million for construction actually completed and materials purchased but yet to be used in the bridge. Currently, the project has not been finalized as $500,000 of the total of $74.9 million is being retained to assure that the contractor fulfills its obligations under the termination agreement."

[GAO COMMENT: We have revised the report to reflect this language.]

Page 7, paragraph 2:

Work was suspended on the northbound bridge but did continue on the southbound structure until normal winter shutdown late in 1982.

[GAO COMMENT: We have revised the report to reflect this language.]

Page 15, paragraph 1:

We find no definitive evidence that HNTB believes a deficient expansion joint design caused the mishap. They state on page 35 of their report to MDOT on the mishap, "The failure....was caused by the insufficient strength of the expansion joint in span 12 to resist the moments resulting from the construction loads on cantilever 11NS." This has been interpreted by MDOT to indicate that construction loads and conditions, approved or otherwise, caused the expansion joint's capacity to be exceeded.

[GAO COMMENT: We have revised the report to reflect this language.]

Page 16, paragraph 2:

The number of tendons across the expansion joints was reduced from 30 to 24 only after a re-examination by BVN/STS of loads and conditions affecting the joint. The contractor's proposed erection sequence placed reduced forces on the joint which made the tendon reduction appropriate.

[GAO COMMENT: We believe this simply adds detail to the discussion presently in the report.]

Page 17, paragraph 3:

The fifth sentence seems worded rather strongly. Perhaps more appropriate is, "No evidence has been found that MDOT or the contractor were made aware of this assumption."

[GAO COMMENT: The report statement is taken from an FHWA document detailing factors related to the mishap. We have revised the report accordingly.]

APPENDIX V

Page 20, paragraph 1:

While it is true that the contractor became somewhat dependent on ZCE, it is incorrect to infer that ZCE routinely provided stress calculations to the contractor. Prior practice had been for ZCE to review and reject unacceptable manuals, then discuss with the contractor the location and magnitude of any overstresses. The contractor would alter the manuals and resubmit them. MDOT is told that the only instance that ZCE provided calculations regarding erection loading to the contractor occurred in the approval sequence of the erection manual being used at the time of the mishap.

[GAO COMMENT: As noted in the report, this discussion reflects FHWA's view of events related to the mishap. FHWA states in its comments that it believes the GAO report to be substantially accurate and comprehensive.]

Page 23, paragraph 3:

The report states in Chapter 1 that it was not the intent to make any independent judgments of engineering matters related to the cause of the mishap. Nonetheless, it seems clear from a reading of Chapter 4 that the liability for the failure is being placed primarily upon ZCE. Chapter 4 of the draft ends:

"MDOT stated that it realizes that ZCE was wearing two hats. MDOT told us that responsibility for the mishap runs from the contractor to ZCE to MDOT."

The meaning of the last sentence is unclear. Is it to be taken that the contractor is primarily at fault? Since this runs counter to preponderance of information presented in Chapter 4, and is not the official position of MDOT, we suggest that this confusing sentence be deleted.

[GAO COMMENT: The basis for this material was statements made to us by MDOT officials. Based on these comments, however, we have deleted this material from our final report.]

We wish to thank your office for giving the department the opportunity to review and comment on the draft report and we understand the copies will remain the property of the United States General Accounting Office and will not be improperly discussed by this department.

Sincerely,

James P. Pitz
Director

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