Rec H-408

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C.

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Forwarded to:

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Federal Highway Administration
Washington, D.C. 20590

SAFETY RECOMMENDATION(S)

H-84-40 through -54

At 1:30 a.m., e.d.t., on June 28, 1983, a 100-foot-long suspended span between piers 20 and 21 of the eastbound traffic lanes of the Interstate Route 95 highway bridge over the Mianus River in Greenwich, Connecticut, collapsed and fell 70 feet into the river below. Two tractor-semitrailers and two automobiles plunged into the void in the bridge and were destroyed by impact from the fall. Three vehicle occupants died, and the other three received serious injuries. 1/

The suspended span which collapsed was attached to the bridge structure at each of its four corners. To support the weight of the northeast and southeast corners of the suspended span, each corner was attached to the girders of the cantilever arm of an adjacent anchor span by a pin and hanger assembly. The pin and hanger assembly includes an upper pin attached through the 2 1/2-inch-thick web of the girder of the cantilever arm and a lower pin attached through the 2 1/2-inch-thick web of the girder of the suspended span. One and one half-inch-thick steel hangers connect the upper and lower pins—one on the inner side and one on the outer side of the web.

Sometime before the collapse of the suspended span, the inner hanger in the southeast corner of the span came off of the inner end of the lower pin. This action shifted the entire weight of the southeast corner of the span onto the outer hanger. Over a period of time, the added weight initiated a fatigue crack in the top outer end of the upper pin. The outer hanger gradually worked its way farther outward on the pin, and when it reached the fatigue crack, the shoulder of the pin fractured off and the assembly failed. The span briefly balanced on its connections at the other three corners and then collapsed, southeast corner first, into the river 70 feet below.

The National Transportation Safety Board determined that the probable cause of the collapse of the Mianus River Bridge span was the undetected lateral displacement of the hangers of the pin and hanger suspension assembly in the southeast corner of the span by corrosion-induced forces due to deficiencies in the State of Connecticut's bridge safety inspection and bridge maintenance program.

1/ For more detailed information read Highway Accident Report—"Collapse of a Section of Interstate Route 95 Highway Bridge Over the Mianus River, Greenwich, Connecticut, June 28, 1983" (NTSB/HAR-84/03).

Neither the Federal Highway Administration (FHWA) nor the American Association of State Highway and Transportation Officials (AASHTO) have developed a written inspection technique to detect hanger displacement. Measurement of spaces between members was advocated in both the FHWA "Manual for Maintenance Inspections of Bridges" (1970) and the Connecticut Department of Transportation (ConnDOT) "Field Bridge Inspection Booklet." The FHWA was aware of the problem because the AASHTO "Manual For Bridge Maintenance" (1976) contained the hazard advisory about the difficulty of pin and hanger bearing inspection. However, the FHWA did not initiate a project to address the inspection problem, and no action was taken by either AASHTO or the FHWA to develop a workable inspection technique. Such action was within the FHWA's technical development responsibilities with respect to bridge inspection.

On April 20, 1971, the FHWA issued the National Bridge Inspection Standards, which were based generally on the "Manual for Maintenance Inspections of Bridges," published in 1970 by AASHTO. The standards require that: (1) all States have a bridge inspection organization, (2) inspectors meet minimum qualifications, (3) each structure be rated as to its safe load-carrying capacity, and (4) inspection records and bridge inventories be prepared and maintained in accordance with the standards. The standards further require that every bridge in a public road be inspected at regular intervals not to exceed 2 years. The depth and frequency of inspections depend on such factors as age, traffic characteristics, state of maintenance, and known deficiencies. The evaluation of these factors is entirely the responsibility of the individual in charge of the inspection program; the weight to be given these factors is not specified in the standards.

The AASHTO "Manual for Maintenance Inspections of Bridges," intended to inform bridge inspectors of what to look for during inspections, was first issued in 1970 and was prepared by the AASHTO subcommittee on bridges and structures. This manual was incorporated by reference in the National Bridge Inspection Standards and thereby became an enforceable standard. The AASHTO "Manual for Bridge Maintenance" was first issued in 1976 and was prepared by the subcommittee on maintenance. Page 182 of this manual contained a specific hazard advisory on pin and hanger bearings: "Rusting between the plates is very difficult to detect unless bearing is dismantled." Both AASHTO manuals were approved by the AASHTO Standing Committee on Highways, whose secretary was the FHWA Associate Administrator for Engineering and Operations. As the FHWA Associate Administrator, he coordinated the activity of the two FHWA Divisions and Offices involved with bridge design, inspection, and maintenance. The chiefs of these two divisions also were Secretaries to the two AASHTO subcommittees which prepared the AASHTO manuals. Employees of the FHWA Construction and Maintenance Division worked on details of the AASHTO manuals as part of their Federal employment. The manuals were published by AASHTO, and copies were sent to the States by the FHWA. The FHWA regarded this work on the AASHTO manuals as part of its responsibility to help transfer technology.

Whenever new technical information about bridge maintenance is developed from any source, it can be published as an FHWA document or as an AASHTO voluntary guideline. In this instance, the hazard advisory and dismantling information on pin and hanger bearings was published only in the AASHTO "Manual for Bridge Maintenance." The FHWA secretary of this subcommittee said that he was not aware of any policy that would have prevented putting the hazard advisory also in the "Manual for Maintenance Inspections of Bridges." The latter manual was revised twice after its initial version was issued, and the hazard advisory was not included in either revision. He also said that the hazard advisory could have been added to the FHWA "Bridge Inspector's Training Manual" as an improvement. However, the FHWA did not modify the "Bridge Inspector's Training Manual" at any time during the 13 years after it was issued. Neither the FHWA nor AASHTO did any further study on the subject of pin and hanger bearings inspection, and no research has been proposed to address the subject.

The bridge inspectors did not use a written checklist specific to this bridge on the job. They did not follow the details in the ConnDOT "Field Bridge Inspection Booklet" and the FHWA "Bridge Inspector's Training Manual" during their inspections. Both documents contained considerable detail not applicable to the Mianus River Bridge, and this may explain why they were not used. Moreover, the items to be inspected were not arranged in a sequence of movement over the bridge. The inspectors apparently had worked out their own sequence of inspection, but it was not in a written form. The bridge reports were filled out from notes and memory after the inspectors had left the bridge. This method did not ensure that all items were observed.

The bridge inspector's report of September 1982 rated "alignment of members" at "8," a rating that means the rated part is subjectively judged to be in as good condition as when built. There were no written, objective, dimensional standards for measuring "alignment of members," even though the FHWA "Bridge Inspector's Training Manual" makes it clear that misalignment raises questions regarding the condition of bearings. Misalignment found in other spans after the accident was due to corrosion, which does not develop in a short time. Therefore, the Safety Board believes that at least three of the four suspended spans had been misaligned vertically (sagged) for some time, that the spans may have been misaligned at the time of the September 1982 bridge inspection, and that the vertical alignment possibly had not been adequately inspected. The high rating assigned to "alignment of members" was misleading and may have prevented the engineers in the inspection program who received the reports from being alerted to the serious problems which misalignment can indicate.

After the inside hanger had been displaced off the end of the lower pin at the southeast corner, the hanger would have moved along the upper pin so as to be at least 1/2 inch farther away from the girder than when it was installed. The spacer washers on the upper pin were observed to be dished outward by rust anywhere from 1/2 to 1 inch; they would have been occupying the additional space between the hanger and the girder. The junior inspector's finding of a "handful of flaked rust" in the joint did not cause him to record anything more than the general entry "laminated rust" in the "bearing" section of the inspection form, without any designation of which "bearing" (pin and hanger). Neither inspector noticed the change of dimensions that was observable, possibly because they did not get close enough, and an opportunity to detect the problem and prevent the collapse was missed.

A ConnDOT engineer stated that dismantling of the pin and hanger assembly for inspection had not been considered before the collapse of the span. Had such consideration been given, and dismantling then been found too disruptive or costly, the need to address the uninspectable condition in some other way would have been obvious. It would have been logical, had the problem actually been studied, to direct closer attention to the presence of rust or to changes in span alignment, for example. Despite the hazard advisory in the AASHTO maintenance manual, ConnDOT did not realize, before this accident, that the safety of the bridge could not be ascertained with certainty without careful pin and hanger inspections.

In light of the techniques used successfully after the accident, it now appears that the pin and hanger assemblies could, in fact, have been inspected for severe damage and rust without dismantling the hangers. Cleaning to remove rust which had developed between washers probably would have uncovered the problem. Holes could have been drilled in pin caps to permit examination of the end of the bearing surfaces. Measurements of hanger location and misalignment of spans to indicate bearing trouble could have been specified. These methods did not require large research projects, but did require some study. However, even though the AASHTO manual had advised that bearing inspections were critical and that dismantling of the pin and hanger assembly was advised, neither AASHTO nor the FHWA initiated a study of the problem.

The advisory statement on dismantling hangers in AASHTO's "Manual for Bridge Maintenance" was clear, but the fact that a bridge might collapse if bad bearings were not discovered was not explained. Further, the AASHTO statement did not actually "recommend," much less assert, the critical need for a detailed inspection, much less one involving dismantling of bearings. Given the nature of the AASHTO advisory, failure to dismantle was most understandable. The advisory was based on the technical judgment of AASHTO that good practice calls for dismantling for inspection, but AASHTO did not word the statement in a way that clearly suggested an imperative need to follow this practice. AASHTO's failure to include the advisory in subsequent revisions of the "Manual for Maintenance Inspection of Bridges" left the problem unaddressed in any current AASHTO document. The original AASHTO document seems to have made little or no impression on ConnDOT employees. The purpose of the National Bridge Inspection Standards—to avoid a repetition of a previous catastrophic bridge collapse—was thereby defeated.

Updating of Federal training materials also might have alerted ConnDOT bridge safety inspectors to the critical need of inspecting hangers carefully. ConnDOT inspectors received recurrent federally funded training, but it did not alert them to the need to inspect hangers closely or how to do it. The training relied on the FHWA "Bridge Inspector's Training Manual," which had not been revised significantly since 1970. Thus, publication of the AASHTO "Manual for Bridge Maintenance" in 1976, with its advisory about the need for and the difficulty of inspecting pin and hanger bearings, did not help users of the "Bridge Inspector's Training Manual."

The "Bridge Inspector's Training Manual" should have been improved since 1970 in several ways beyond the addition of AASHTO technical information. It should have been issued in a looseleaf format to ease updating. The manual should have been designed to complement bridge inspection forms used by the States. It should have trained inspectors to develop an inspection sequence checklist for each bridge. Descriptions of critical failures and objective measurements should have been included. The manual should have been organized so that pages could be arranged to refer to specific bridges.

The determination of the proper pin diameter in the pin and hanger assembly depended primarily on the bearing stress chosen. The American Association of State Highway Officials (AASHO) specifications stated that the bearing stress to be used in calculating the minimum diameter was 12,000 psi for pins subject to rotation (not due to deflection) and 24,000 psi for pins not subject to rotation. The design calculations indicated that the maximum angular movement of the pin would be 4°20', which in 1953 was not considered to be rotation, and the designer chose a bearing stress of 12,000 psi. The design checker (employed by the same design firm) disagreed that this amount of movement was sufficient to be considered rotation and changed the bearing stress to 24,000 psi. The consulting engineer hired by ConnDOT in conjunction with its investigation of this accident stated that the higher bearing stress was a proper interpretation of the 1953 AASHO specifications. The designer's calculations indicated that the actual bearing stress on the pins in the Mianus River Bridge design under both live and dead loads was 17,900 psi. The bearing stress due to the dead load only was calculated to be 11,900 psi.

The bearing stress on the pin at the southeast corner of the fallen span under the dead load, combined with the maximum live load, was calculated to be 17,900 psi. This stress is lower than the 24,000 psi allowed by the 1953 AASHO "Standard Specifications for Highway Bridges" for pins not subject to rotation, but more than the 12,000 psi allowed for pins subject to rotation. The use of 24,000 psi in the original design was in accordance with accepted engineering design at the time. That is, in selecting the bearing stress, the pins in the pin and hanger design were not considered rotating members. The design specifications for such bridges have been changed or clarified over the years, and the allowable bearing stress in the design of a similar assembly today would be 14,000 psi for the design of a pin, (see 1983 AASHTO "Interim Specifications, Bridges), or about 29 percent higher than the calculated stress achieved under maximum live load loading. Assuming 17,900 psi stress actually occurred, it is still only about 50 percent of the yield strength.

The Safety Board has concluded that at the time the Mianus River Bridge was designed, standards for designing stuctures did not give sufficient attention to ensuring inspectability and maintainability. Inspectability and maintainability are not prominent goals in the state-of-the-art of bridge design even now. These considerations, which are elements of "reliability and maintainability," essentially require that a structure be designed so that it can be inspected and maintained as a reliable system. Inspection manuals and maintenance manuals, when based on a specific bridge and its environment, are of more value to workers than general instruction books such as the "Bridge Inspector's Training Manual." This manual was not used by inspectors because it was not targeted toward specific bridges and because it contained much material that had no application. The Safety Board believes that the bridge safety inspection unit should review the plans for a new bridge to determine if the structure can be safely and adequately inspected and maintained. Inspectors also should conduct a postconstruction survey of a new bridge to ensure that specifications for inspection and maintenance have been met by the builder.

The primary factor in the failure of the pin and hanger assembly was corrosion. The changes made to the bridge since the accident have restored the geometry of the pins and hangers at the other suspended spans and reduced the bearing stresses. Since the major structure of the spans is essentially unchanged, and so long as corrosion is controlled, this circumstance offers an opportunity to observe whether the skewed design of the spans and the calculated out-of-plane movement of the large longitudinal girders actually causes the hangers to move outward on the pins in the absence of corrosion. Notwithstanding its findings, the Safety Board would encourage capitalizing on the opportunity to test the structure to determine whether the calculated out-of-plane movements occur. A similar opportunity to observe tendencies to movement of hangers on pins in skewed spans in the absence of corrosion exists at other skewed-span bridges on the Federal Highway System. The FHWA should conduct detailed inspections of the Mianus River Bridge and other representative bridges having a skewed and nonskewed suspended span design with pin and hanger assemblies to determine whether there is a significant difference between the two designs in terms of the movement of hangers on pins due to either dead or live loading.

The General Accounting Office (GAO) issued a report in 1975 concerning the FHWA's program for identifying, improving, and replacing unsafe bridges on the Federal-aid highway system. 2/ The report emphasized the need for more attention to the problem at both the Federal and State levels. It concluded that the FHWA did not actually require the 3-week inspection training course based on its "Bridge Inspector's Training Manual," and that relatively little use had been made of the course. In Connecticut, for example, the course has been condensed to a 4- or 5-day session and is given on a 3-year cycle. FHWA's review of ConnDOT's compliance with the National Bridge Inspection Standards did not review the adequacy of their training course--in fact, it did not even mention that one existed. The FHWA should review each State's bridge inspection training program during the annual bridge inspection program audit.

2/ "Unsafe Bridges on Federal-Aid Highways Need More Attention," Comptroller General of the United States, General Accounting Office, Report to Congress, July 2, 1975 (RED-75-385).

The GAO report recognized that identification of structural defects, corrosion, and fatigue was becoming more important because many bridges were old and the heavy truck traffic was increasing. It identified a need to develop inspection equipment for use by bridge inspectors to detect structural defects not visible to the eye so as to protect the public against bridge failures. Research has been done in this area, but the resulting technology has not yet filtered down to the inspection level. The inspectors of the Mianus River Bridge, for example, did not have and never used equipment to perform nondestructive tests. The FHWA's review of ConnDOT's compliance with the National Bridge Inspection Standards did not address the need for such equipment by the inspection teams.

Therefore the National Transportation Safety Board recommends that the Federal Highway Administration:

> Develop a detailed and comprehensive integrated bridge inspection procedure using all available source materials, including but not limited to the Federal Highway Administration's "Bridge Inspector's Training Manual" and the American Association of State Highway and Transportation Officials' "Manual for Bridge Maintenance (1976)" and "Manual for Maintenance Inspection of Bridges (1978)." (Class II, Priority Action) (H-84-40)
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> Amend 23 CFR 650.303 to include an integrated bridge inspection procedure in its entirety or to incorporate such a procedure by reference. (Class III, Longer Term Action) (H-84-41)
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> Develop a model bridge inspector's field handbook in a convenient checklist format which encompasses all the elements of an integrated bridge inspection procedure to be prescribed by 23 CFR 650.303 if amended as recommended by the Safety Board. (Class II, Priority Action) (H-84-42)
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> Establish a bridge inspection enforcement program that will assure compliance with 23 CFR 650.303 amended as recommended by the Safety Board. (Class II, Priority Action) (H-84-43)
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> Develop and disseminate procedures for inspection of hidden elements of pin and hanger assemblies which do not involve the dismantling of the assemblies. (Class III, Longer Term Action) (H-84-44)
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> Prescribe objective dimensional standards for the alignment of bridge spans to facilitate detection of misalignment caused by deterioration of pin and hanger assemblies. (Class II, Priority Action) (H-84-45)
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> In cooperation with the States, identify bridges that have a pin and hanger assembly design using bearing stresses above those allowed by the 1983 Interim Specification-Bridges, 1983 of the American Association of State Highway and Transportation Officials, and designate them for frequent inspection. (Class II, Priority Action) (H-84-46)
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> Augment the current inventory and rating methodology of the National Bridge Inspection Standards, which emphasizes an overall rating for planning large-scale replacement or rehabilitation funding, to require inspections and ratings of sufficient depth and detail to address all elements critical to safety. (Class II, Priority Action) (H-84-47)

Require that the design of any Federal-aid bridge include an analysis of inspectability and maintainability. (Class II, Priority Action) (H-84-48)

Conduct detailed inspections of the Mianus River .Bridge and other representative bridges having a skewed and nonskewed suspended span design with pin and hanger assemblies to determine whether there is a significant difference between the two designs in terms of the movement of hangers on pins due to either dead or live loading and whether such movement is acceptable. (Class III, Longer Term Action) (H-84-49)

Require each State to develop an individualized inspection procedure for each bridge under State inspection jurisdiction that has critical elements whose failure will almost certainly result in a catastrophic failure of the bridge. (Class II, Priority Action) (H-84-50)

Prescribe criteria for in-depth inspections of pin and hanger assemblies based on objective measures of the risk of hidden deterioration, such as the time since the last inspection, and/or whether the pin and hanger assembly is dismantled. (Class II, Priority Action) (H-84-51)

Prescribe an objective standard for repair or replacement of pin and hanger assemblies according to measured conditions of misalignment, distortion, or changes in the position of elements of the assembly. (Class II, Priority Action) (H-84-52)

Change the format of the "Bridge Inspector's Training Manual" to provide for page-change updating, to key the manual to inspection forms, to prescribe mandatory examinations and inspector evaluations of individual critical elements as well as overall conditions, and to describe an optional methodology for effective on-site inspection. (Class II, Priority Action) (H-84-53)

Include in the annual bridge inspection program audit a review of the State's bridge inspection training programs. (Class II, Priority Action) (H-84-54)

BURNETT, Chairman, GOLDMAN, Vice Chairman, and BURSLEY and GROSE, Members, concurred in these recommendations.

By: Jim Burnett
Chairman