H-517A

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

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In reply refer to: H-88-12
through -15

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On April 5, 1987, two of the five spans of the New York State Thruway (I-90) bridge over the Schoharie Creek fell about 80 feet into a rain-swollen creek after pier 3, which partially supported the two spans, collapsed. Ninety minutes after the initial collapse, pier 2 and a third span collapsed. Four passenger cars and one tractor-semitrailer plunged into the creek, and 10 persons were fatally injured. 1/

The Schoharie Creek Bridge, which was opened in 1954, was generally designed and constructed to comply with the 1949 American Association of State Highway Officials (AASHO) "Standard Specifications for Highway Bridges" as required by the design contract. Section 3.1.1 of the standards called for a careful study of local conditions including flow (discharge) and frequency, performance of other bridges in the vicinity, and other information pertinent to the design of the bridge and likely to affect the safety of the structure. In response to written questions from the National Transportation Safety Board, the bridge designer, Pavlo, stated that he did not study the history of Schoharie Creek before preparing the final design. Madigan-Hyland Consulting Engineers (M-H), who developed the preliminary plans, design plans, specifications, and quantity and cost estimates, conducted a limited hydraulic review as indicated by its hydraulic sheet. However, the sheet did not call for comments nor were comments added concerning the creek's flood history or the performance of structures along the creek during prior floods, even though some of the information was readily available at the time. The New York State Department of Public Works (DPW) subsequently provided such information on some floods to M-H.

1/ For more information, read Highway Accident Report--"Collapse of New York State Thruway Authority (I-90) Bridge Over the Schoharie Creek, Amsterdam, New York, April 5, 1987" (NTSB/HAR-88/02).

Correspondence between M-H and the DPW relating to hydraulics usually addressed the length of the bridge and the elevation of the backwater, but not the frequency and magnitude of previous floods or their effects on other structures over the Schoharie Creek. For example, Safety Board investigators were unable to find in the M-H hydraulic sheet any mention of the three floods that exceeded 50,000 cubic feet per second (cfs), which occurred during the first half of the 20th century, let alone an analysis of their importance to the design and construction of the bridge.

The M-H hydraulic sheet does indicate that M-H was aware of the potential for erosion in the banks and the streambed of the Schoharie Creek, but its failure to review the available history limited its appreciation for the potential for scour at this bridge site. If M-H had visited some of the other structures along the creek, such as the aqueduct 3,000 feet north of the bridge, it probably could have observed scour near the piers and this may have heightened its concern for scour.

Section 3.5.2 of the AASHO Standards stipulated that the bottom of the footing of a pier in a stream should not be less than 6 feet below the permanent bed of the stream. Further, section 2.1.2 of the AASHO Standards stated that the elevation of the bottom of the footing, as shown on the plans, "shall be considered as approximate only and the engineer may order... changes in...elevation of footings."

Documentation on this bridge is inconsistent concerning the elevation of the streambed at the piers. According to 1951 soil boring tests and a March 1952 field survey, the elevation of the streambed at the bridge site at that time was 276 to 277 feet. However, the design plans (dated September 1952) showed the elevation of the streambed near pier 2 at approximately 273 feet at the northwest corner of the pier and about 275 feet at the southeast corner of the pier. Further, according to a survey for the final quantity estimates, the ground at pier 2 had an elevation of just below 273 feet. The survey also showed the elevation of the bottom of the footing to have been 270 feet (3 feet below the streambed at the northwest corner of pier 2).

To comply with section 2.1.2 of the AASHO Standards, the design engineer or the engineer in the field should have modified the design plans to place the bottom of the pier 2 footing at an elevation about 267 feet or lower. This elevation would have placed the bottom of the footings 6 feet below the streambed elevation of 273 feet indicated in the final quantity estimates.

Although the lowest streambed elevation shown in any of the design documentation was 273 feet, the elevation of the maximum scour depth near pier 2 was measured at approximately 265 feet after the accident. Thus, even if the bottom of the footing at pier 2 had been placed 6 feet below the streambed at an elevation

of 267 feet or slightly lower, the collapse of pier 2 in the accident probably would not have been averted although it may have been delayed. However, the undermining of the foundation beneath pier 2 occurred only after the creek flow was diverted by the debris from spans 3 and 4; consequently, this design deficiency did not contribute to the initial collapse of the bridge.

Unfortunately, in the early 1950s, no method was available to predict scour depth. Today, methods do exist to estimate the maximum depths of scour conservatively, but these methods may not be as precise as desired. The current American Association of State Highway and Transportation Officials (AASHTO) requirement for spread footings is very similar to the 1949 AASHO requirements. Based on this collapse, as well as on an improved understanding of hydraulics and an improved ability to predict scour, the Safety Board believes that AASHTO should modify its requirements for the depth of the footings (section 4.4.2.1 of the Standard Specifications for Highway Bridges) and require that the depth be based on estimates of the maximum potential depth of scour at the bridge site, rather than on the existing streambed elevation.

Scour piles may have provided the stability needed for the substructure to withstand the scour of the 1987 flood since the maximum scour depth observed at the bridge site was 9 feet below the bottom of the footing of pier 3. The AASHO Standards stated that scour piles should extend not less than 10 feet below the footing. However, since the Safety Board cannot be certain how deep the scour hole at pier 3 may have become had spans 3 and 4 not fallen when they did, it is not possible to conclude that piles driven in accordance with the AASHO recommendations for pile depths would have prevented the bridge collapse. Certainly, if piles were driven deeply enough, the piers would not have lost their support. Therefore, the Safety Board concludes that had the Schoharie Creek Bridge been designed with piles to protect against scour, the collapse might not have occurred, depending on how deeply the piles were driven below the footings.

However, AASHO specifications and design standards in the early 1950s were not absolutely clear as to when piles should be specified by bridge designers. Section 3.5.1 of the AASHO Standards specified that at locations where unusual erosion might occur and where the soil conditions permitted the driving of piles, piles should be used to protect against scour, even if the safe bearing resistance of the natural soil was sufficient to support the structure without piling. Although section 3.5.1 used the words "unusual erosion," it did not define these words or provide any guidance on how one would determine if "unusual erosion" might occur.

Using formulas available today, Colorado State University (CSU) predicted a maximum depth of scour at pier 3 of 26 feet. (The maximum depth observed at the accident site was 15 feet.) It is possible that had the bridge not collapsed when it did, with its debris changing the creek flow, the depth of the scour hole at pier 3 might have increased and perhaps even approached the 26-foot depth estimated by CSU. Obviously, a predicted depth of scour of 26 feet would have justified the use of piles at this site although, to have been effective, the piles would have had to be driven well below the 10-foot depth recommended by the 1949 AASHO Standards.

Section 4.3.1.2 of the current AASHTO Standards still allows piles to be driven to a depth of 10 feet, as did the 1949 AASHO Standards. However, section 4.3.5.4 of the current AASHTO Standards states, "Subsurface investigations shall be made that will determine the probable depth of scour or flotation of material and the condition of lateral support of the piles." Although this could be interpreted by some designers as overriding section 4.3.1.2, other designers may simply follow the provisions of section 4.3.1.2. Thus, the Safety Board believes that section 4.3.1.2 should be modified to require that the depth of piles exceed the predicted maximum potential depth of scour.

When the Schoharie Creek Bridge was designed and built, the use of riprap was a recognized means of providing protection against scour and riprap was specified in the contract. Without piles, the integrity of the bridge foundation depended completely on the maintenance of riprap for protection against scour. Based on pictures and inspection logs, the Safety Board concludes that, as indicated on the design plans, the construction company did install a thick layer of riprap around piers 2 and 3. This layer of riprap, which included large rocks, protected the pier foundations during the flood of record in 1955 and numerous smaller floods. The 1955 flood of record had the potential to move large quantities of riprap from the front of piers 2 and 3. Although the inspection report for the acceptance of the bridge on May 31, 1956, did not mention riprap movement, photographs taken on October 30, 1956, showed movement of riprap northward along piers 2 and 3. Other photographs taken from 1954 to 1977 during low water disclosed that some of the rocks had moved northward during that period of time.

Photographs taken in 1956 indicate that riprap originally placed at the south end of pier 3 moved northward along the east side of the pier. To the east of pier 3, a 3.5-foot increase in riprap over that specified in the design plans is visible in the 1956 photographs. This represented as much as 65 percent of the riprap that had been originally placed at the south end of the piers, assuming that few cobbles were mixed in with the riprap. This indicates that the south end of pier 3 may have lacked significant protection due to lack of riprap since 1956.

Inspections in 1977 and 1979 indicated that some of the riprap and streambed material had moved at pier 3 and even more had moved at pier 2. Due to the lower water velocities at pier 2, lesser amounts of cobble and other larger material may have been transported into the scour area at pier 2 than into the area around pier 3. After 1977, the frequency and magnitude of floods increased, and the movement of riprap away from pier 3 and its replacement with cobbles and streambed material probably increased.

Further, based on the magnitude of their flows, their direction, and their similarities in velocity, the floods of 1955 and 1987 (as demonstrated by photographic evidence and by the results of the physical models and the computer analyses) had similar erosion capability. The Safety Board thus concludes that had the piers been protected by riprap at the time of the April 1987 flood as they were during the 1955 flood, the bridge probably would not have collapsed.

From the time the Thruway was opened, the New York State Transportation Authority (NYSTA), as did the New York State Department of Transportation (NYSDOT) and many other organizations, used maintenance personnel to inspect bridges for both maintenance needs and safety inspections. The inspections in the NYSTA Albany division were accomplished not by engineers but by personnel whose primary responsibilities were in bridge maintenance. The Albany assistant division engineer (bridges) was not a professional engineer but had received the training and had the years of experience required by the Federal Highway Administration (FHWA) National Bridge Inspection Standards (NBIS) to qualify for conducting bridge inspections.

However, in his 1986 inspection of the bridge, and in previous inspections, the Albany assistant division engineer (bridges) failed to evaluate the condition of the riprap at the piers properly, and he failed to take the dropline readings necessary to evaluate the conditions in the streambed. These two tasks were specifically required in the NYSDOT Bridge Inspection Manual (BIM-82) and earlier documents on bridge inspections. The fact that he overlooked these two tasks indicated that he either did not think they were important or he did not understand their importance. In addition, the engineer's supervisors, who should have reviewed his reports, apparently did not review his reports or failed to recognize the seriousness of the omissions and therefore did not attempt to correct the situation.

The Albany assistant division engineer (bridges) may have assumed that the bridge piers were built on piles and therefore did not regard riprap maintenance as important. In his 1986 inspection of the bridge, he gave piles a rating of "9," indicating condition unknown, rather than "8," not applicable. At the Safety Board's public hearing, he also indicated that he thought the bridge was constructed on piles. Some of the bridge inspection reports that he signed as far back as 1970 indicate that he thought the bridge was built on piles, but other reports indicate the opposite.

Entries in the maintenance log of the Schoharie Creek Bridge date back to 1955. None of the entries address the maintenance of riprap. The Albany assistant division engineer (bridges) said that he did not recall riprap ever having been placed or maintained around the pier footings. Further, there is no evidence to indicate that riprap had ever been replaced around the piers after the bridge was opened to traffic in 1954.

In 1979, an engineering firm conducted bridge inspections for the NYSDOT to comply with the NBIS inventory requirements for off-system bridges. Sketches made by the assistant team leader during that inspection clearly showed that riprap around piers 2 and 3 was missing. The measurements on the sketches, when compared with the original design plans, showed a significant decrement in the riprap cover of the footing. The measurements and photographs from the inspection clearly indicated that riprap was not piled at an even level around the plinth. This information should have alerted a person knowledgeable in river mechanics and structures that riprap had moved, posing a danger to the structure. However, the team leader, a registered professional engineer, gave both piers 2 and 3 a rating of 6 for its scour condition. This was the best rating that could be given if erosion or scour had affected, in any way, the material above the bottom of the footing but had not undermined the footing. A rating of 7 would have indicated that there had not been any loss of material around the piers. The team leader also coded the pier-piles column in the bridge inspection report as "8," meaning that no piles were present under the piers.

The Safety Board believes that the sketches showed that a significant amount of riprap had moved away from the upstream ends of the piers in 1979 and, especially since there were no piles, the engineering firm should have, in accordance with its agreement with the NYSDOT, immediately called the NYSDOT project manager to alert him. The call also should have been followed with a letter. However, there is no evidence that the firm so notified the NYSDOT (or the NYSTA) of the riprap deficiency.

When the NYSDOT received the report, it did not notify the NYSTA of the missing riprap, indicating either that NYSDOT personnel did not review the report or that they believed the missing riprap required no attention. It is quite likely that NYSDOT personnel did not review the report since they only reviewed some of the inspection reports and those they did review were generally reviewed for coding and format errors only.

When the NYSTA finally received the report in April 1980, it did not replace the missing riprap, indicating either that it also did not review the report or that it did not consider the situation serious enough to require correction. If the report was reviewed by the NYSTA, the sketches and the rating elements should have alerted the reviewer that the bridge was not built on piles and that the depletion of riprap was important. Further,

the inspections should have relieved the NYSTA of the need to perform a bridge inspection that year; the time saved could have, and should have, been used to thoroughly analyze the report. (These inspections of the Schoharie Creek Bridge were on March 26 and August 15, 1979; the NYSTA's inspection was on October 21, 1979.)

In 1982, a major rehabilitation project greatly improved the superstructure and substructure above the water line based on inspections, reports, and plans prepared by an engineering firm hired by NYSTA. Unfortunately, the plans finalized by the NYSTA did not call for the replacement of missing riprap with 600 cubic yards of 600-pound riprap, as had been specified in these plans. Replacement riprap was removed from the plans at the direction of the NYSTA technician responsible for finalizing the plans.

Memoranda written in 1978 and 1980 by NYSTA personnel indicated that the assistant superintendent of maintenance (bridges), the director of construction and design, and the design unit head were aware that riprap had been called for as part of the rehabilitation plans. When a technician decided to delete riprap from the final plans, these same supervisors either checked the plans and agreed with his decision, or they did not check the plans. The Safety Board believes that a failure of the supervisor to review this decision would have been a major deficiency in his oversight of a subordinate. In either case, however, the decision not to replace the riprap was a critical decision that contributed to the cause of the accident.

The circumstances of this accident show that better guidance is needed. Inspectors (and some supervisors) from the NYSTA, the NYSDOT, and the firm hired by NYSDOT either failed to understand the importance of riprap or failed to recognize that sufficient riprap had migrated from piers 2 and 3 to pose a danger to the bridge.

The Safety Board believes that the inadequate guidance in the replacement of riprap provided to the NYSTA inspectors resulted, in part, from the lack of specific guidance available at the time from the FHWA or AASHTO. In fact, it is not clear that the situation is any better today. The Safety Board has reviewed literature from several organizations that provided guidance on bridge inspection and maintenance and has found no specific guidance on when to replace riprap and very little on when to repair scour damage at piers founded on spread footings. Many bridge engineers state that specific guidance cannot be provided, but that inspectors need to use their engineering judgment.

The Safety Board is concerned that bridges similar to the Schoharie Creek Bridge may not be receiving proper riprap maintenance because there is no proper guidance as to when to replace riprap. The Safety Board is aware that specific guidance cannot cover every possible condition and that bridge inspectors indeed need good engineering judgment. The Safety Board also recognizes that experienced bridge engineers may generally be able to recognize when riprap needs to be replenished or replaced or when other foundation repairs are required. However, most bridge inspectors are not now, and are not likely to be, experienced bridge engineers. The Safety Board is thus convinced that specific guidance must be provided to bridge inspectors.

The Safety Board believes that research is needed to determine the size and amount of riprap needed for scour protection and the degree of depletion that may occur before replacement is necessary. (The Safety Board recognizes that highway maintenance departments cannot replace each rock as it moves.) The Safety Board is concerned that bridges similar to the Schoharie Creek Bridge may not be receiving proper riprap maintenance because there is no proper guidance as to when to replace riprap. Therefore, the Safety Board believes that, until research is done to establish better guidance, AASHTO, the NYSDOT, and the NYSTA should modify their guidance to specify that, after each inspection of a bridge that depends upon riprap for scour protection, any missing riprap must be replenished to design specifications or to a higher level of protection.

The Safety Board believes that not enough data is currently available to determine with sufficient accuracy and reliability the movement of riprap under different stream conditions. Current research can only establish a broad range of velocities that would move riprap of a given size (weight). Thus, riprap stability analyses can provide bridge designers with only very rough estimates of sizes of riprap needed to protect a bridge foundation. Present equations and calculations used to predict riprap stability need to be refined.

The current AASHTO Manual for Bridge Maintenance - 1987 and its predecessor (1976) provide a "rough guide to the selection of an adequate stone size at bridge crossings." This table indicates that riprap with an average stone size of 600 pounds will provide adequate scour protection even when the average velocity of a stream is 10 to 15 feet per second (fps). The results of the CSU study show that the velocity at a pier can be greater than the average stream velocity as a result of bends in the streambed. Further, the curve data indicate that velocities of 10 to 15 fps could move riprap weighing as much as 1,000 to 6,000 pounds. The other AASHTO specifications of 6-inch stone for streams with velocities up to 7 fps and 100-pound stone for velocities of 7 to 10 fps also appear to be too low when compared to the movement of 300-pound riprap around piers 2 and 3 of the Schoharie Creek Bridge. The Safety Board believes that AASHTO should issue an addendum to this recent publication to caution the user not to rely on the information in the table.

Therefore, the National Transportation Safety Board recommends that the American Association of State Highway and Transportation Officials:

Revise section 4.4.2.1 of the Standard Specifications for Highway Bridges removing any reference to a minimum depth of 4 to 6 feet for bridges over water and stating instead that the minimum depth of footing be based on historical data for scour at or near the bridge site and mathematical analyses of maximum potential scour depth. (Class II, Priority Action) (H-88-12)

Modify section 4.3.1.2 of the Standard Specifications for Highway Bridges to require that the depth of piles exceed the predicted maximum potential depth of scour. (Class II, Priority Action) (H-88-13)

Provide specific guidance on maintenance of foundations of bridges that are dependent upon riprap for scour protection to specify that following each inspection the riprap be replenished to meet the design specifications. (Class II, Priority Action) (H-88-14)

Issue an addendum to the Manual for Bridge Maintenance-1987 that strongly cautions the user that the chart on page 160, which is a "rough guide to the selection of an adequate stone size at bridge crossings," is probably inadequate to ensure that all the riprap will remain in place under the average velocities listed; issue an errata sheet to correct previous editions. (Class II, Priority Action) (H-88-15)

Also, the Safety Board issued Safety Recommendations H-88-16 through -20 to the Federal Highway Administration; H-88-21 to the U.S. Department of Transportation; H-88-22 to the New York State Department of Transportation; and H-88-23 to the American Association of State Highway and Transportation Officials, the International Bridge, Tunnel and Turnpike Association, the National Association of Counties, the National League of Cities, and the National Association of Towns and Townships.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility ". . . to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any actions taken as a result of its safety recommendations and would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendations H-88-12 through -15 in your reply.

BURNETT, Chairman, KOLSTAD, Vice Chairman, and LAUBER and NALL, Members, concurred in these recommendations.

By: Jim Burnett
Chairman