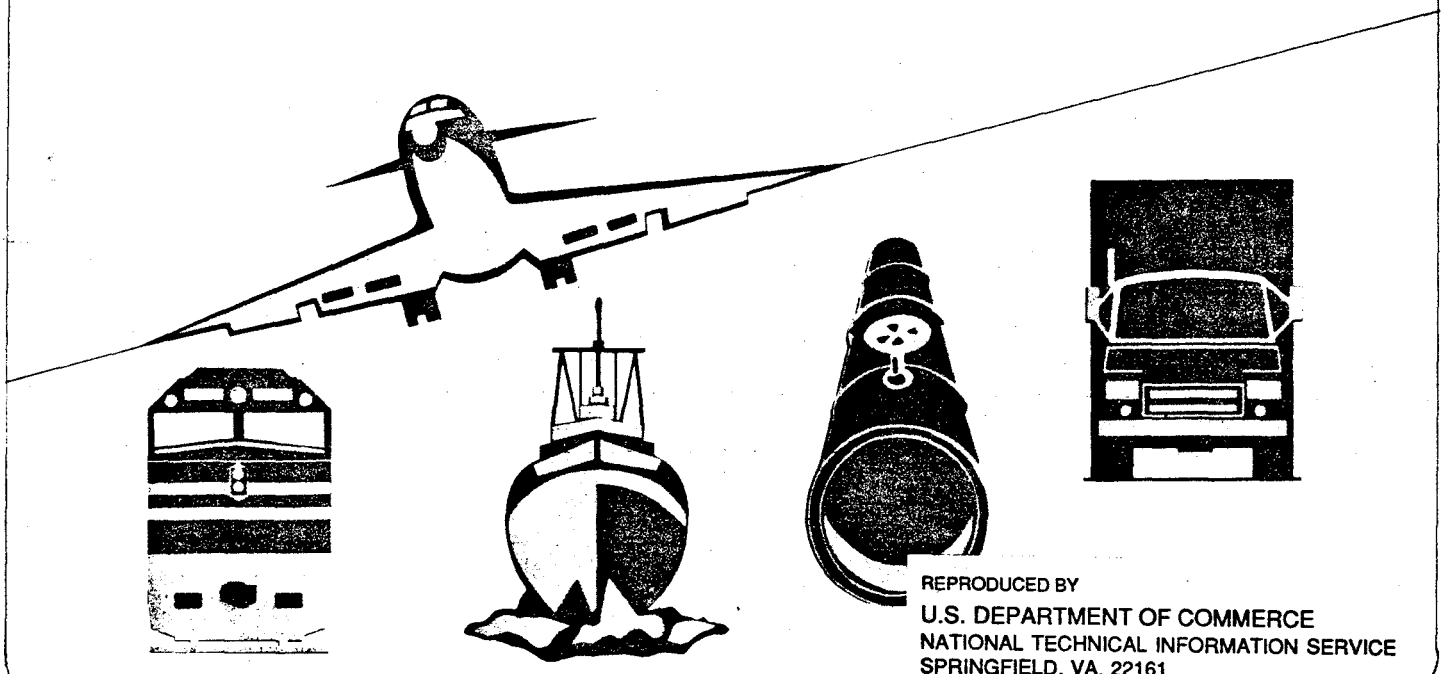
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NTSB/HAR-89/04

NATIONAL TRANSPORTATION SAFETY BOARD

HIGHWAY ACCIDENT REPORT

COLLAPSE OF THE S.R. 675 BRIDGE SPANS
OVER THE POCOMOKE RIVER
NEAR POCOMOKE CITY, MARYLAND
AUGUST 17, 1988



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16. Abstract

This report explains the collapse of a highway bridge over the Pocomoke River near Pocomoke City, Maryland on August 17, 1988. The safety issues discussed in the report include the Maryland State Highway Administration inspection and inspection report review procedures; State and Federal bridge load posting procedures; Federal requirements concerning the examination and testing of submerged timber piles; procedures concerning the identification and detection of bacteria, fungi, and aquatic insect larvae infestation of submerged timber piles; the use of untreated timber piles for bridge construction; and the identification of bridge deficiencies. Recommendations addressing these issues were made to the Maryland State Highway Administration, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the International Association of Chiefs of Police.

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EXECUTIVE SUMMARY

On August 17, 1988, at about 1:00 a.m. e.d.t., a 85 foot section of the 275 foot long S.R. 675 bridge over the Pocomoke River fell about 30 feet into the river after two pile bents supporting the bridge collapsed. Witness reports indicated that the bridge may have been sagging before the collapse and no vehicles were involved in the collapse sequence. The weather was clear and dry, and water conditions were reported to be calm.

The National Transportation Safety Board determines that the probable cause of the collapse of the S.R. 675 bridge spans was the inadequate response of the Maryland State Highway Administration to deficiencies noted in the underwater bridge inspection reports. This resulted in the failure to repair or replace submerged untreated timber piles, which had deteriorated from the combined effects of bacteria, fungi, and aquatic insect larvae infestation, and abrasion by tidal currents. Contributing to the collapse was the improper batter of the timber piles and the preexisting cracks in the superstructure girders.

The primary safety issues raised by this accident are the adequacy of the Maryland State Highway Administration (SHA) inspection and inspection report review procedures, the adequacy of SHA and Federal bridge load posting procedures, the adequacy of Federal requirements concerning the examination and testing of submerged timber piles, the adequacy of procedures concerning the identification and detection of bacteria, fungi, and aquatic insect larvae infestation of submerged timber piles, the use of untreated timber piles for bridge construction, and the identification of bridge deficiencies.

Safety Recommendations addressing these issues were made to the Maryland State Highway Administration, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the International Association of Chiefs of Police.

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

HIGHWAY ACCIDENT REPORT

COLLAPSE OF THE S.R. 675 BRIDGE SPANS OVER THE POCOMOKE RIVER, NEAR POCOMOKE CITY, MARYLAND AUGUST 17, 1988

INVESTIGATION

The Accident

About 12:49 a.m. eastern daylight time, on August 17, 1988, traffic was light on the Pocomoke City (S.R. 675) Bascule[1] Bridge over the Pocomoke River near Pocomoke City, Maryland. (See figure 1.) A motorist stated that about 12:50 a.m. while traveling about 25 mph westbound across the bridge, it felt as though the front wheel of her car hit a curb as she passed over the west side spans. After crossing the bridge, the motorist parked at a market adjacent to the west end of the bridge, exited her vehicle, and then heard a loud splash behind her. At the same time, several men who were gathered in a parking lot across the street from the market, and within 50 feet of the west bridge abutment, stated that after the car passed over the bridge, there was a large "cracking sound." The three west side spans and two supporting pile bents[2] then collapsed and fell into the river. (See figure 2.) These witnesses also stated that prior to the collapse they had heard a series of "snapping, banging, and clanking" sounds emanating from the general area of the bridge. No other passenger cars or pedestrians were on the bridge at the time of the collapse. The weather was clear and dry, and the water conditions were reported to be calm.

The Worcester County Central[3] (911) emergency dispatcher was notified of the collapse at 12:54 a.m. and dispatched Maryland State Police and Pocomoke City Police units to the site. Officers arrived shortly after 1:00 a.m. and spoke with witnesses, made a visual search of the bridge and river, and determined that no vehicles or pedestrians had fallen into the river when the bridge collapsed. The police then closed the bridge until the arrival of State Highway Administration maintenance forces, at about 2:15 a.m., who then established a detour around the bridge and barricaded the bridge approaches.

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[1] A bascule bridge consists of single or dual leaves which are mechanically rotated and lifted to provide an opening for marine navigation.

[2] A pile bent is a transverse structural framework composed of piles and a pile cap.

[3] The S.R. 675 Bridge connects Somerset County, Maryland on the west side of the river with Worcester County, Maryland on the east side.

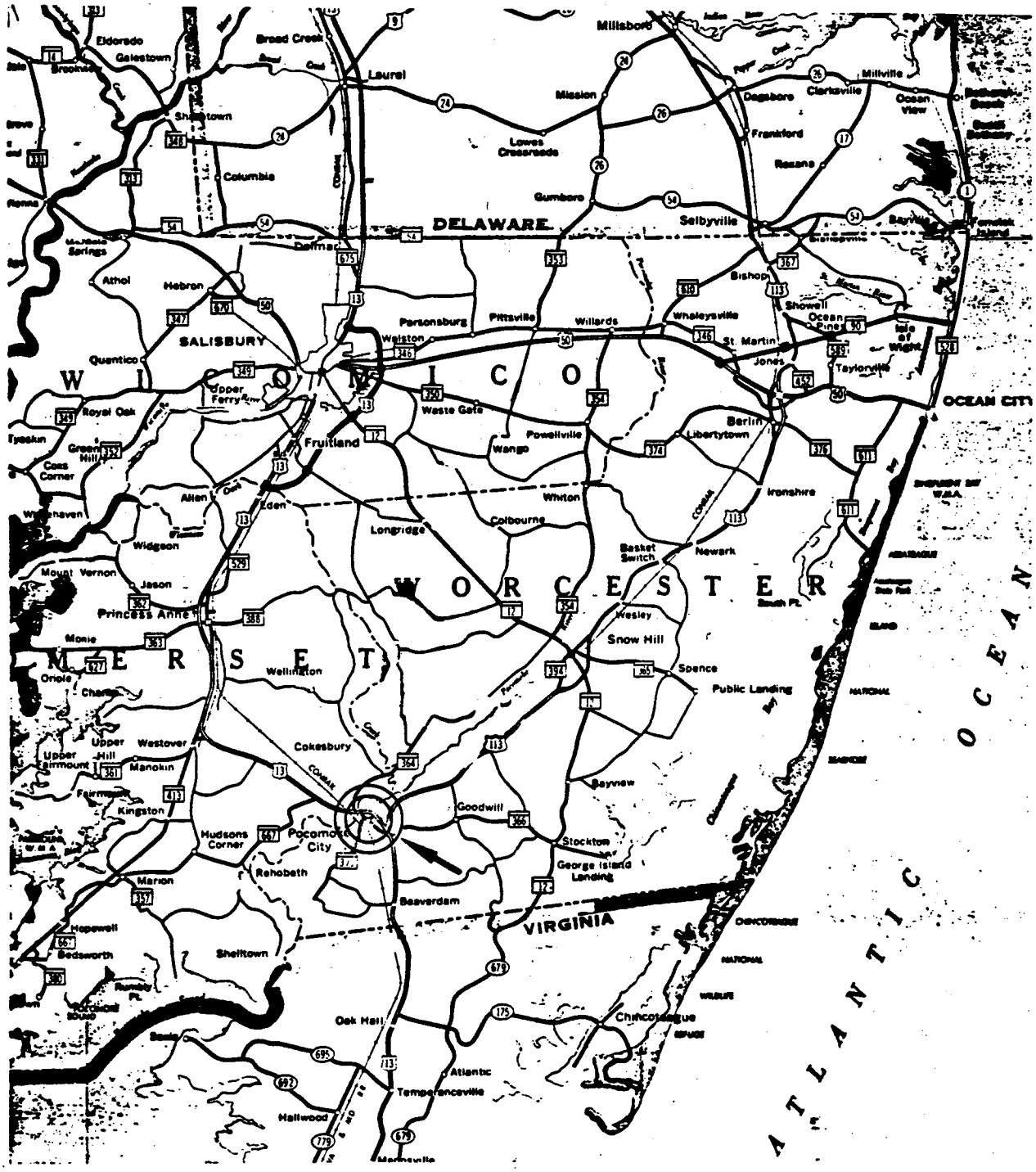


Figure 1.--Accident Location

About 7:30 a.m. on August 15, 1988, two days before the collapse, a motorist traveling west to east across the bridge observed a dip in the bridge deck. He stated that the pedestrian crosswalk railing along the first and second spans on the west end of the bridge appeared to be bowed downward 3 to 4 inches, with the maximum deflection midway between the spans. The same motorist again crossed the bridge traveling west to east at about 7:30 p.m. on August 16, 1988, and observed that the dip was more severe, about 12 to 14 inches in depth midway between the spans, with the railing no longer attached to the roadway. He assumed the bridge tenders were aware of the dip in the bridge and he did not feel it was necessary to advise anyone. The manager of the market on the west shore at the bridge site stated that during the morning of August 15, 1988, he observed a crack on the south side

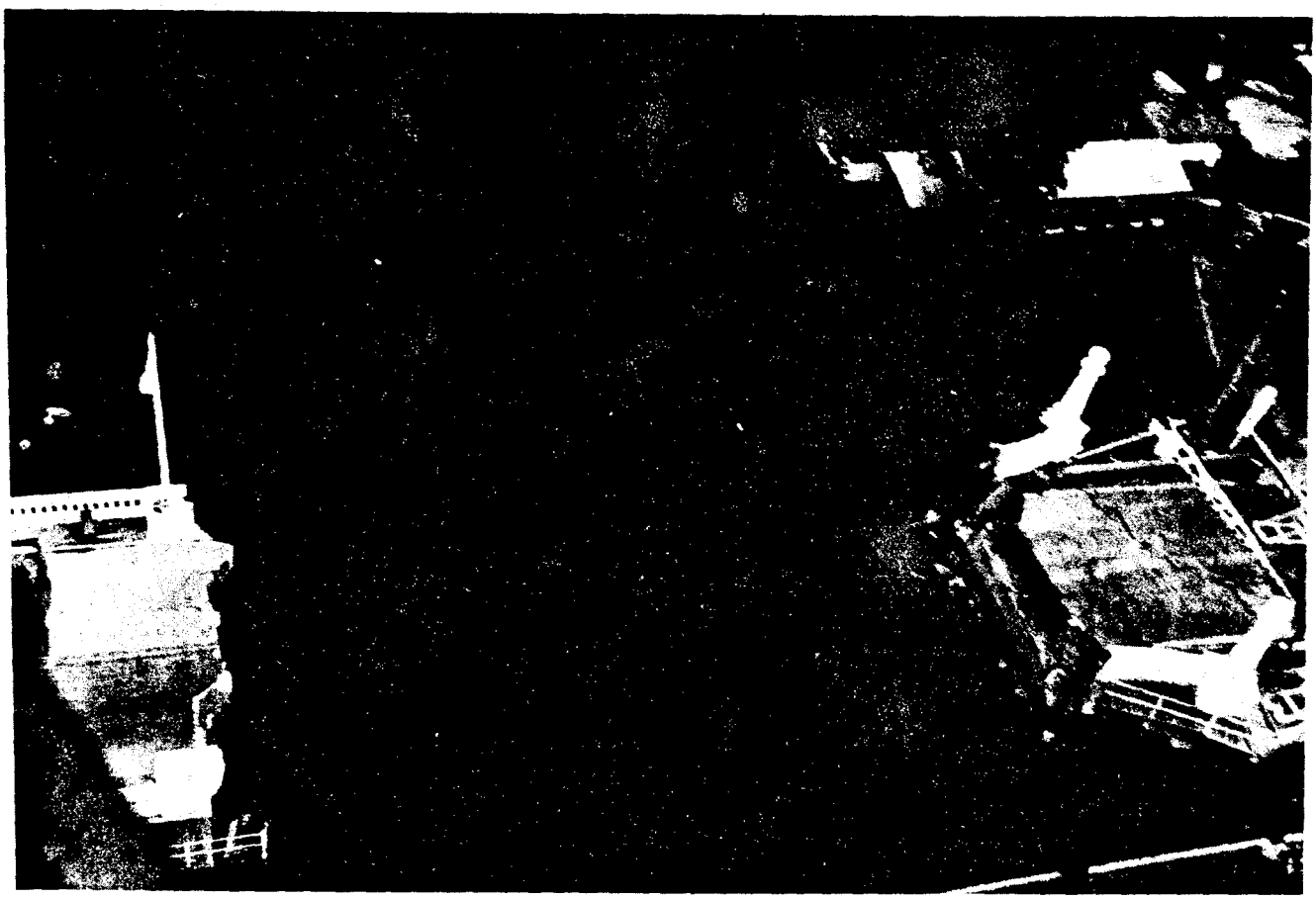


Figure 2.--The Pocomoke City (S.R. 675) Bridge following the collapse of the west side spans.

vertical face of the bridge between the first and second west side spans, and about a 2-inch dip in the bridge at this location. On the morning of August 16, 1988, he again observed the bridge and stated that at the same location, the bridge appeared to have sunk even further to about 10 inches. He did not advise any of the local authorities.

About 11:00 a.m. on August 16, 1988, the day before the collapse, another motorist was traveling westbound across the bridge. He observed a "v" shaped depression about 10 to 12 inches deep and about 20 feet long, extending across the width of the bridge deck at the first west side span. After driving across the bridge, he observed a crack on the south side vertical face of the bridge that coincided with the depression in the deck. Following these observations, the motorist immediately drove to the Pocomoke City Police Department and reported the condition of the bridge to the police dispatcher. However, the dispatcher did not notify the officers on duty at the time, or record the complaint in the police log. Later that afternoon, at about 4:30 p.m., another motorist advised the Pocomoke City Police Chief of a low spot on the bridge. In response to the complaint, the Chief went to the bridge at about 5:00 p.m. and inspected the east side spans. The Chief stated that he observed a pothole at the east abutment, but he did not inspect the bridge's west side spans. He made no further observations of the bridge prior to the collapse.

Highway Information

Maryland State Route 675 (S.R. 675), which runs generally east-west adjacent to U.S. Route 13, is the main business street for Pocomoke City, Maryland. The 1.5-mile-long section of roadway was part of U.S. Route 13 until 1959, when a new highway bridge was constructed over the Pocomoke River about 1500 feet north of the city. At that time, the existing bascule bridge and accompanying roadway were redesignated as a state highway. The posted speed limit for the bridge was 25 mph, and the two-lane, two-way roadway was delineated with solid white edgelines and a double yellow centerline. In 1987, the average daily traffic count for this highway was about 3,300 vehicles.

Bridge Information

The S.R. 675 bridge was designed in 1919 and was opened for vehicles in 1921. The bridge consisted of six pile bents, two abutments, and seven spans with lengths of 36, 36, 13, 105, 13, 36, and 36 feet, respectively, for a total length between abutments of 275 feet. The center span was a two-leaf bascule, which, when raised, provided a 65-foot-clear span for ships to navigate through. The bridge was manned 16 hours each day (from 6:00 a.m. to 10:00 p.m.) by a tender who operated the bascule controls from a two-story building located on the bridge at the southeast corner of the bascule. The bridge was equipped with marine navigation lights, illuminated traffic gates, post mounted traffic signals, and street lights.

At the time of the collapse, the 24-foot-wide bridge deck was the original 6.5-inch-thick concrete deck reinforced with steel bars. On each side of the deck, a 32-inch-high concrete reinforced barrier was attached to

a 5-inch-high curb. Alignment of the bridge deck was straight and the roadway had a parabolic crown[4] for drainage with a maximum 5-inch-drop from center to the curb. On the north side of the bridge a wooden walkway supported by a steel I-beam and cantilevered trusses, was attached to the exterior concrete deck girder.

The superstructure was constructed to be redundant and was capable of transferring loads between members. All of the concrete in the deck, girders, abutment, and pile bents was poured as a monolithic structure, the bridge members were tied together with steel reinforcement bars (rebars) in most locations, and there were no expansion joints in the bridge, except at the center of the bascule.

The deck was supported by four longitudinal reinforced concrete girders. Rebars varied in size and placement throughout the length of each girder. Typically, there were five 1-inch-diameter rebars in the bottom of each girder. Further, four 0.875-inch-diameter rebars were located in the center of the spans and were bent toward the tops of the girders. Two 0.875-inch diameter rebars were placed longitudinally in the tops of the girders near each pile bent and were angled downward toward the center of the girders. Additional rebars of various diameters were centered laterally throughout the girders near the pile bents, and stirrups[5] were spaced from 8 to 18 inches around the longitudinal rebars. Reinforced concrete diaphragms[6] separated the girders at 6-foot intervals and the exterior girders were equipped with reinforced concrete brackets that supported the cantilevered deck and traffic barrier. (See figure 3.)

The main superstructure girders were supported by abutments and pile bents. Both full height reinforced concrete abutments had flared wing walls, were supported by 23 untreated timber piles each, and were protected by stone riprap.[7] Each abutment was tied into the roadway approach with a 2-foot-square, 28-foot-long reinforced concrete dead man.[8] The dead man was attached to the abutment at the girder level by four 6-inch by 12-inch concrete beams, reinforced with six 0.75-inch-diameter rebars, which extended through the abutment and about 3 feet into the main girders.

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[4] A parabolic crown is an element of the highway cross section created by raising the roadway centerline above its edges.

[5] A stirrup is a U-shaped rod, bar or angle piece providing a stirrup-like support for a bridge girder.

[6] A diaphragm is a reinforcing member placed within a bridge deck system to distribute stresses and improve strength and rigidity.

[7] Riprap is stone, blocks of concrete, or similar protective covering material deposited on the beds and banks of rivers and streams to prevent erosion and scour by water flow.

[8] A dead man is a large buried weight used to anchor and prevent horizontal slippage of an abutment.

The main fixed[9] span girders and the bridge deck were supported by four multiple pile bents. At each pile bent, the interior deck girders were supported by a 1.67-foot-high, 19.08-foot-long, 4.0-foot-wide concrete pile bent seat that rested on the reinforced concrete pile cap. The exterior deck girders rested directly on the pile cap and adjoined the ends of the pile bent seat. The pile caps were an average of 4.5 feet wide and 25 feet long, and extended 2 feet below the river mean low water level. (See figure 4.) Each pile cap was supported by 10 untreated timber piles that were generally embedded 2 feet into the concrete cap. Design plans indicated that the piles were to be about 1 foot in diameter, and were to be battered[10] at a 1:8 slope; and opposing piles were to be offset by 30 degrees and spaced apart about 2.5 feet in width and 5.17 feet in length. (See figure 5.) The piles were to be embedded in the river bottom which consisted of mud, sand, and clay (about 0 to 9 feet deep), stiff clay (about 9 to 42 feet deep), clay (about 42 to 48 feet deep), and coarse sand (48 to 63 feet deep). The piles were designed to be exposed to water 12 to 20 feet between the bottom of the pile cap and the river bed. No as-built plans or calculations existed for this bridge, and the original design plans did not include the pile length, width, or wood type.

The two pile bents supporting the bascule span contained the bascule machinery, trunnion assemblage,[11] counterweights, and operator's building. Each pile bent was supported by 69 untreated timber piles that were spaced 2.5 to 6 feet apart. The operator's building was supported by an additional 15 piles. Based on design plans, the piles were to be embedded 5 feet into the 23.5-foot by 33-foot pile cap. The pile cap extended 13.75 feet below the river mean low water level, and the piles were designed to be exposed to water from 6 to 10 feet between the pile cap and river bed. The bascule pile bents were protected from collisions with ships by timber dolphins[12] and fenders. These protection elements were originally constructed of untreated timber, but were replaced in 1932 with creosote-treated timber members.

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[9] A fixed span is a bridge superstructure member anchored in its location on the substructure.

[10] A pile driven in an inclined position to resist forces which act in the horizontal and vertical directions.

[11] An assemblage consisting essentially of a pin fitted into a supporting bearing and forming a hinge or axle upon which the movable span swings during an opening-closing cycle.

[12] A group or cluster of piles driven in one or two circles about a center pile and drawn together at their top ends around the center pile to form a buffer or guard for the protection of channel span piers or other portions of a bridge exposed to possible injury by collision with waterbound traffic.

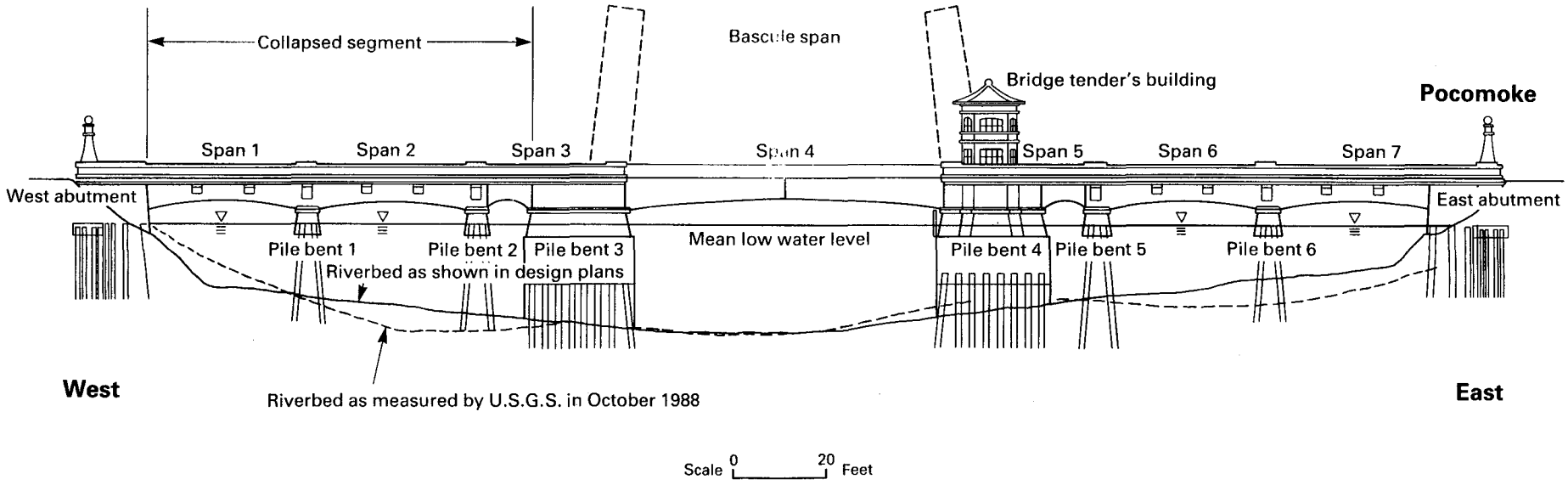


Figure 3.--Plan view of the Pocomoke Bridge

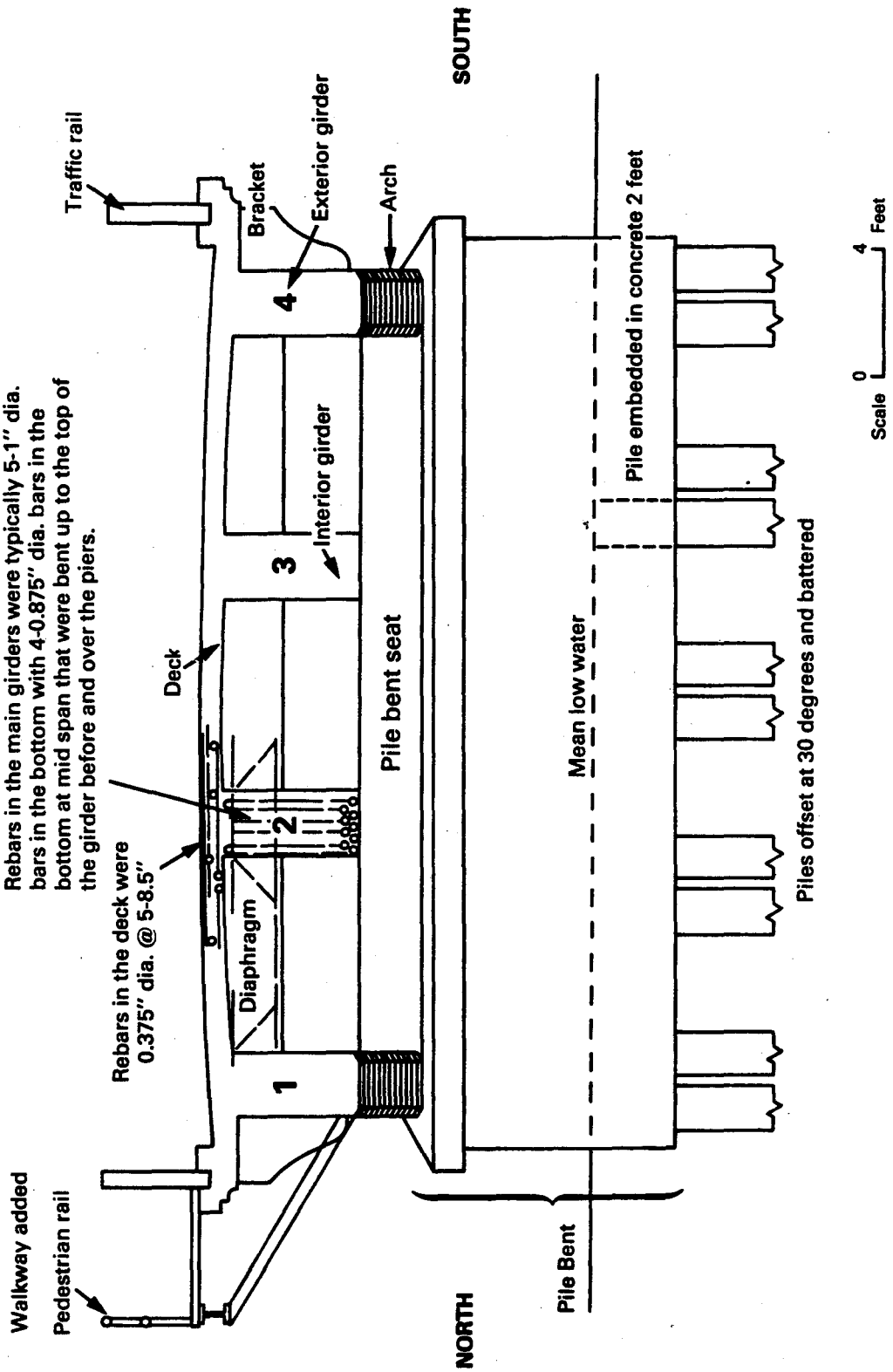
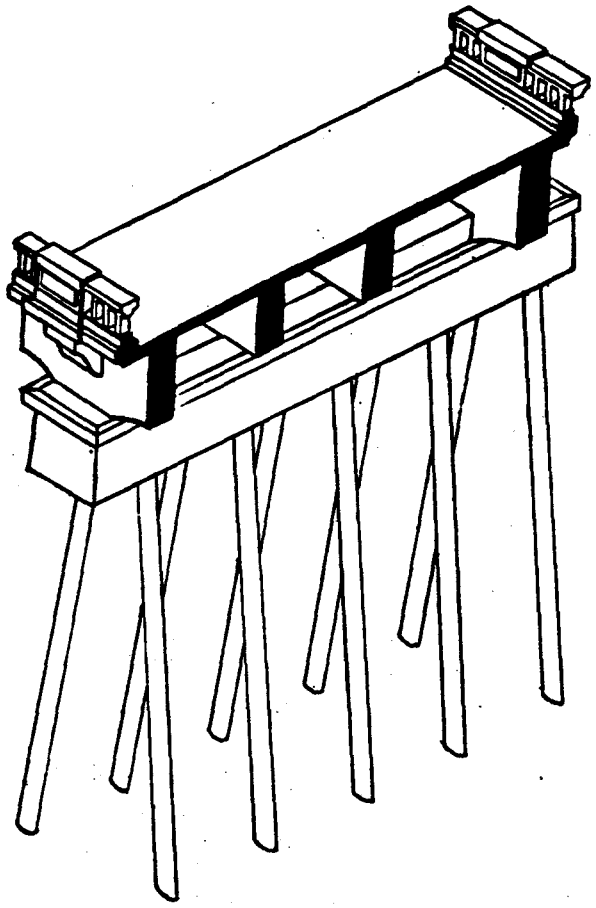


Figure 4.--Pile Bent cross section.

(A) Pile bent 2 as designed.



(B) Pile bent 2 as built.

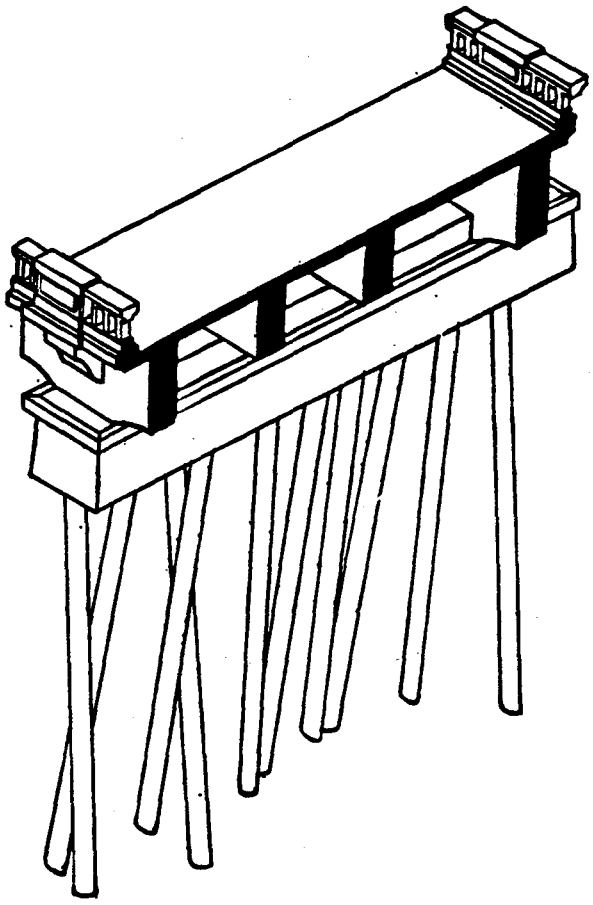


Figure 5.--Pile group design.

The design load[13] used for this bridge was an 18-ton truck with a 10-foot wheelbase and a 5.5-foot gauge, two-thirds of the weight carried on the rear axle. In 1919, few standards were available to assist bridge designers. The first federally subsidized roads were constructed between 1912 and 1918 under the auspices of the Office of Public Roads at the Department of Agriculture, in conjunction with the U.S. Post Office, as a means for the delivery of rural mail. The American Association of State Highway Officials (AASHO)[14] first began to compile standards in 1921. The earliest AASHO standard specifications for highway bridges emerged in 1925[15] and indicated that "untreated piles shall not be used in water which is infected with marine borers." A 1931 revision of this AASHO manual added specifications concerning the dimensions of timber piles; a minimum tip[16] diameter for 40-foot piles was 8 inches, for 40 to 60-foot piles was 7 inches and for a 60-foot pile or longer was 6 inches. The minimum diameter for a pile 4 feet from the butt end was 11, 12, and 13 inches for piles of less that 20 feet, 20 to 40, and greater than 40 feet, respectively. One of the first State of Maryland specifications regarding bridge design, issued in 1939,[17] allowed untreated yellow pine timber piles for bridge piling and required pile dimensions similar to the 1931 AASHO specifications.

The original design plans indicated that the bridge deck girders were to be continuous from each abutment to the second fixed span pile bents. The short spans adjacent to the bascule were designed to be 1-foot-thick slabs, fixed to the bascule pile bents and supported by rollers on the fixed span pile bents. No girders were indicated for these spans in the design plans. However, as built, the two short spans had girders similar to the other fixed spans making the spans continuous from the abutments to the bascule.

Bridge Damage and Wreckage Documentation

During the collapse, two of the three west-side spans (numbered from west to east, 1, 2, and 3) and both pile bents (numbered from west to east, 1

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[13] The load comprising the magnitudes and distributions of wheel, axle or other concentrations used in the determination of stresses, and stress distributions for the various portions of a bridge structure.

[14] Now the American Association of State Highway and Transportation Officials (AASHTO).

[15] American Association of State Highway Officials, Standard Specifications for Highway Bridges and Incidental Structures. AASHO, Washington, D.C., June 1, 1925.

[16] Due to natural taper of timber piles, the tip end, which is generally embedded in the mudline, is smaller in diameter than the butt end, which is generally embedded in the pile cap.

[17] State of Maryland Specifications for Materials, Highways, Bridges, and Incidental Structures, State Road Commission, Annapolis, MD, October, 1939.

and 2) fell into the river below the mean low water level. (See figure 6.) (Due to suspended material in the water, visibility was limited to 6 to 12 inches.) Span 1 fell such that the west side of the span was partially visible above the water where it was leaning against the west abutment.

Following the collapse, the Maryland Department of Transportation, State Highway Administration (SHA) hired divers to work in conjunction with a SHA bridge inspection team to examine and document the submerged bridge wreckage. They reported that the bridge deck and girders angled down from the west abutment for about 37 feet and then continued across the river bed at a more level slope. There was a 2.5-to-3-foot vertical gap between the top of the west abutment and the fallen slab of span 1. The spans were positioned on top of the pile caps which were lying on their west side. The east end of span 1 appeared to be resting on top of the west end of span 2. In turn, the west end of span 2 was resting on pile bent 1. The east end of span 2 and the west end of span 3 were resting on pile bent 2, and the east end of span 3 was resting on the ledge near the bottom of the bascule pile bent. Spans 1 and 2 appeared to be intact, while span 3 was cracked at midspan. Pile bent 1, along with spans 1 and 2 had moved southward several feet during the collapse, and broken piles were lying in the stream bed at this location. All of the piles in both pile bents were broken. The east side row of piles in pile bent 1 had broken off between 6 inches and 15 feet from the cap, and the piles on the west side were broken and splintered between 6 inches and 10 feet from the cap. The piles from pile bent 2 broke off closer to the pile cap than those in pile bent 1. The east row of piles broke off 1 to 2.5 feet from the bottom of the cap, and the west row of piles broke off flush to 2.5 feet from the cap. Also, the divers reported a small amount of debris, consisting of small trees and branches, lodged against the piles near the pile cap.

In late August, 1988, salvage work began on the bridge wreckage. A barge crane equipped with a guillotine was used by the SHA to retrieve the wreckage from the river. Segments of the bridge that were generally less than 50 tons were extracted from the river intact. These included most of the piles, bridge railing, and ornamental features. However, the contractor was forced to chop the main elements of the bridge into manageable pieces for extraction, and cut several piles that were embedded in the pile caps. After the large sections of the bridge wreckage were extracted and the river bed was scraped to retrieve additional material, divers used water jets in an attempt to find remaining pile fragments embedded in the river bed; however, none were located. After recovery efforts were terminated, the bridge wreckage was placed on shore and assembled as closely to its original configuration as possible. Pieces were examined and identified based on aggregate patterns, rebar patterns, location of diaphragms and other physical features. (See figure 7.)

Superstructure Components. Examination of the wreckage revealed that the girders were fractured at the abutment and near the bascule pile bent. The girders were also cracked diagonally in plane with the deck, just east of pile bent 1. The rebar at this location exhibited signs of necking down. The break measured 37 feet from the west end of span 1 on the south side exterior girder, and 39 feet on the north side exterior girder. Further, a

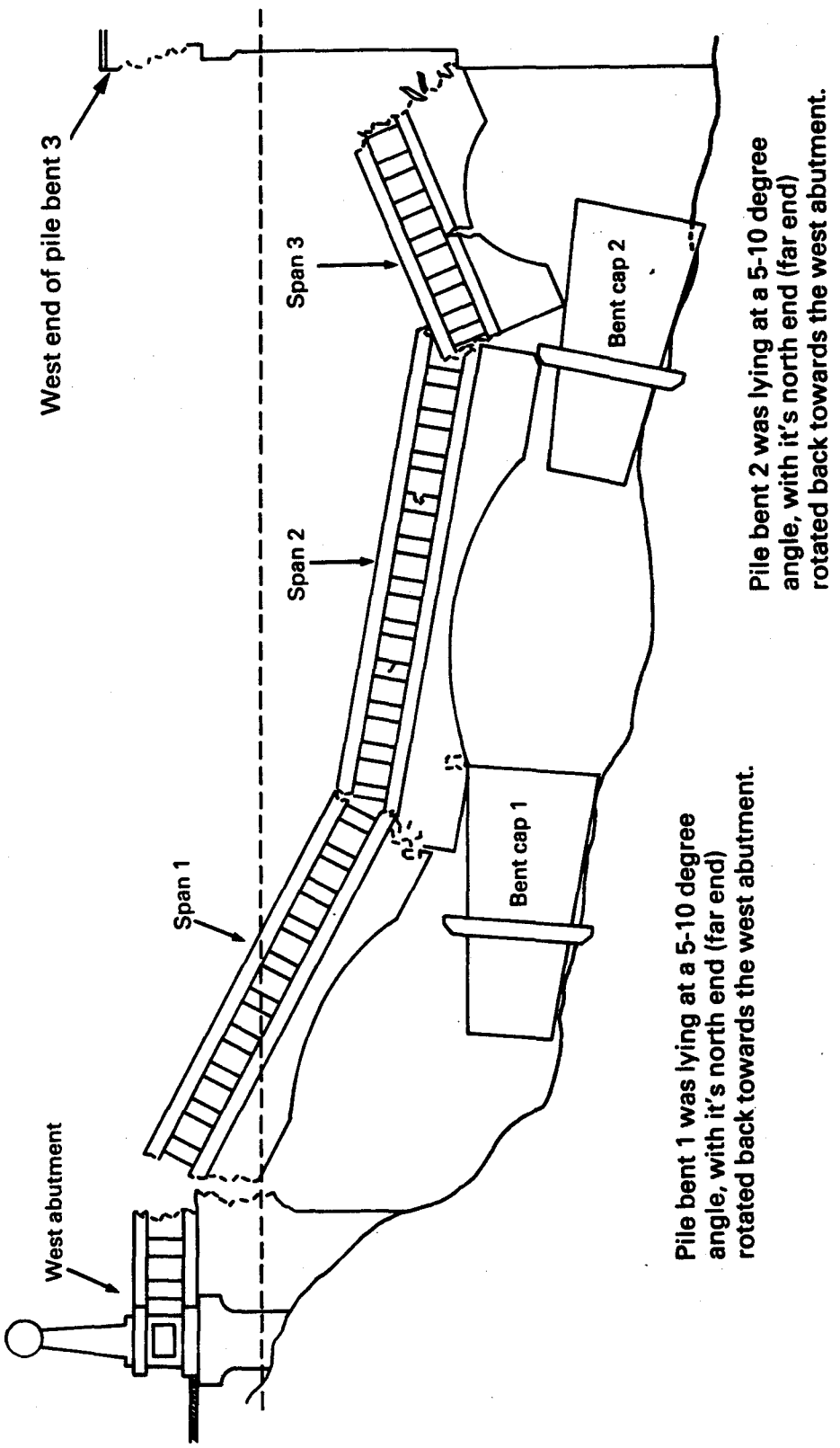


Figure 6.-- Profile view of the collapsed spans based on the diver reports, looking north.



Figure 7.--View of bridge members reassembled in layout yard.

break in the girders was observed across span 3, but it could not be as well documented as the break just east of pile bent 1, because the concrete segments of the spans interior girders were either too small to examine thoroughly or were not retrieved. Additionally, some of the rebar from the interior girders appeared to have been pulled out of the concrete, and only a few rebars in the exterior girders of span 3 were necked down. The fracture in the center of span 3 measured 77 to 81 feet from the west end of span 1. Portions of the span 3 girders remained attached to the bascule span. (See figure 8.)

Substructure. The concrete in the pile bents did not appear to break during the collapse. Due to the immense size and weight of the pile bents, they were split with the guillotine before being salvaged. As a result of this chopping, several of the piles fell out of the pile cap and were not recovered. In addition, several piles had been sawed off during salvage. The concrete around the embedded butt ends of many of the piles had spalled[18] off 4 to 6 inches from the edge of the pile, and up to 4 to 6 inches deep. The spalled concrete in the pile caps was encrusted with barnacles and had a dark discolored appearance. Further, the concrete was separated from the pile butt ends .2-to 1.5-inches and a .2-inch diameter probe could be pushed up along the side of the piles 5 to 18 inches. In some cases the loss in pile cross section was indicated by growth rings[19] (up to 7), which were visible on the piles further up in the cap. For pile bent 1, from the top of the pile to the bottom of the concrete (2 feet), five of the ten piles had a reduction in diameter of 2 inches or less. Four of the piles in pile bent 1 had a reduction in diameter of 2 to 4.5 inches; one pile was not recovered. In pile bent 2, three piles were missing, and one pile was damaged during salvage and could not be measured to determine the reduction in diameter. Three of the piles that were examined in pile bent 2 had a diameter reduction of 0 to 1-inch, and three piles were reduced 1.0 to 2.25 inches. At the bottom of the pile caps, the original timber construction forms[20] were still attached to the cap and were positioned on each side of the pile rows.

The direction and slope were measured for five piles from pile bent 1. Three piles were battered in the opposite direction from what was indicated on the design plans and their slope varied between .0294 and .176 feet per 1-foot. The direction of batter and slope were determined for nine piles from pile bent 2. Six of the piles were also battered in the opposite direction from what was indicated in the design plans; their slope varied

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[18] Spalls are circular or oval depressions in concrete caused by a separation of segments of the surface concrete, revealing a fracture parallel with and slightly inclined to the surface.

[19] With most species in temperate climates, there is sufficient difference between the wood formed early and that formed late in a growing season to produce well-marked annual growth rings.

[20] Milled lumber that was erected around the pile butt ends during construction to form a mold for the concrete pile cap. The timber forms varied in size up to 12 inches square.

between .047 and .136 feet per 1-foot; and two of these piles were adjacent rather than being offset as designed. (See figure 5.)

West Abutment. In late September 1988, excavation of the west abutment began. The tie backs[21] were exposed and examined and four tie backs were found with six square rebars in each. The tops of the concrete tiebacks were eroded and the end of the rebar in three tiebacks were tapered or necked down and no longer attached to the west span girders or the abutment. One tie back was still attached to the abutment.

SHA Bridge Development, Inspection, and Maintenance Organizational Structure

Within the Maryland Department of Transportation State Highway Administration, the Office of Maintenance, and the Office of Bridge Development are responsible for the design, maintenance, inspection, and repair of the State's bridges. The Office of Maintenance is directed by a Deputy Chief Engineer who reports to the SHA Chief Engineer. The Office of Maintenance is responsible for statewide highway maintenance including bridges, and is divided into seven districts. Each district office is managed by a district engineer and includes assistant district engineers for maintenance, construction, and traffic.

The Assistant District Engineers for Maintenance coordinate and schedule the routine maintenance and repairs of State bridges. The scope of work accomplished during these routine functions is determined by the Assistant District Engineer and his staff. The Office of Maintenance also responds to recommendations from the Office of Bridge Development. It is the Assistant District Engineer's responsibility to coordinate maintenance activities with the Office of Bridge Development. However, when determining the scope of these maintenance activities, the Assistant District Engineers only have access to a summary of the inspector's comments and the narrative portions of the biennial inspection reports concerning a particular bridge.

The Office of Bridge Development has the major responsibilities for bridges within the State, and is directed by a Deputy Chief Engineer who reports to the SHA Chief Engineer. The Office of Bridge Development is divided into two bureaus. The Bureau of Bridge Design is responsible for the design of new bridges, and the Bureau of Bridge Inspection and Remedial Engineering (BI&R) is responsible for superstructure and underwater inspections, maintenance of bridge inspection files, and the review of inspection reports and development of subsequent corrective measures.

Maintenance and Repair

The S.R. 675 bridge bascule span received frequent maintenance that included periodic greasing of the mechanical mechanism, replacement of the navigation lights, and structural and mechanical repair of the bascule leaves and machinery. During the life of the bridge, maintenance of the fixed spans

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[21] The concrete beams and rebars connecting the dead man with the bridge abutment.

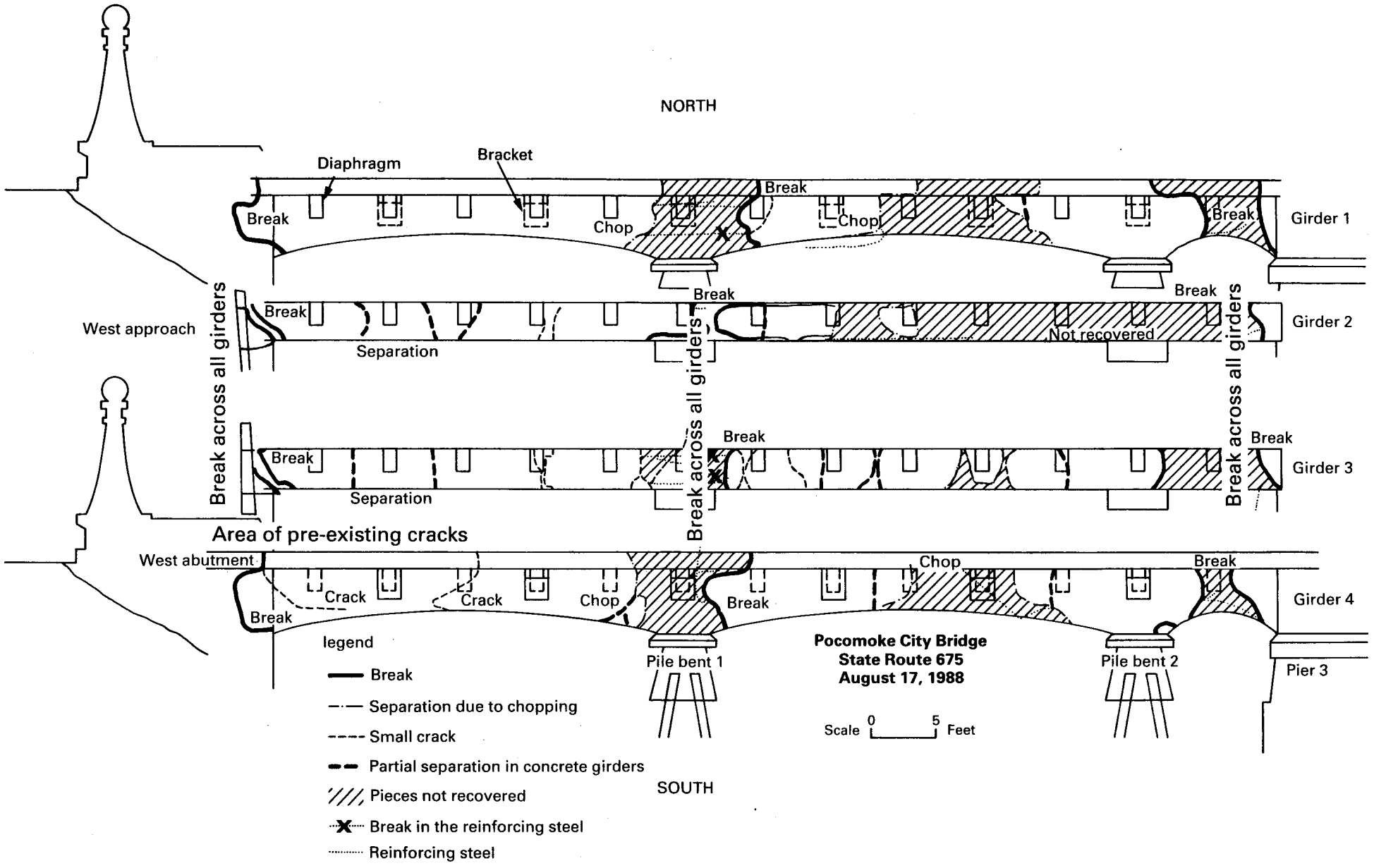


Figure 8. – – Pattern of failure in main girders.

was limited to the construction and subsequent repair of the cantilevered walkway, and routine cleaning of the deck curb and drainage devices. During the inspection of the bridge wreckage and east side spans, minor concrete patching of the girders and abutments was evident; however, no records could be located that identified this work. The only recorded maintenance of the non-bascule sections of the bridge was a 1970 repair of a large separation in the west abutment. There were no records that indicated any maintenance had been performed on the pile bents or piles, or on areas where spalled concrete and cracking of the girders and diaphragms had been identified in inspection reports.

Bridge Tenders. The Office of Maintenance maintained the contracts for the two bridge tenders who were employed to operate the bascule. One tender had 12 years and the other tender had 4 years of experience working exclusively on this bridge; the tender with 12 years experience had also worked on another bascule bridge. Under the terms of the contract between the District office and the bridge tenders, the tenders were required to open and close the bridge as necessary and "make frequent inspections of bridge and opening machinery, reporting the need for any repairs to the Office of Administration's Resident Maintenance Engineer[22] by telephone."

One of the tenders was on duty from 6:00 a.m. to 10 p.m. on the evening prior to the collapse. The tender stated that he had inspected the bascule and navigation lights during the morning and walked over the east side span of the bridge several times during his shift; however, he did not notice any peculiarities with the bridge. The tender described his job responsibilities as "to watch for boat traffic, open and close the bridge and as far as inspection of the bridge, whatever was pertinent to the operation of the bascule." During Safety Board depositions conducted in November 1988, a SHA representative indicated that the tenders were not expected to make an inspection of the structure during the course of their duties. Their inspections were intended to be limited to a check of the highway gates and river navigation lights. Neither tender stated that he noticed any discrepancies related to the west side spans prior to the collapse.

Bridge Inspection

Bureau of Bridge Inspection and Remedial Engineering. The Chief of the Bureau of Bridge Inspection and Remedial Engineering supervises 41 employees; he is qualified under the National Bridge Inspection Standards (NBIS) to hold this position. The BI&R is responsible for the inspection of approximately 5,000 structures within the State. About 2,400 structures are State-owned and are inspected by SHA forces. The remaining 2,600 bridges are owned by local municipalities, who generally contract private consultants to perform bridge inspections. These inspections are monitored by the SHA.

The State computer bridge inventory indicated that 169 structures within Maryland have timber substructure elements. However, the file could not

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[22] This contract reflected an old SHA table of organization. The bridge tenders were to report to the Assistant District Engineer for Maintenance.

distinguish which structures had exposed submerged piles such as the S.R. 675 Bridge. The State also operates 21 moveable bridges, most of the bascule design.

During Safety Board depositions, the Chief of the BI&R stated that based on Federal Highway Administration (FHWA) evaluations, the SHA complies with the Federal requirements for biennial above-water inspections and 5-year inspection intervals of underwater structures. Above water inspections of State-owned bridges are conducted by the BI&R's Condition and Inspection Section. The Chief of the Condition and Inspection Section is qualified under NBIS for this position, and at the time of the collapse, he supervised four 3-person permanent bridge inspection crews. Each crew was composed of a crew chief, an experienced inspector, and an inspector in training. All of the crew chiefs and most of the experienced inspectors had attended formal FHWA bridge inspection courses, but few had college engineering or technical educations, although this is not required by NBIS. Each crew was assigned a permanent region within the State, and submitted reports to the BI&R Remedial Design Section after completing each inspection. (See discussion on Bridge Inspection Policies.)

The SHA does not have divers on staff to conduct underwater bridge inspections. All underwater inspections are conducted by contractors, who are generally required to use at least one experienced diver reporting to a registered professional engineer at the site of the inspection. Similarly to the above water inspections, the underwater inspection reports are sent to the BI&R Remedial Design Section for review.

Bridge Inspection Policies. Based on the above water and underwater inspection reports, engineers from the BI&R Remedial Design Section complete an inventory form identifying and rating about 350 elements on each bridge.[23] A review of the State's records revealed that since 1980 the SHA has complied with the NBIS coding system, which requires about 100 rating elements. SHA's coding system follows the NBIS rating system with an expanded version that includes an additional 250 rating elements. The data contained in the inspection reports are used by SHA to develop a numerical sufficiency rating for each bridge, with 100 as the highest rating and 0 representing an entirely insufficient bridge. Factors such as structural adequacy, safety, serviceability, functional obsolescence, and necessity for public use are considered during the rating. The same sufficiency rating is used by FHWA to rate and evaluate bridges nationally. The BI&R engineers coding the inventory forms are also expected to review the data in the inspection reports to identify any bridge defects or deficiencies that the inspection crews may have missed. During this review, the BI&R engineers do not routinely refer to design plans or compare reports with information in the bridge file unless an obvious defect is discovered or the inspection crew has alerted the BI&R of a discrepancy with the bridge. In 1988, the SHA calculated that the S.R. 675 Bridge had a 18.72% sufficiency rating.

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[23] See Appendix B for the 1988 S.R. 675 Bridge inventory form.

Following the discovery of a structural defect within a bridge that the inspection Crew Chief determines requires an immediate on-site inspection by an engineer, the Crew Chief either notifies the BI&R Chief by telephone or submits a defect reporting sheet within ten days of the inspection. After a defect sheet or notification is received by the BI&R Chief, it is assigned to one of the two design section teams in the Remedial Design Section of the bureau. Each design section team has a section team leader; each section team is divided into two design groups, and each design group is comprised of three engineers. The design groups review the bridge plans and information in the bridge file, and an examination of the bridge is made by two engineers assigned to the project. During their inspection, the design group engineers are accompanied by the inspection crew that reported the defect. Although the engineers assigned to the design groups are graduate civil engineers, they generally do not have professional engineer licenses, and few have attended courses related to bridge inspection. The Remedial Design Section contracts out some of its work, such as load rating calculations or complex bridge design work.

The SHA also administers an annual bridge replacement and rehabilitation program. Based on the inspection reports, a list is developed of the State's worst 200 to 300 bridges. These bridges are then given an on-site inspection by an engineer from the Remedial Design Section of the BI&R, and an engineer from the Bureau of Design. Following the inspections, a committee consisting of members from both bureaus in the Office of Bridge Development identify which structures are in the poorest condition, and determine which bridge replacements or repairs will be funded by a Special Projects Fund. The committee evaluations are then sent to the Office of Maintenance District Offices who perform some of the recommended repairs. The replacement or repair work that cannot be performed by the District Offices is contracted to outside consultants after the Assistant District Engineer for Maintenance has coordinated the scope of work with the Chief of the BI&R.

Superstructure Inspection. The S.R. 675 Bridge superstructure had been inspected every two years since 1970. The three-person inspection crew responsible for inspecting the bridge was also responsible for the inspection of 300 bridges on the Maryland Eastern Shore and in Anne Arundel County. This crew had no other duties and performed bridge inspections throughout the year. According to the inspection crew chief, the crew was equipped with all the necessary inspection tools, and a snooper truck was available upon request.

Prior to 1980, the SHA utilized its own coding system for the evaluation of bridge elements. The system had five rating categories that ranged from "in need of immediate repair" to "in good condition." In 1980 the SHA changed its bridge rating and coding system to comply with NBIS. (See the discussion on the NBIS)

The bridge superstructure had been inspected 11 times in the last 18 years. In 1970, when the bridge was first inspected, the inspectors reported that all items were in good condition except the west abutment and wing walls, and the concrete in the pile bents, deck, and balustrade. No maintenance records were found for repairs to the concrete, but the west

abutment was repaired before 1972, and the rating was raised to good condition in the 1972 inspection report. In 1976 the west abutment began to crack again, and the rating was lowered to "in need of preventive maintenance." The ratings for the girders were lowered to the category of "in need of painting within one year." By 1978 the bascule leaves were in need of repair and three cracks had developed in the west side of the bridge; in three girders of span 1 near the west abutment; in two girders of span 1 near the center of the span, and in three girders of span 3 near the center of the span.[24] In the 1978 inspection report, most of the main structural elements were rated from fair to generally fair condition. In an inspection during 1980, the south exterior girder was reported to be cracked near the west abutment. Before the next inspection in 1982, the bascule was rehabilitated.

The 1982 inspection report revealed that the crack in the west abutment had widened to four inches. In response to this inspection report, engineers from the Remedial Design Section of the BI&R inspected the bridge in 1983 to determine the extent of concrete deterioration in the superstructure. This inspection focused on cracks in the abutments, spalled concrete on the diaphragms and girders, exposed rebar stirrups on the bottom of the west side span girders, and some cracking in the deck. The engineers concluded that the "entire superstructure appears to have been poured monolithically without any provisions for shrinkage, expansion or contraction. The fine vertical and horizontal cracks may be due to this." The 1983 report did not include any recommended maintenance.

In 1984 the inspection ratings were lowered, and BI&R engineers were requested by the inspection crew to further inspect several of the girders and the west abutment. In March 1986, engineers from the Remedial Design Section of the BI&R responded to the 1984 inspection crew request, and inspected the bridge. During this inspection the engineers utilized a scuba diver who inspected all of the piles within the pile bents and the exterior piles of the bascule pile bents. The diver reported that the piles were in "very good condition," but that the tremie concrete[25] in the bascule pile bents was eroding. The engineer's report noted that the west abutment wingwalls were cracked and had settled about 3 inches; however, there were no signs of undermining of the abutment. The engineers noted that backfill was washing out through the cracks, and a crack in the backwall joined with cracks in the girders to form one continuous crack. Cracks and spalled concrete in the girders and diaphragms were also noted in the inspection.

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[24] Concrete essentially is a compressive material whose tensile strength is small compared to its compressive strength. To offset this limitation, steel, which has a high tensile strength, is used to reinforce concrete. Cracks frequently occur in reinforced concrete bridge members due to tensile loading, shrinkage, temperature changes, etc. However, these cracks are often expected and generally do not affect the reinforced concrete members ability to support loads.

[25] Tremie concrete is concrete poured under water by means of a long pipe.

The engineers recommended several maintenance procedures to correct the deficiencies, and they concluded that: "The crack in the west abutment backwall suggests movement (settlement) which should be ruled out since the abutment is on piles." The engineers concluded that the crack in the abutment was due to the lack of expansion joints in the bridge. In an April 24, 1986 memo to the Chief of the BI&R, the engineers requested that the inspection crew inspect this structure every year due to specific concerns about the west abutment.

As a result of the next inspection, in May 1986, the inspection ratings were lowered again for five of the major structural elements to "poor" (the concrete girders), and "fair" condition (the abutments, pile bents, bascule leaves, and diaphragms). A broken rebar and stirrup were observed at the west abutment in the south side interior girder. The poor rating indicated that repair or rehabilitation was required immediately; however, no maintenance was performed for these elements. Contrary to the April 1986 memo, the structure was not inspected nor scheduled for inspection during 1987.

The last crew inspection prior to the collapse was performed in April 1988. The ratings for structural elements remained the same as in the 1986 inspection report, except the bascule was lowered to the "generally fair condition." This inspection report noted that the cracks at the abutment had not increased; however, "the majority of concrete girders throughout the structure have longitudinal and random cracking, hollow sounds, deteriorated areas and many girders have large diagonal, hollow cracks at bearing areas, with potential spalls and several rusted rebar, section loss and bearing loss." A defect sheet was submitted by the Inspection Crew Chief on May 5, 1988 to the Chief of the BI&R, and as a result, BI&R engineers inspected the bridge on June 7, 1988, two months before the collapse. Two engineers from the Remedial Design Section of the BI&R inspected the bridge to evaluate the amount of concrete deterioration and rusting of the steel reinforcement bars in the girders, and the bascule span structural steel. The inspection identified the spalled and cracked concrete previously seen and a diagonal crack near the abutment in two of the span 1 girders. The engineers identified this crack as a shear failure. As a result of the inspection, the engineers recommended the removal of all deteriorated concrete, cleaning of the rebar, and a concrete repair with pneumatically applied mortar. They also recommended that the northwest wingwall be closely monitored for settlement. In Safety Board depositions, the engineers that performed the 1988 inspection stated that they had not observed any superstructure defects that would have resulted in the collapse.

Load Restrictions. A total of 904 bridges within Maryland are posted with load restrictions. In March 1987, SHA contracted with Diver Brothers Consulting Engineers to calculate the load rating for the S.R. 675 bridge. Diver Brothers calculated the maximum allowable truck load in several different configurations for the concrete deck, diaphragms, girders, and bascule members. The substructure elements of the bridge were not considered in these calculations. In May 1987, SHA engineers checked and concurred with Diver Brothers calculations, and SHA determined that the bascule governed the maximum safe load, with a maximum gross load of 50,000 pounds at a maximum

speed of 25 mph. According to the Chief of the BI&R, a safety factor of about 1.6 was built into the load rating formulae. In March 1988, the bridge was load posted for a 25-ton weight restriction and a 25 mph speed limit. Following the load posting, SHA advised the Maryland State Police, municipal governments, and local school districts of the restriction.

Underwater Inspections. The S.R. 675 Bridge received three scheduled underwater inspections since 1977. Each inspection was performed by a different contract consultant, and varied in magnitude and length from the others.

In 1977 the bridge was inspected by Steigerwald Company and Atlantic Marine Divers. The SHA file concerning this inspection was incomplete. The inspection indicated that all of the accessible piles were in good condition, but the concrete in the tidal area was deteriorated. The report did not have detailed measurements; there were few sketches and diagrams; and comments were limited to spalling observed in the concrete and problems associated with the bascule tenders building. During the inspection, two piles were measured from one of the east side pile bents. Their length was 12 feet, 10 inches, and the inspection report indicated that one pile was 10.5 inches in diameter, and the other pile was 9.07 inches. The report also noted that there was 60 percent deterioration of the concrete in one east side pile bent cap. No records were found to indicate that SHA performed any maintenance to correct this deficiency.

In April 1981 an underwater inspection was conducted by L.A. Melka Marine Construction and Diving. The crew consisted of two divers, two support workers, and a professional engineer. SHA provided the crew with the bridge design plans; however, the crew did not have access to the previous underwater inspection report. The inspection consisted of divers reporting to the engineer in a boat on the surface. The divers examined piles mostly by feel due to the limited visibility in the river, and they measured the diameters of two to three piles in each pile bent. The pile diameters were measured near the top, near the middle, and about one foot from the mudline. The inspection crew stated that they were not given any guidance in the contract or by SHA officials as to which piles were to be measured. Minor deterioration of the piles was noted for the exterior .25 inches, and the report indicated that all of the untreated fixed span piles were covered with bark. In response to Safety Board inquiries, the inspectors stated that increment bore samples[26] were not taken since the SHA contract specifications only required bore samples from piles that had evidence of fungus decay or vermin damage. The concrete pile caps were rated fair, with various degrees of spall around the piles at the bottom of the caps. The engineer indicated that the timber form work on the bottom of the pile bent caps did not seriously interfere with the inspection of these areas. Several of the piles in pile bent 2 had a 1-inch-deep, 1-foot-wide abrasion beginning about 1 foot above the mudline. The engineer indicated that this abrasion reduced the pile diameters to 8 inches and occurred more on the upstream and downstream

[26] A measured cylindrical sample extracted from the pile by means of a boring tool.

sides than on the east and west sides, creating an oval shape in the piles. He attributed this abrasion to the heavy sediment being carried by the river current. The inspection indicated that the west abutment had cracks 3 to 7 inches long and 1 to 8 inches wide that could be penetrated with a probe 6 inches to 4 feet.

As a result of the 1981 inspection, the inspection crew submitted the following recommendations to SHA: "(1) In view of the size of the piles on pier (pile bent) 1, 2, 5, and 6, it is recommended that the design calculations be reviewed, taking into consideration the present traffic loading; (2) Patch the abutment cracks with concrete, and encase the areas of the timber piles that have loss of section with fiberglass jackets and epoxy encasements; and (3) Patch the spalled areas of pile bents 1, 2, 5, and 6 with epoxy grout, and encase the large scour and deep spall area of the bascule pile bents with concrete, and patch the small spalled areas with epoxy grout." During Safety Board inquiries, the inspection crew engineer stated that the intent of recommendation 2 was to bring the narrow portions of the piles back up to the size he believed was necessary for the bridge design. However, he was not aware of the original design size of the piles. The crew also notified an SHA state field inspector on the day following the inspection that the piles on the S.R. 675 bridge appeared small, "although the piles may have been designed to be that size and may actually be adequate."

During Safety Board depositions, the Chief of the Bureau of Inspection and Remedial Engineering and two of the engineers in the Remedial Design Section indicated that they were not aware of any calculations made in response to the 1981 inspection recommendation to check the load-carrying capacity of the pile bents.

Another underwater inspection was conducted in 1986. This inspection consisted of a diver and a Professional Civil Engineer. The specifications for this inspection[27] indicated that the timber was to be investigated for any indications of cracking, corrosion, erosion, marine borer attack, spalling, scouring, or other deterioration. The inspection method for timber piles was to include but not be limited to checking all piles for vermin attack, for evidence of fungal decay, for collision damage and damage by overstressing, and for excessive weathering. All timber piles were to be sounded and probed with a heavy duty ice pick. Increment bore samples were to be extracted from piles with evidence of fungal decay to determine depth of penetration, and the cores were to be sent to the SHA Bureau of Bridge Inspection and Remedial Engineering. This inspection contract, similar to the previous contracts, was awarded on the basis of the lowest competitive bid. The crew was provided with only 2 sheets of the 11-sheet bridge design plans and without previous inspection reports. One of the design sheets described the bridge protection members, and the other was a top view of the bridge.

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[27] See Appendix C for the complete 1986 SHA underwater inspection contract.

At Safety Board depositions, the diver stated that during the 1986 inspection he went over each pile testing it every two to three feet with an ice pick. Typically the circumference was measured for only one pile per bent and that pile was assumed to be the average pile in the bent. The circumference was measured about one quarter of the length down the pile. At least two piles in the structure were drilled and probed and one increment bore sample was taken.

The inspection report described the condition of the structure as follows: both abutments were in fair condition, and repairs were required due to scale. The concrete caps of all pile bents were severely spalled below the water line with exposed rebar in some locations. The piles in pile bent 1 were reported to be in good condition, with ice pick penetration of about .5 to .75 inches. The piles in pile bent 2 were reported in good condition, with ice pick penetration of .75 inches. The bascule pile bents were rated in fair condition, with severe spalling of the bent cap and tremie pour. The report also indicated severely deteriorated concrete in the girders and pile caps, with exposed rebar and a diagonal crack through two girders in the first span at the west abutment. The inspection report recommended that SHA repair all severely scaled concrete surfaces, repair or replace two wingwalls at the west abutment, repair timber piles at pile bent 2, 5 and 6, and repair voids in the concrete walls at the mudline of the bascule pile bents.

The report did not indicate the timber form work on the bottom of the pile caps, and it indicated only two pile diameter measurements, although in Safety Board depositions, the contract engineer stated that the crew had taken one measurement at each pile bent. One of the two pile measurements included in the report was from pile bent 2, indicating that one pile had an 8.6 inch diameter. The single increment bore sample that was taken was placed in a plastic drinking straw for storage. The sample was not given to SHA until the day after the bridge collapse. The contract engineer stated that his interpretation of timber core sample quality was based on whether the sample remained intact when extracted. If the core came out whole, it was of good quality, if it crumbled when extracted, it was considered to be decayed. The sample from the S.R. 675 bridge was intact, and therefore the engineer assumed that it was not decayed. Other than visual examination, no tests were performed on this sample, and no other core samples were ever taken from the bridge piles. At the time of the bridge collapse the SHA had no established procedure for the examination of timber core samples. In Safety Board depositions, the contract engineer indicated that he did not know what the original pile diameters were and thought that the lack of as built plans limited the inspection. He stated that since there were no instructions as to how many times to measure piles, the few piles that were measured were done so at only one elevation.

Revisions to the SHA Inspection Procedures. Following the S.R. 675 bridge collapse, and as a result of a joint review by the Safety Board and SHA of the Maryland bridge inspection program, the Chief of the BI&R indicated that the SHA:

a. is establishing a fifth and sixth inspection crew in the Condition and Inspection Section of the Bureau of Inspection

and Remedial Engineering,

b. has abolished the low-bid method of contracting underwater inspections and replaced it with a professional services contract. This type of contract will allow consultants and the SHA to discuss and modify individual contracts to address unique considerations,

c. has increased in fiscal year 1989 the number of quality control inspections by consultants to verify rating procedures and to assure uniformity from 12 to 30; these consultant reviews will now include the underwater inspection reports,

c. has scheduled all bridges with timber piles to have a supplemental inspection that includes: pile diameter measurements; batter and direction of piles; smallest cross sectional area and location; maximum ice pick penetration; and length of exposed pile. The collection of these data will ultimately allow a structural evaluation of each substructure capacity, and the information will be required on all future underwater inspections,

e. will consider the existing pile size during load rating evaluations for bridge substructures,

f. will modify the special provisions section of underwater inspection contracts to require that dimensions of the substructure be verified,

g. will make the underwater contracts open-end, so that the contract consultant who inspected the bridge will be able to perform the rating analysis, if necessary,

h. will begin to rate substructures regardless of whether they are timber bridges or not, concentrating first on the structures that were not designed for an HS-20[28] vehicle,

i. is considering designing bridges using an HS-25 design vehicle, since The Maryland DOT permits 65,000-pound dump trucks, and

j. will provide the Bureau of Bridge Inspection and Remedial Engineering with control of the scope and schedule of maintenance and repair work performed on all State bridges.

Guidelines and Standards for Bridge Inspections

National Bridge Inspection Standards. In December 1967, the Silver Bridge at Point Pleasant, West Virginia, collapsed and killed 46 persons. The Safety Board's investigation of this accident revealed that many States did not have formal bridge inspection programs or systems for keeping bridge inventory information. In response to this tragedy, the U.S. Congress enacted the Federal Aid Highway Act of 1968, which directed the Secretary of Transportation to establish national bridge inspection standards.

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[28] The standard AASHTO designation for the live or moving loads to be applied on the deck for determining the operating and inventory ratings. An HS-20 vehicle is a three axle, 20-ton truck. An HS-25 vehicle is a three axle, 25-ton truck.

As a result of this legislation, the NBIS became effective in April 1971. The NBIS required the inspection of all public bridges in the Federal-aid system. The Surface Transportation Act of 1978 extended the requirements of NBIS to all bridges carrying public roads, even if they were not part of the Federal-aid system. The FHWA administers the program.

The NBIS[29] stipulates 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; (4) inspection records and bridge inventories be prepared and maintained in accordance with the standards; (5) fracture-critical bridge members be identified and inspected; and (6) bridges with underwater members that cannot be visually evaluated during periods of low flow or examined by feel for condition, be described, the inspection frequency stated, not to exceed five years, and the inspection procedure specified." The NBIS further requires all bridges to be inspected at 2-year intervals, but the individual States can decide the level and detail of inspections for particular bridge elements. Inspections are to be made in accordance with the "Manual for Maintenance Inspection of Bridges,"[30] published by AASHTO. As of October 1988 the frequency for inspection of some new bridges may be increased to four years with the approval of the FHWA. 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, and the weight to be given to each factor is not specified in the standards. The standards do not require that either the individual in charge of bridge inspections or the inspection team leader be tested on bridge inspection procedures. However, to qualify for these positions, individuals must be registered as professional engineers, qualify for registration, qualify as a level III or IV bridge inspector under the NICET[31] certification program, or have a specified minimum number of years of experience and have completed a comprehensive course based on the FHWA's "Bridge Inspector's Training Manual."[32]

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[29] See appendix D for the complete NBIS as promulgated in 23 CFR Part 650, Subpart C.

[30] The first edition published in July 1970. Subsequent editions have been printed in 1974, 1979, and 1984.

[31] The National Institute for Certification in Engineering Technologies (NICET) provides a nationally recognized certification program for the evaluation of engineering technicians and technologists. Certification is provided at four levels for technologists, and at one level for technicians, and is based on the applicants education, training, work experience, and written examinations.

[32] The "Bridge Inspector's Training Manual" was developed by a joint Federal-State task force and published in 1970.

AASHTO and FHWA Inspection Guidelines. The AASHTO Manual recommends that underwater elements of piers be inspected at five year intervals, and it also states that bridge inspectors should examine timber piles for decay by taking borings and using hammer testing. The manual further states, "Special attention should be given to contact surfaces of timber when exploring for decay." Further, the AASHTO Manual states that:

> "With some exceptions, the weaker elements of older bridges are usually in the superstructure, not in the piers or abutments... Where steel is severely corroded, concrete deteriorated, or timber decayed, make a determination of the loss in a cross-sectional area as closely as reasonably possible so that the net section can be calculated. Lowering load capacities below those otherwise permitted or other remedial action may be necessary if such conditions exist... A practical procedure in making the safe load determination is through the normal sequence of calculations for (1) floor, (2) stringers, (3) floor beams, and (4) trusses, girders, etc... In computing stresses or allowable loads, generally one unit only shall be considered in any one lane. The possibility of there being two or more maximum legal loads following each other in the same lane shall not be considered for spans of less than two hundred feet... The probability of having a series of closely spaced vehicles of the maximum allowed weight becomes greater as the maximum allowed weight for each unit becomes less. That is, it is more likely to have a train of light-weight vehicles. This makes it necessary to consider more than one vehicle in the same lane of all spans including those less than 200 feet under certain conditions... However, unless otherwise determined by the Engineer, no more than one lane is to be loaded with consecutive units at the same time, and only one load in the adjacent lane will be considered."

The FHWA "Bridge Inspectors Training Manual" indicates that during underwater inspections, an experienced diver will note insect infestation and deterioration of timber piles and measure the amount of pile loss and estimate the remaining section. The manual states that factors causing deterioration include fungi, vermin such as termites, powder post beetles, carpenter ants, and marine borers such as shipworms, or limnoria. The manual further elaborates on fungus decay by stating a knife, ice pick or increment bore can be used to test for decayed wood. In the section on timber-mechanical wear, the manual states: "Wear due to abrasion is readily recognized by the gradual loss of section at the points of wear. The inspector should report the location, the general area subject to wear, and the loss in thickness." In the section on pile bents the manual states "check the condition of the cap at those points where the beam bears directly upon it, and at those points where the cap bears directly upon the piles."

Recent FHWA rulemaking[33] stated, "The 5 year maximum between underwater inspections is appropriate until a sufficient national data base to alter the

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[33] Federal Regulations Vol.53, No.166, August 26, 1988.

period is established and evaluated. Many structures subject to adverse underwater conditions should be inspected more often."

FHWA Oversight of the Maryland Bridge Inspection Program

The FHWA reviews State bridge inspection programs to determine if a State is meeting load rating and inspection frequency requirements and has qualified inspectors, and the FHWA determines if the programs comply with the bridge inspection and inventory requirements. The reviews are conducted on three levels: (a) the FHWA division office conducts an annual review of the State's bridge inspection program and discusses with State officials the State's compliance with the minimum requirements of the NBIS; (b) the FHWA regional office conducts additional reviews to determine if the division annual review is reasonable and sound; and (c) the FHWA headquarters office in Washington, D.C., reviews regional programs and provides overall administration of the NBIS.

Since 1972, the FHWA division office has annually reviewed Maryland's Bridge Inspection Program. These reviews have included FHWA inspections of about 12 State and municipally owned bridges and comparison with the SHA inspection reports, as well as a review of the State's underwater inspection program for compliance with NBIS. Overall, the annual reviews highlighted the State's progress in inspecting bridge features that were identified as issues following major bridge collapses, and the adequacy of the State's load rating program. Between 1983 and 1987, the FHWA review comments focused on the State's ability to have local municipal bridges comply with NBIS for frequency of inspection and load rating. During this period, many local bridges had not been inspected within two year intervals, and many had not yet been evaluated for load rating. In the 1987 review, FHWA commented that the SHA had completed the load rating analysis and underwater inspections for State owned bridges, and the SHA had three consulting firms under contract to perform bridge inspections for local jurisdictions not complying with the two-year frequency for inspections. However, 556 municipal government owned bridges still had not been inspected within the two year cycle. During the FHWA reviews, the inspection report evaluation process performed by the SHA BI&R was described; however, the written reviews did not discuss any attempts by the FHWA to analyze the procedure or to determine if maintenance and repair work was being accomplished by the State as recommended in inspection reports. As a result of the 1987 review FHWA suggested that the State identify bridges prone to collapse due to scour, that someone be hired in-house by MD DOT to monitor the local jurisdiction programs rather than hiring a consultant, and the State should host a bridge management system workshop.

In June 1988, the FHWA Maryland Division office devised and implemented a plan for the review of SHA follow-up activities regarding inspection report recommendations. According to the FHWA, engineers from the division office will annually select and review about twelve bridge inspection reports that have recommendations for maintenance or repairs. The FHWA engineers will assess the repair measures instituted by the SHA, and will conduct an on-site inspection of each bridge to ensure that the repairs are sufficient and completed. Additionally, the FHWA will review SHA's follow-up repair

activities for all State bridges with fracture critical members. According to the FHWA, these reviews began in late June 1988 and involve bridges that received scheduled inspections following the program inception date; therefore, the S.R. 675 bridge was not evaluated prior to its collapse.

Maryland State Bridge Audit

In November 1987 the Maryland Department of Fiscal Services conducted an audit of the State Highway Administration procedures for the inspection, maintenance, and repair of bridges. The reviewing agents had the following comments:

a. "The Bureau's [BI&R] procedures require that bridge deficiencies reported by the inspection team be reinspected by a staff engineer within ten working days after the engineer receives such an assignment from the Bureau Chief. However, the review disclosed that the assignment of engineers to reinspect deficient bridges, as well as the reinspection of the bridges were not completed in a timely manner. A sample of 14 bridges were selected to determine compliance with the policy. These 14 bridges were not assigned for inspection by the Bureau Chief to the staff engineers for an average of 46 working days. After the assignment to the staff engineers, 46 additional working days elapsed before the bridge was reinspected by the staff engineers."

b. "The control log of bridge inspection work orders frequently did not indicate the priority ranking of bridges with deficiencies in 1987 of the 164 entries made from January 1, 1986 to May 12, 1987.[sic] Additionally, there were no procedures to reevaluate the original priority rankings assigned to correct the deficiencies."

c. "While bridge inspection reports with deficiencies were reviewed and initialed by the supervisor, there was a lack of documentation to indicate that supervisors reviewed reports that contained no deficiencies."

d. "The control log of bridge inspection work orders was maintained on a manual basis, had over 100 open work orders, was used extensively by Bureau personnel, and was updated frequently for new information related to bridge deficiencies."

e. "A formal comprehensive preventive maintenance program had not been established to identify the nature and frequency of preventive maintenance procedures to be performed on the various types of bridges."

f. "Although the bridge inventory data base could accommodate inclusion of information on bridge maintenance and repair, the data was not included in the bridge inventory files. No centralized record was readily available to provide information on the various types of maintenance and repairs that have been performed on all bridges."

The Maryland Department of Fiscal Services concluded this report by submitting it's findings to the Bureau of Inspection and Remedial Engineering. In March 1989, the Chief of the BI&R responded to the audit

findings in a letter to the Department of Fiscal Service. In the letter, the Chief of the BI&R indicated that the following modifications had been made to BI&R policies and procedures:

a. "The Bureau of Bridge Inspection and Remedial Engineering has modified the internal time objective between job assignment and structural inspection from 10 days to 15 days."
b. "Starting October 1st [1989] we will establish a documented design priority for all jobs and this priority will be assigned during the review meeting with the Bureau Chief. This design priority will replace the structural inspection priority. Also, since the log has been automated, our updating will be more comprehensive, eliminating the problems with indicating the priority rankings on the log."
c. "Effective September 1, 1987, the Bridge Inspection Section Leader will be required to review, initial and date the front of all condition inspection reports and 10% of all written comments of these reports for completeness and propriety. Given that the Section receives approximately 1,000 reports annually with a finding of no deficiency, the sampling of these reports should provide the control recommended."
d. "The Bureau [BI&R] received a word processor/design computer in July 1987 and immediately began automating the log as a top priority. This task should be completed by December 31. [1989]"
e. "The Administration [SHA] has initiated a reorganization of the procedures by which Bridge Maintenance either Preventive or Reactive are accomplished. This reorganization will insure that preventive maintenance is accomplished, monitored and documented on a routine basis."
f. "Beginning January 1, 1989, the Bureau of Bridge Inspection and Remedial Engineering will begin entering individual maintenance and repair efforts which cost over $100,000. Repairs performed before this date and as far back as January 1987 will be identified to the extent possible and added to the inventory data base."

Meteorological Information

At the time of the collapse, the weather in Salisbury Maryland, about 18 miles north of Pocomoke City, was 70 degrees F, with a dewpoint of 68 degrees F. The winds were calm and the visibility was 7 miles. Clouds were scattered at an elevation of 25,000 feet, and the temperature range the day before the collapse was 70 to 89 degrees. The last rain reported prior to the collapse was August 12, 1988, when 0.51 inches were measured. At the bridge site, the Pocomoke River was controlled by tidal currents.

Tests and Research

The U.S. Geological Survey (USGS), SHA, Department of Agriculture Forest Products Laboratory, The University of Maryland, The Smithsonian Institution, the Safety Board and others conducted extensive tests to establish the environment and conditions surrounding the bridge collapse. Testing included a velocity and flow variability study of the river; measurement of the river

bed profile; property analyses and strength testing of the concrete and steel rebar; and the examination of soil borings to determine the conditions of the river bed. Further, strength tests of the timber piles were conducted, and environmental data along with the piles was examined to determine the presence of bacteria, fungi, decay and insects. In addition to this research, computer mathematical modeling was performed to further examine factors that may have influenced the bridge collapse. The results of these tests and on-scene examinations are summarized below.

U.S. Geological Survey Tidal Profile Study. On October 5 and 6, 1988, a 25-hour depth and velocity profile study of the river was conducted immediately upstream of the bridge. The study was performed after the bridge wreckage had been removed from the river and during a period when there was no salvage barge constricting the river flow. The measurements were taken the day preceding an apogean tide[34] when tidal currents generally have decreased speed. Twenty depth profiles and velocity measurements were completed during the study period. Each profile consisted of point velocities monitored at 20, 60, and 80 percent of the measured depth at 10-foot increments across the river. Two complete high-tidal exchanges and two complete low-tidal exchanges were monitored and measured during the study period.

Normal tidal exchanges in the Pocomoke River occur about every 6.5 hours in transformation from low to high tide. During the study the maximum measured velocity of 2.20 feet per second (fps) occurred on an ebb current about 150 feet from the eastern shore at 60 percent of the measured depth of 24.2 feet. During the observation period, the tide changed a maximum of about two feet in elevation. Flow varied between 667 and 6,592 cubic feet per second (cfs), and although a slight bend was present in the east side of the river, velocities near the west bank were generally higher. The maximum velocities in the area of the collapsed pile bents were 2.0 fps at bent 1 and 1.5 fps at bent 2. The velocity measurements vertically along pile bent 1 were 2.00 fps near the top at 20 percent depth, 1.92 fps at 60 percent, and 1.23 fps near the bottom at 80 percent depth. The maximum velocities over the remainder of the river varied between 1.4 fps and 1.75 fps. The depth of the river bed at pile bent 1 was 19.6 feet, and the deepest section of the river was at pile bent 2. (See figure 2.)

Based on data obtained since 1950 from the Willards, Maryland gauging station, about 35.73 river miles upstream from the S.R. 675 bridge, the maximum flood of record, 1,870 cfs, occurred on February 26, 1979. The flow at Willards is based on a drainage area of 60.5 square miles. Thus, from the data provided by the USGS the Safety Board calculated the maximum flood since 1950 at the S.R. 675 bridge to be about 12,765 cfs. This is equivalent to about twice the daily tidal flow at the bridge. At the Willards station the maximum discharge measured the month prior to the collapse was 388 cfs. Therefore, the Safety Board calculated that the maximum flow at the S.R. 675 bridge, during the month preceding the collapse, was about 2,600 cfs.

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[34] An apogean tide occurs when the moon is farthest from the earth. This tidal condition was similar to tidal conditions at the time of the collapse.

Concrete Testing. The SHA conducted concrete strength tests to determine the compressive strength and modulus of elasticity[35] properties of the bridge members. A total of fourteen, 4.25-inch core samples were extracted from the girders near the fractures, and in the pile caps and deck. The cores were tested following American Society for testing and Materials (ASTM) Standard C-39-86 "Compressive Strength of Cylindrical Concrete Specimens," C469-87a "Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," and C192-88 "Making and Curing Concrete Test Specimens in the Laboratory." Additionally, the Safety Board obtained four 6-inch core samples from one girder and had them tested in accordance with the above listed ASTM standards.

The compressive strength of the 4.25-inch core samples extracted from the girders ranged from 3,650 to 7,140 pounds per square inch (psi). The elastic modulus obtained for these samples ranged between 973,894 to 1,800,000 psi. The core samples from the pile cap and the deck had a compressive strength of 8,143 and 6,510 psi, respectively, and their elastic modulus was similar to the test results from the girder samples. Due to the low modulus of elasticity[36] obtained during these tests, strain gauges were attached to one sample resulting in a compressive strength of 5,400 psi and an elastic modulus of 3,580,000 psi. Two of the 6-inch core samples were moisture cured prior to testing and yielded a compressive strength of 4,455 psi and an elastic modulus of 3,410,000 psi. The remaining 6-inch samples were air dried prior to testing and yielded a compressive strength of 5,105 psi and an elastic modulus of 4,050,000 psi.

Rebar testing. The SHA obtained 10 rebar samples from the bridge near the fractured girders and tested them in accordance with ASTM standard A617/A617M, "Axle-Steel Deformed and Plain Bars for Concrete Reinforcement," for yield strength, tensile strength, elongation, modulus of elasticity, and chemical analysis. Additionally, the Safety Board laboratory examined rebars from the west abutment tie back, the west side spans, and a bolt segment from the submerged pile cap form work.

The modulus of elasticity of the samples examined by the SHA ranged from 13,976,240 to 33,000,000 psi. The yield strength ranged from 43,090 to 77,550 psi, and the tensile strength ranged from 63,600 to 82,810 psi. ASTM grade 40 steel is currently the lowest intermediate billet steel used for concrete reinforcement and has a minimum yield strength of 40,000 psi and a minimum tensile strength of 70,000 psi.

A metallurgical examination of the concrete encased tie back rebars from the west abutment revealed that five were necked down and fractured, while one rebar had been pulled out of the dead man. Two of the fractured rebars showed features typical of a recent overstress separation, while the

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[35] A constant that relates the stress and strain for certain materials within their elastic limits.

[36] Generally, concrete has an average modulus of elasticity between 3,000,000 psi and 4,000,000 psi.

remaining rebars exhibited heavy oxide corrosion in the fracture areas. The fractured rebars were heavily corroded and displayed a cross sectional area reduction of as much as 39 percent.

Soil Borings. Following the collapse, the SHA extracted four soil borings from the Pocomoke River bed at the bridge site to determine the river subsoil profile. The samples were taken near each abutment, near pile bent 1, and near pile bent 5. The sample extracted near pile bent 1 was taken to a depth of 103.5 feet below the water surface. In general, the SHA reported that from 23.5 to 33.5 feet the soil was dense to very loose brown coarse sand, with a resistance of 2 blows per foot.[37] According to the SHA, this soil was considered loose, and the Safety Board calculated that it would not support loads in excess of .5 tons per square foot (tsf).[38] From 33.5 to 59.0 feet below the water surface the soil was identified as moist soft to medium stiff gray silt with some clay, resisting 2 to 12 blows per foot. The SHA considered this soil loose to firm silt, and the Safety Board calculated that it would only support maximum loads of 1 tsf. The next stratum was classified by SHA as firm, compact, and very compact sand with a bearing capacity range from 2.25 to 5 tsf. The layers below this were identified as very compact gray brown coarse sand, or grayish green sandy clay. The resistance of the lower stratum soil was from 30 to 182 blows per foot, and Safety Board calculations indicated that this soil had a bearing capacity in excess of 4 to 5.5 tsf.

Examination of the Timber Piles for Marine Borers and Bacterial Degradation. The Department of Agriculture Forest Products Laboratory (FPL) examined twelve samples of the timber piles from the collapsed bridge. The majority of these samples were recovered segments of the exposed piles; however, several were the pile butt ends that had been extracted from the pile cap wreckage. Additionally, FPL examined and compared a timber plank sample from one of the bascule fenders, a pile sample from a nearby dismantled dock, and a timber pile from one of the dolphins. The timber was examined for structural condition including attack by marine borers, decay, and degradation. Each sample was inspected visually and microscopically, and during the microscopic examination, slivers of wood were macerated in chromic-nitric acid, rinsed, and studied under polarized light.

FPL determined that all of the bridge pile samples were untreated southern pine, that all samples of exposed pile were encrusted with barnacles, and that there was no evidence of marine borer damage. The visual

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[37] Blows per foot are the number of times a drop hammer hits a soil sample, which indicates the bearing strength of the soils. In this instance, the drop hammer was 300 lbs, the spoon hammer was 140 lbs, and the drop was 30 inches.

[38] Hough, B.K., Basic Soils Engineering, The Ronald Press Company, New York, New York, 1969, pp. 308-309, Bearing Capacities.

examination revealed the presence of blue stain,[39] degradation, brittle failures, and ring separation. Under favorable conditions of mild temperatures and ample moisture and oxygen, wood can become noticeably discolored in less than a week. Since the samples were not shipped to FPL for several months after the collapse, researchers indicated that it is possible that stain fungi infected the piles after they were removed from the water. However, the pile sample from the dismantled dock was observed to be infected with blue stain when it was removed from the river.

FPL reported that during microscopic examination, extensive bacterial infestation was detected in all of the timber samples. Three types of bacteria were identified in the samples: cavitation, tunneling, and erosion. Cavitation bacteria form cavities within the cell walls. Tunneling bacteria penetrate the wood cell walls producing channels within the walls, and erosion bacteria gradually attack the layers of the wood cell walls. With prolonged attack, all three can greatly reduce the strength and related properties of wood, but little is known quantitatively about these effects. The ring separations observed in the timber piles were probably a result of the cavitation bacteria. These forms of bacterial attack are slow compared with wood decay fungi, are promoted by wet conditions, and were not commonly known to designers at the time the bridge was constructed.

Soft rot[40] was also observed in some of the samples examined by FPL. (See figure 9.) Typically, soft rot is relatively shallow and is confined to the outer layers of submerged piles. The soft-rot cavities were numerous at the surface of all samples and common several inches from the surface of most of the samples. According to FPL, the unusually light weights of some samples attested to their advanced states of degradation. However, FPL could not determine the rate at which degradation and erosion occurred, except to note that bacterial degradation is a very slow, long-term process.

FPL indicated that brittle failures were clearly present in some samples and to a lesser degree in several others. Brittle failures are characterized by fractures across the wood grain rather than jagged fractures that follow the grain for considerable distances. Brittle failures are common in degraded wood but may also be indicative of overstressing. Further, one pile sample had ring separations that may have been due to shake.[41]

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[39] Blue stain is a bluish or grayish discoloration of sapwood caused by the growth of various fungi. Stain has only a slight effect on the strength of wood, but it can significantly reduce shock resistance and toughness.

[40] Soft rot is caused by fungi related to mold and is prevalent in wet environments. The affected timber is greatly degraded and the outer wood layers appear soft.

[41] Shake is the separation of wood along the grain occurring between the annual growth rings. Shake can occur in a standing tree or during felling.

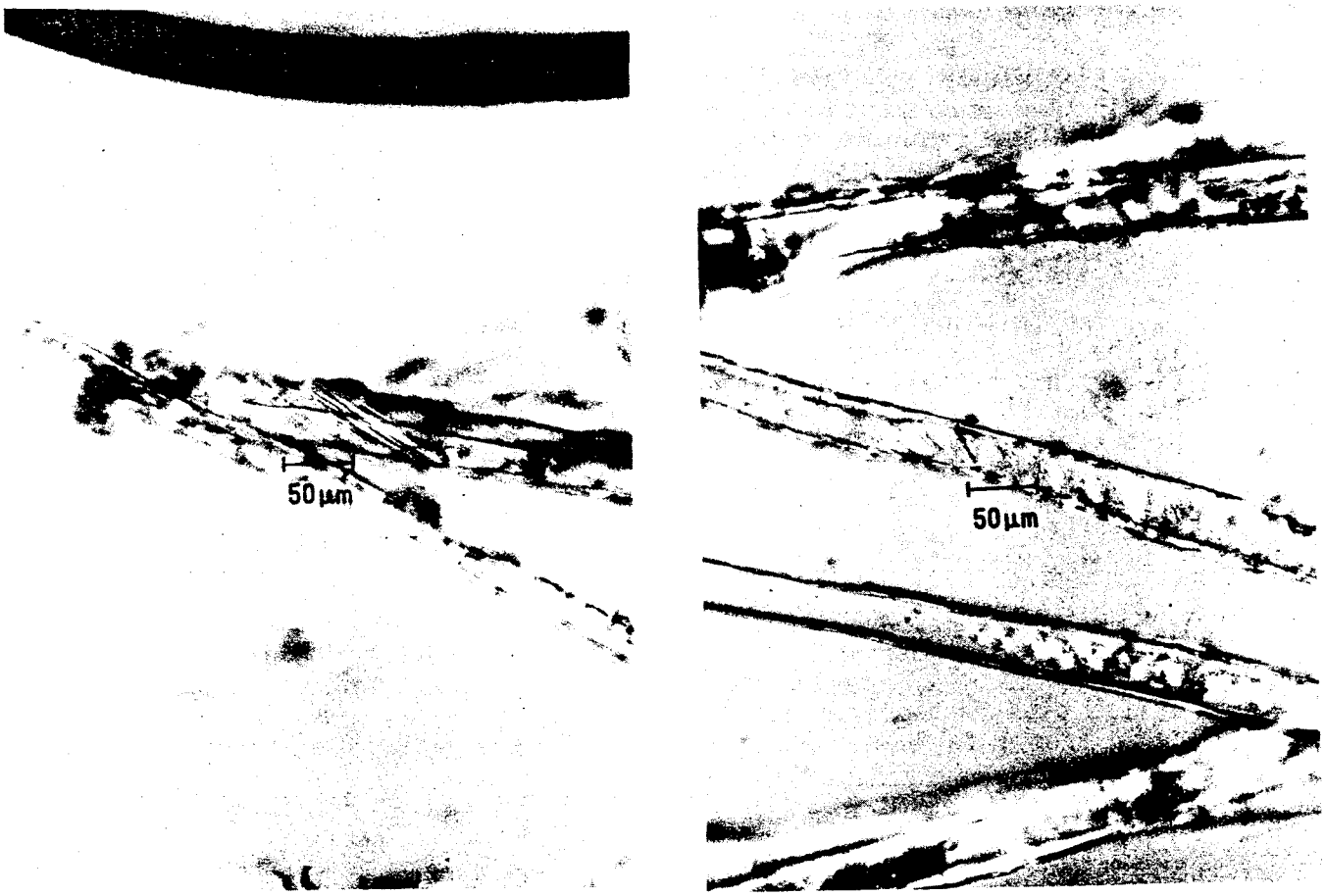


Figure 9.--FPL electron microscope photographs of soft rot and bacterial degradation from the surface of a pile sample.

FPL concluded, "Erosion of the pile surfaces caused significant loss of section. Near the tops of the piles, the diameter was reduced by about 3 inches, and near the bottom about 1 inch. This erosion was very likely the result of combined actions of currents, eddies, and suspended particulate on wood surfaces which had been softened by microbes. [bacteria and fungi] Preservative treatment, especially creosote, retards the development of soft rot and bacteria in submerged wood and thereby can reduce the rate of surface erosion."

The timber pile sample from the dismantled dock near the bridge was identified as untreated white oak, and had been submerged in the river for over 75 years. Microscopically there was little evidence of bacterial or fungal attack in this sample. The creosote treated timber plank from the fender, and creosote treated timber pile from the dolphin exhibited an abundance of decay fungi and soft rot cavities in the wood cell walls. However, the infestation appeared to be limited to the extreme outer surface of the wood.

Examination of Piles for Aquatic Insect Larvae. The Smithsonian Institution Department of Entomology examined several samples of the exposed timber piles from the bridge. Department researchers concentrated their effort on small oval shaped holes that covered the circumferential surface of the recovered piles. When examined, several insect larvae were discovered within the small recesses. The insect larvae and their retreats were identified as caddisflies.[42]

The Smithsonian Institution reported that the type of caddisflies found in the S.R. 675 bridge piles dig small retreats (pits) in the surface of the timber during their larval stage. The next generation of larvae may inhabit the same hole or dig new holes if unoccupied retreats are not available. Several larvae may also live in the same retreat, enlarging the hole until retreats intersect, creating large irregular depressions. While most species in the mid-Atlantic States have a single life cycle annually, research has documented as many as two or three generations per year in Georgia and Virginia, respectively.

Eight counts on three of the S.R. 675 bridge piles were made to determine the number of pits and the average size of each pit. The number of pits counted in a 9-square-inch area ranged from 14 to 29. The surface area of the pits ranged from 15 to 20 mm by 5 to 8 mm, and the pits varied in depth from 1 to 2 mm. Assuming the pits were rectangular rather than oval,

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[42] Caddisflies are an order of insects closely related to the moths and butterflies that have a four stage life cycle. The first three stages(egg, larvae, and pupa) live in an aquatic habitat. During the fourth stage (adult), the female places fertilized eggs on a suitable substrate by descending into the water, by dropping an egg mass into the water, or by laying the eggs near the edge of the water. When living in the water, the larvae and pupae either construct a portable case or dig a shelter into the substrate for protection.

Some species dig small holes into submerged timber for protection. The homes consist of a retreat which shelter the larva. This retreat is fixed to the substrate after the larva chews out a small depression to reduce its profile. In addition, an anterior net of some type which strains food from the flowing water is attached to the shelter. At the end of the larval stage, all species construct a shelter for the ensuing pupa. At this time the shelter is enlarged, deepened and strengthened. After completion of the pupal period, the pupa cuts its way out of the shelter, swims to the surface, and flies away, thus beginning the cycle again.

it was calculated that the pits occupied from 18 to 80 percent of the surface area, averaging 46 percent. (See figure 10.)

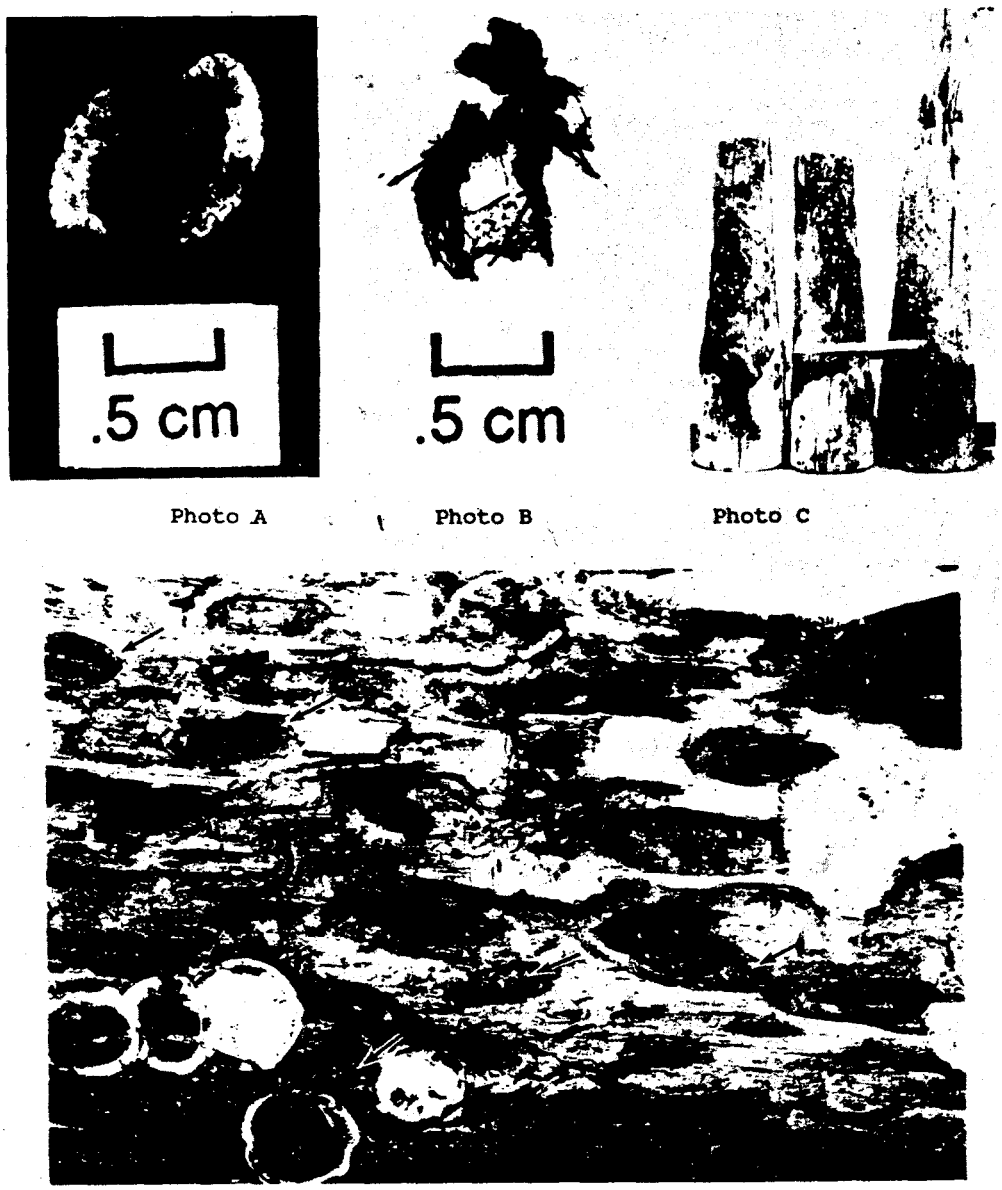


Figure 10.--Photographs of the S.R. 675 bridge piles and aquatic insect larvae; (A) caddisfly larvae, (B) the remains of a trap net, (C) three pile butts that depict a cross sectional reduction, and (D) caddisfly damage to the pile surface (the arrows indicate mesh shelters).
(Courtesy of the Smithsonian Institution)

The Smithsonian Institution concluded that the timber piles supporting the S.R. 675 bridge were probably not infested with caddisflies until after the piles had been "conditioned" [decayed] by bacteria or fungi. Further, the Smithsonian concluded that caddisfly larvae allowed the bacteria and decay fungi to penetrate deeper into the wood, while removing conditioned wood from the pile surfaces, thereby accelerating the degrading effects of the bacteria and decay fungi.[43]

Timber Pile Strength Tests and Measurements. The University of Maryland and Safety Board investigators measured the original and reduced pile diameters for the west side span pile bents. The original diameters were determined from the pile butts, and in pile bent 1 ranged from 9.88 to 15.25 inches, averaging 11.76 inches. The reduced pile diameters were determined from the exposed sections of the pile butts below the pile cap. The reduced diameters for the piles in pile bent 1 ranged from 8.30 to 11.12 inches, averaging 9.51 inches, and had an average diameter loss of over 2 inches. For pile bent 2 the original diameters ranged between 10.19 and 12.75 inches, averaging 11.26 inches. The reduced diameters for the piles in pile bent 2 ranged from 9.75 to 11.09 inches, averaging 10.21 inches, and had an average loss of more than 1 inch.

The timber piles from the bridge were tested for compressive strength and for static bending by the University of Maryland in accordance with ASTM standard 143-83, "Standard Methods of Testing Small Clear Specimens of Timber." Tests were conducted on both saturated and air-dried samples (12 percent moisture content) of differing lengths and sections. Additionally, static bending tests were conducted on smaller 1 x 1 x 16-inch samples to determine the modulus of elasticity.

Thirty-six small air-dried and saturated samples from pile bents 1 and 2 and from the east side span pile bents were tested. The average compressive strength of the saturated samples was 3,272 psi, and the average compressive strength of the air dried samples was 5,239 psi.[44] The average modulus of elasticity for the saturated samples was 1,258,400 psi,[45] and the average modulus of elasticity for the air dried samples was 1,415,900 psi. Further, compressive strength tests were conducted on 10 saturated full pile samples[46] from the east side span pile bents. Three tests were conducted on piles from pile bent 5, averaging 2,875 psi, and seven tests were conducted on pile samples from pile bent 6, averaging 2,650 psi.

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[43] See appendix E for more information concerning caddisfly infestation of submerged timber.

[44] Generally, southern pine has an average compressive strength of 3,510 psi (saturated), and 7,130 psi (dry).

[45] Generally, southern pine has an average modulus of elasticity of 1.4 million psi (saturated), to 1.7 million psi (dry).

[46] The full section lengths were 2.5 to 3.0 times the pile diameters and were based on ASTM recommendations.

Computer Modeling. The University of Maryland (UMD) used several computer models to determine the effects of dead loads[47] and incrementally applied static live loads[48] on the superstructure and substructure of the west side bridge spans. Two live loads were utilized in the computer analyses; a 65,000-pound dump truck[49] (a load which the bridge could have experienced recently), and an H-20-44[50] truck (a load similar to the 1919 design load for the bridge). Due to limitations with the computer programs, impact loads[51] were not considered during the analyses.

The UMD analyzed the bridge superstructure to determine the loads necessary to crack the concrete girders, and also to determine how those loads were distributed to the substructure members. Two different computer programs were used to model the bridge superstructure.[52] During the computer modeling, the UMD utilized various mean properties of the bridge elements and assumed several functional bridge characteristics. The west side superstructure was analyzed as three continuous spans, and the assumed boundary conditions of the spans were as follows: the west abutment acted as a pinned support; pile bents 1 and 2 acted as spring supports; and the bascule pile bent acted as a fixed support, due to the massiveness of the bent. The depth of the main reinforcing steel in the bottom of all the girders was modeled to be consistent with the bridge design plans.

Both superstructure computer analyses indicated that when the uncracked girders of the west side spans were loaded with an H20-44 vehicle, the

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[47] A static load due to the weight of the structure itself.

[48] A load such as traffic load that is applied statically to a structure.

[49] A three axle, 65,000-pound dump truck with 13,000 pounds distributed to the front axle, and 26,000 pounds distributed to each of the rear axles, the axles are separated by 13.5 feet and 4.5 feet, respectively.

[50] An AASHTO design vehicle weighing 40,000 pounds with 8,000 pounds distributed to the front axle and 32,000 pounds distributed to a single rear axle, separated by 14 feet.

[51] A load allowance or increment intended to provide for the dynamic effect of a load applied in a manner other than statically.

[52] SAP-IV - A general two dimensional computer program that performs linear, elastic analyses of large, complex structural systems subjected to either static or dynamic loads. The program determines maximum loads, moments of inertia, sheers, and interactions of structural elements.

DESCUS-I - A finite element, two dimensional, computer program specifically for bridges. The program also performs linear, elastic analyses of complex structural systems subjected to either static or dynamic loads. The program also determines maximum loads, moments of inertia, sheers, and interactions of bridge structural elements.

girders would crack near the center of span 1, and in span 3 near the bascule pile bent. The loads needed to crack the girders were: 1,815 kip/feet[53] in the exterior girders, and 1,979 kip/feet in the interior girders. These loads were calculated assuming no reductions of the girders due to corrosion of rebars or loss of concrete.

The substructure elements for pile bents 1 and 2 were modeled using the three-dimensional PILE[54] computer program. The UMD evaluated the piles at both original and reduced diameters, and with an average unsupported length of 15.3 and 22 feet for pile bent 1 and 2 respectively. University researchers documented the pile spacing, the direction of batter, and the batter slope. The piles for which the batter and slope could not be determined were assumed plumb for modeling purposes. Further, the additional loss of pile capacity due to decay and bacteria infestation of the remaining pile cross sections was not considered. Since the pile length could not be determined from the design plans or during salvage, two pile lengths, 50 and 65 feet, were analyzed. The UMD selected these pile lengths because 50-foot piles were probably the longest locally grown piles available when the bridge was constructed, and 65-foot piles were the longest piles that could have been transported to Pocomoke City by rail at that time. The UMD developed four substructure study scenarios, one using the 50-foot pile length and three using the 65-foot pile length.

The UMD concluded in its analysis of the first study scenario (50-foot length, reduced diameter piles) that had the bridge been supported by 50-foot length piles, the west side spans could not have supported the bridge dead load and the bridge would have collapsed long ago. Due to the low density characteristics of the soil that would have surrounded 50-foot length piles, the piles would have failed in embedment (settlement). The UMD also indicated that even without the reduced pile diameters, the 50-foot piles could not have supported the bridge dead load over its 67-year life because the diameter of a pile is not a major factor in its ability to support a load in friction.

In the first computer model scenario with a pile length of 65 feet, the bridge was assumed to be in new condition with sound girders and full diameter piles. The second 65-foot length pile scenario assumed that the bridge girders were cracked, and that the bridge had original diameter piles. The third assumed that the girders were cracked and that the piles were reduced in diameter. As a result of these computer analyses, the UMD concluded that the most critical location within the bridge structure was at pile bent 1. The computer analyses indicated that when the bridge model with cracked girders and reduced pile diameters was loaded with a 65,000-pound

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[53] One kip = 1,000 pounds per square inch.

[54] PILE - A three-dimensional computer program that models the bridge substructure as an elevated platform supported by partially embedded piles. The program determines the deflections and rotations of a pile cap about its origin; pile group stiffness; and the forces and moments of inertia needed to buckle individual piles.

full dump truck, the load on pile bent 1 was 94 percent of that needed to buckle the piles in the pile bent. The piles in pile bent 2 experienced 58 percent of their buckling load when they were subjected to the same vehicle loading conditions. Further, when the 65,000-pound vehicle load was applied to the computer model that assumed cracked girders but original diameter piles, the piles in pile bent 1 experienced only 49 percent of the load needed to buckle them. Therefore, the UMD study indicated that the reduction in pile diameters for pile bent 1 and 2 was a major factor in the collapse of the bridge structure. The UMD believed that contributing factors included the preexisting cracks in the girders, the close spacing and improper batter of the piles, which would reduce the pile group efficiency[55] and thus the pile group load carrying capacity, as well as repeated loadings over a period of 68 years, which would reduce the lateral support of the soil surrounding the piles.

Other Information

Water Quality Information. The Pocomoke River, which maintains an average depth of about 15 feet and an almost uniform width of 400 feet, flows about 17 miles from the bridge site to the Pocomoke Sound in the Chesapeake Bay. Water characteristics of the Pocomoke River were obtained from data collected near the S.R. 675 bridge by the Maryland Department of Environment (MDE) from 1974 to 1982 and again in 1988. The United States Environmental Protection Agency (EPA) also provided river data from between 1954 to 1960 and from 1986 to 1987. Additionally, the MDE provided information on industrial plants that had discharge permits near the S.R. 675 bridge.

The Pocomoke River is affected by the geological formation in southern Maryland which is an extension of the Dismal Swamp. The rotting vegetation from the swamp environment results in the formation of tannic acid, which tends to increase suspended material and give the river a dark brown or black color. Suspended solids were measured and averaged about 26.4 milligrams per liter. According to the USGS, water is visibly very dirty when this number is higher than 100 and clear when it is below 10.

Salinity was measured about 13 to 22 parts per thousand (ppt) near the mouth of the Pocomoke River in the Pocomoke Sound. Near the bridge site, salinity varied from just barely detectable to 4.12. The higher salinity values usually occurred during the late summer months when the freshwater flow to the river was minimal.

The MDE provided copies of Surface Water Discharge permit applications for six companies in the area of the bridge. A review of these permits indicated that the current discharge into the river had no significant effect on the water quality. The latest discharges sampled from these companies were examined and found to be typically within the pH limits and under the temperatures allowed by their permits.

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[55] The ability of the piles within the pile group to act as a single column element.

In 1970, the State of Maryland Department of Water Resources, Water Quality Investigation Division, conducted a survey of the Pocomoke River. The purpose of the survey was to determine general water quality of the river and the impacts of municipal and various industrial effluents on the water quality. The survey indicated that the outfalls from the Snow Hill Municipal Sewage Treatment Plant and the Maryland Chicken Processors, Inc. severely loaded the river with organic material, nutrients, and bacteria. The same conditions existed to a lesser extent from the industrial outfalls of the Pocomoke City Municipal Sewage Treatment Plant in the vicinity of Pocomoke City. At that time the sewage treatment plant at Snow Hill and the Chicken Processors plant contributed to oxygen depletion in the area. According to the MDE, improvements in sewage treatment have greatly improved oxygen levels in the Pocomoke River since the 1970 study. In 1971, the Pocomoke waste treatment facility was fully operational, and major waste discharges from industries, which had previously discharged waste into the river, were tied into the system. In 1979 the Snow Hill Sewage Treatment Plant was improved and the Chicken Processor Plant closed.

As one measure of water quality, the MDE collects data on the insects that live in the water. Near the Pocomoke City Bridge site, caddisflies were collected and counted. The number of larvae per 1.5 square feet was provided from 1976 to 1986 and averaged 543.5, with a high in 1977 of 1,837 and a low in 1986 of 50. Further, the Safety Board calculated that in 1977, caddisflies may have occupied 30 to 100 percent of the bridge substructure pile surfaces. Prior to the accident MDE did not share this information with the SHA. However, following the discovery of the caddisfly larvae infestation during the investigation, the Safety Board solicited data from the MDE that resulted in the identification of 10 other locations in Maryland where high levels of caddisfly larvae had been measured. Consequently, the SHA has initiated underwater inspections of bridges in those areas.

MDE concluded that the suspended organic material in the water would favor the filter-feeding type insects such as the caddisfly. The dominance of the caddisfly had tapered off since the 1970's, and MDE attributed this reduction to the closing of the Chicken Processors plant and improvements in the Snow Hill Sewage Treatment Plant, which would lessen the organic input to the river. This particular species of caddisfly appears to favor tidal freshwater areas where suspended particulate seem to be maintained by the tidal action.

FHWA and AASHTO Publications

A review of FHWA and AASHTO publications dealing with bridge inspection and maintenance found no discussion of caddisfly infestation. The "Bridge Inspectors Training Manual" and AASHTO's "Manual for Maintenance Inspection of Bridges" mentioned fungi and bacteria degradation of both treated and untreated timber piles. Both texts also contained information on gathering increment bore samples from the timbers, but, neither discussed tests or examinations that could be conducted on the samples to determine the existence or level of bacterial and fungal infestation.

The AASHTO Design Manual did discuss limitations on the use of untreated timber piles. Section 4.3.2.1 of the Manual states that untreated timber piles can be used in permanent construction under the following conditions: "(1) for foundation piling when the cutoff is below permanent ground water level; (2) for trestle construction when it is economical to do so, although treated piles are preferable; (3) and they shall not be used where they may be exposed to marine borers."

National Cooperative Highway Research Program

A recent Transportation Research Board publication addressed the use and inspection of timber in bridges. The National Cooperative Highway Research Program (NCHRP) Synthesis 118, July 1985, "Detecting Defects and Deterioration in Highway Structures," stated that increment bore material can be tested for moisture content and preservative penetration, or it can be cultured for positive evidence of decay fungi. The report discussed a "Pilodyn," an instrument that can measure the depth of penetration of a pointed pin shot into the wood. The penetration is used for estimating the degree of decay (soft rot) which in turn is correlated with loss of strength. According to the report, ultrasonic devices are the most promising means being developed for the rapid nondestructive testing of timber piles, and to discover voids and differences in moisture content and density. It concludes; "Such measurements [measurements of voids, moisture content, and density] are possible using existing techniques, but tend to be labor intensive and consequently expensive." The report also included a nationwide survey which showed that in most states visual inspections were conducted; ice pick or nails were used to determine penetration resistance; and increment boring tools were used to extract core samples. In twelve states sounding hammers were used to determine voids and soundness; in one state the chemical composition content of piles was examined, and in 14 states pile samples were cut and examined for strength, fungi, vermin, weathering, and preservative treatment.

Truck Traffic on Bridge

Maryland weight enforcement records indicated that there had not been any enforcement activities concerning the S.R. 675 bridge weight restrictions by either the State Police or the Maryland Department of Transportation since the bridge had been load posted with a 25-ton weight limit in 1988. Records also indicated that there had not been any complaints from the public about heavy vehicle traffic on the bridge. An investigation of the local motor carriers revealed that few carriers have used the bridge for routing their heavy trucks (over 25,000 pounds) since the new U.S. Route 13 bridge was constructed in 1959; however, the bridge was the main route for trucks between its construction and 1959. The last large vehicle that was known to have crossed the bridge was at 8:00 a.m. on August 16, 1988, the day before the collapse, when a partially loaded tractor-semitrailer weighing about 21,000 pounds used the bridge to make a delivery in Pocomoke City. Additionally, municipal school buses crossed the bridge eight times daily during the school year.

Bridge Replacement Information

Following the collapse, the SHA conducted underwater and superstructure inspections of the remaining spans and erected a temporary pedestrian walkway. A decision was made to replace the collapsed west side spans and to dismantle and replace the east side spans with new abutments, new pile bents supported by steel "H" piles, and continuous steel girders that were to be cantilevered across the short spans at the bascule. The bascule was to remain in place, and a previously arranged maintenance contract for the rehabilitation of the trunnion assembly was to go forward. The initial bid accepted for the replacement of the side spans was $1,534,320.50.

After the construction of the new spans began, and following Safety Board inquiries concerning the condition of the bascule pile bents, the SHA made a more thorough inspection of the bascule pile bents and discovered discrepancies between the actual placement of the piles in the bent and the bridge design plans. As a result of this inspection, the SHA decided to place concrete mini-piles under the bascule pile bents to form a foundation independent of the timber piles. SHA estimated that the final cost for the replacement bridge construction including the additional changes would be over $3,000,000.00.

ANALYSIS

General

The post-collapse emergency response and survival aspects were not factors in the severity of this accident. No vehicles fell into the river, and no one was injured as a result of the collapse. The 911 emergency police dispatcher was advised of the collapse shortly after the incident, and the police response to close the bridge following the collapse was timely.

Physical evidence and witness observations indicated that the west side bridge spans showed signs of deformation at least two days prior to the collapse. Consequently, it is likely that the collapse was imminent, and thus the passenger car that crossed the bridge just prior to the collapse did not influence the outcome of this accident.

Failure Modes

A post-collapse inspection of the bridge wreckage revealed three obvious areas where the superstructure had cracked; near the west abutment; just east of pile bent 1, and near the center of span 3. The cracks in span 3 and just east of the west abutment coincided with cracks observed in several previous inspection reports, and the crack just east of pile bent 1 coincided with witness observations of the bridge prior to the collapse. This evidence suggested that the bridge collapsed as a result of a superstructure failure. However, the untreated timber piles that supported the west side spans exhibited a reduction in cross sectional area of as much as 35 percent. Therefore, it was also possible that the substructure could no longer support the bridge loads and failed, causing the superstructure to fail. Accordingly, the Safety Board evaluated the possibility of a failure of the

bridge superstructure members, including the west abutment, due to pre-existing deficiencies of its structural members or an excessive load, and the possibility of a failure of the substructure due to excessive water loads, scour, or pile deterioration.

Mode 1: Failure of the Superstructure and Abutment. Two days prior to the collapse witnesses reported a crack in the south exterior girder just east of pile bent 1. Witnesses also reported a sag or "v" shaped depression in the bridge deck that coincided with this crack. This area was consistent with a fracture across all four superstructure girders discovered during an examination of the bridge wreckage. However, if this fracture of the bridge superstructure had been the initial event in the collapse, span 1 would not have sagged or bowed downward to the extent indicated by witnesses, and the bridge deck would not have exhibited a sag or "v" shaped depression. A complete girder fracture just east of pile bent 1 would have transformed span 2 into a cantilever arm supported entirely by pile bent 2. As a result, span 1 would have remained stationary supported by pile bent 1 and the west abutment while the west side of span 2 began to displace vertically and separate from span 1. The bridge deck would have exhibited a defined vertical displacement and produced a break similar to a step or curb, rather than a depression. Further, as a result of a superstructure failure at this location, the crack in the deck probably would have been more noticeable, and it is likely that more motorists would have reported it. The only witness to indicate a curb type phenomenon was the driver of the last vehicle to cross the bridge moments before the complete collapse.

The post-collapse examination of the bridge wreckage revealed that the superstructure was also fractured along the lines of a pre-existing crack in span 1 just east of the west abutment. However, if this fracture had initiated the collapse, a condition similar to the previous scenario would have occurred at span 1. The abutment would have remained stationary, and span 1 would have been transformed into a cantilever arm. Although the span would have been supported by both pile bents 1 and 2, it is likely that a defined vertical displacement of the deck would have occurred at this location. There were no reports of this type of fracture in the bridge deck prior to the collapse. Further, if this fracture had been the origin of the collapse, span 1 would have probably been separated from the abutment. However, span 1 was leaning against and partially connected to the west abutment following the collapse.

Another fracture was observed in the area of a pre-existing crack at the center of span 3. It is unlikely though that this fracture would have caused the collapse. There were no reports of a fracture in the bridge deck at this location prior to the collapse. Also, span 3 was originally designed to be a 13-foot simple span, although it was constructed as a fixed span between the bascule pile bent and pile bent 2. A fracture in the center of this span would have made the bridge less redundant, but additional loads placed on pile bents 1 and 2 as a result of the fracture, would not have been greater than the loads the pile bents were originally constructed to support.

The bridge inspection history indicated that there was some displacement and subsequent repair of the west abutment. An examination of the abutment

following the collapse revealed that several of the abutment tiebacks, connecting the abutment to the dead man, had pre-existing cracks and were corroded at least 39 percent in cross sectional area. However, the remaining sound tieback had limited corrosive damage and appeared to have been pulled out of the concrete due to a loss in bonding, rather than a sudden fracture. Due to the continuous construction of the spans, a failure of the west abutment probably would have resulted in an opening in the pavement on the approach to the bridge. The opening would have been limited in size because the massiveness of the bascule span would have fixed the structure in place and would have allowed only slight longitudinal movement to the east. However, even a limited opening would have been noticeable to motorists. No opening or crack of this type was reported by any witnesses or during the June 1988 engineers inspection, and no evidence of this type of opening existed in the bridge wreckage. Further, had the west abutment failed, it is likely that the abutment backwall would have collapsed along with the west side spans.

There was no evidence that the bridge had been damaged by a heavy traffic load during the several days prior to the collapse. The only truck known to have crossed the bridge in that period was a tractor semi-trailer that weighed about 21,000 pounds. No evidence existed that the superstructure had sustained any other substantial vertical or lateral loading before the collapse, and there were no indications that the bascule had been recently overloaded.

Further, the SHA engineers June 7, 1988 inspection of the bridge found cracks attributed only to shrinkage due to a lack of expansion elements within the bridge superstructure. The engineers did not observe any vertical cracks in the girders indicating a fracture, or bearing cracks at the abutments or pile bents. There was also no evidence of significant damage to the bridge from collisions with waterbound traffic. Therefore, based on a review of the bridge wreckage and witness statements, the Safety Board concludes that the collapse sequence did not result from pre-existing defects in the superstructural bridge components, or an overstress of those components.

Mode 2: Failure of the Substructure. Scour or erosion is the most common factor in the collapse of bridges over water. Rapidly flowing water may have eroded or scoured the streambed beneath the S.R. 675 bridge substructure, causing one of its critical elements to fail. However, during the month prior to the bridge collapse, there were no significant flows or floods in the Pocomoke River. The maximum discharge during the month prior to the collapse at Salisbury, Maryland was 388 cfs, which was equivalent to about 2,600 cfs at the S.R. 675 bridge. The 2,600 cfs is less than half of the 6,000 cfs average flow that occurred daily during tidal changes at the bridge. The bridge collapsed within five minutes of the predicted low tide, while the river was flowing at about 2 fps.

Further, flowing water often carries debris such as large trees that could have lodged against the bridge substructure creating considerable lateral forces on the upstream side of the bridge. During the wreckage salvage, divers did report that there were some small trees and perhaps

timbers from form work caught in the pile supports. However, the few trees that were observed around the piles would not have increased scour significantly enough to endanger the bridge, especially with the relatively low velocities and the daily tidal flow reverses. Further, the debris did not accumulate enough at the pile bents to have affected the lateral loading on the substructure.

Over the years, there appeared to have been some slight changes in the streambed profile. The channel filled in between the west abutment and the west side of pile bent 1. However, the channel deepened at the east side of pile bent 1 and surrounding pile bents 2, 5, and 6. As a result, about 1 to 2 feet of each east side pile in pile bent 1, that had been buried in the riverbed when the bridge was constructed, was now exposed to water. Similarly, the piles of pile bent 2 had 4 to 6 feet of their original buried length now exposed to water. These changes would have exposed greater pile lengths to water and would have made the piles more susceptible to buckling and embedment.

Since (a) there were no significant flows the month prior to the collapse that could have scoured out the foundation soil around the piles, (b) the river bed had not changed dramatically over the years, and (c) the soil around the piles had not been eroded more than a few feet as a result of this change, the Safety Board concludes that scouring around the bridge substructure did not occur, and the change in streambed profile was not enough to initiate the collapse sequence.

After examining the piles from pile bents 1 and 2, it was obvious that there was a significant reduction in the cross sectional area of the piles along the entire length exposed to water. At pile bent 1, the piles showed an average reduction in cross sectional area of about 35 percent, and at pile bent 2 the reduction averaged about 18 percent. Pile bent 1 was the substructure element located underneath the area where witnesses saw a crack through the girder and a depression in the bridge deck. Additionally, the piles used to construct pile bent 1 were slightly smaller than those used to construct pile bent 2. Further, because of the pre-existing cracks in span 1 near the west abutment, and at the center of span 3, the redundancy of the west side bridge spans was partially lost. Both live and dead loads were no longer equitably distributed by the superstructure to the substructure members. As a result, the two west side pile groups acted as independent supports, and the magnitude of the loads supported by each pile group was shifted. Further, some of the live and dead load that would have been carried by the bascule pile bent was now being carried by the two west side pile bents. Pile bent 1 supported a portion of the dead load from span 2, and most of the dead load from span 1. This combination of factors suggested that a pile buckling failure would more likely have originated at pile bent 1 than at pile bent 2.

During the UMD computer modeling of the bridge elements, attention was focused on pile bent 1 to determine the loads needed to cause a buckling failure of the piles. The UMD modeled the substructure elements for pile bents 1 and 2, studied four scenarios with variable conditions, and utilized two different assumed pile lengths, 50 and 65 feet. The results of

this computer modeling indicated that the deteriorated piles could not have supported the dead load of the bridge if they had been only 50 feet in length. The computer modeling further revealed that 65-foot piles, that were not deteriorated or reduced in diameter, could support the bridge dead load and a full dump truck weighing 65,000 pounds. This combined weight would have been only 49 percent of the load needed to buckle the piles in pile bent 1, and 40 percent of the load needed to buckle the piles in pile bent 2. However, when the same live and dead loads were applied to the bridge model that had 65-foot piles with reduced diameters, the combined weight was 94 percent of the load needed to buckle the piles in pile bent 1, and 58 percent of the load needed to buckle the piles at pile bent 2.

The bridge design plans did not indicate the pile length, and the SHA was unable to recover embedded pile remnants during the salvage of the bridge wreckage. Therefore, the original pile lengths could not be determined. As a result, the UMD used two assumed pile lengths during the computer analyses. Although there was no evidence to suggest the exact length of the piles, it is unlikely that the piles were longer than 65 feet. A 65-foot pile was the longest pile that could have been transported by rail to Pocomoke City at the time the bridge was constructed. Therefore, the UMD computer models apparently considered the best conditions regarding pile length. Any length less than 65 feet would have reduced the embedded length of the piles, and subsequently reduced the load needed to buckle the piles. Additionally, shorter length piles would have made the piles more susceptible to embedment.

Actual measurements of the reduced pile diameters were used during the computer analysis. However, it was not practical for the UMD to include the effects of certain conditions in its computer analysis. The UMD did not account for any internal decay and degradation of the remaining pile by bacteria or fungal attack. Although this degradation could not be measured by either FPL or the UMD, it is likely that the timber was weakened further as a result of the infestation. The analysis also did not include additional reductions in pile diameters as a result of natural taper of the timber piles. A 1974 USDA report[56] indicates that southern pine poles, 55 to 65 feet in length, typically lose one inch in radius every 16 to 21 feet. Further, the improper batter measurements of the piles in pile bent 1 were not completely available, and so the UMD assumed that 5 of the 10 piles in this bent were plumb. Finally, the UMD did not account for any concrete deterioration in the bridge beyond the girder cracks and spalling of the pile bents. The spalling that was observed around the pile butt ends expanded the length of the piles exposed to water, and reduced the pile area that was fixed in the pile cap; this would have decreased the pile's ability to resist rotation. A small loss in pile fixity (lateral movement or rotation) could translate into a larger loss in piles ability to resist buckling. As a result, the Safety Board believes that those factors that were not considered during the computer analysis would have further reduced the loads necessary

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[56] Bohanne, Billy, Habermann, Herman, and Levgal, Joan E.," Taper of Wood Poles'," USDA Forest Service General Technical Report FPL-2, Madison, Wisconsin, 1974.

to buckle the piles in pile bent 1.

The Safety Board believes that the piles supporting the S.R. 675 Bridge were probably not uniform in length, and some may have been shorter than 59 feet (the depth of the bearing soil at pile bent 1). Therefore, some pile embedment may have occurred during the collapse sequence. However, it is likely that pile buckling would have occurred simultaneously with any pile embedment. Thus, the Safety Board believes that although pile buckling initiated the collapse sequence, some pile embedment may have occurred during or prior to the collapse sequence.

Reasons for Timber Pile Deterioration

The reduction in pile cross section was the result of several related factors working together. The factors included: the deterioration of the timber piles by bacteria; the decay and soft rot fungi; the attack by aquatic insect larvae (caddisfly); and the abrasive effects of the tidal water currents. These factors were interdependent, and in combination, amplified their individual degrading effects. The bacteria and fungi attacked several inches of the outer layer of the piles and weakened the wood in the area of attack making it attractive to the caddisfly larvae. The caddisfly larvae burrowed into the conditioned wood, creating new holes, which helped to further accelerate the attack of the bacteria and fungi into deeper portions of the timber piles. Flowing water carried the food supply needed by the caddisfly to support the growth of the larvae and the pupa. Also, the flowing water carried suspended sediment that abraded the degraded outer layers of the timber piles, causing the surface of the pile to wear. The Safety Board believes that the combined effects of bacteria, decay fungi, aquatic insect larvae, and tidal currents degraded and destroyed the exterior layers of the untreated timber piles, resulting in a reduction in the pile cross sections.

The average reduction in cross sectional area for the piles in pile bent 1 was about twice as much as the reduction in the piles in pile bent 2. This variance in pile degradation may have been the result of the difference in tidal current velocities between the pile bents. The maximum velocity measured at pile bent 1 was 2.0 fps, while at pile bent 2 the maximum velocity was only 1.5 fps. Therefore, it is likely that this increase in velocity at pile bent 1 generated greater abrasion of the pile surfaces. Additionally, the increased velocity at pile bent 1 may have attracted more of the caddisfly larvae, in turn accelerating the combined effects of the bacteria and fungi, the caddisfly larvae, and the tidal currents. The faster flowing water around pile bent 1 would have carried with it more suspended food particulate, making this pile bent a more fertile environment for the larvae.

The data collected by the Maryland Department of Environment indicated that the caddisfly larvae population near the S.R. 675 Bridge fluctuated over the years. This variation can probably be attributed to the shifting levels of pollutants introduced into the river from the Snow Hill sewage treatment plant and the Maryland Chicken Processors plant. The discharge from these facilities included high levels of organic material that became the larvae's

food supply. The greatest caddisfly population measured by the MDE coincided with increased discharges from these facilities. Following the rehabilitation of the sewage treatment plant and the closure of the Maryland Chicken Processors plant, the caddisfly population began to drop. In 1977, during peak discharge periods from these facilities, the caddisfly larvae population was so great that it may have occupied 30 to 100 percent of the bridge substructure pile surfaces. This level of infestation would have facilitated an acceleration of the bacterial and fungal degradation of the timber, and a corresponding increase in the abrasion of the piles by the tidal currents.

Discovery of caddisfly larvae during the examination of the treated fender and dolphin pile samples suggests that the larvae may be impervious to creosote treated wood. However, FPL has indicated that creosote wood treatments will retard bacteria and fungal degradation. Therefore, if the piles that supported the S.R. 675 bridge had been chemically treated, it is unlikely that they would have experienced the same levels of bacterial and fungal degradation as observed on the untreated piles. Consequently, without the bacterial and fungal degradation of the timber, the level of caddisfly infestation and the abrasive effects of the tidal currents on the piles also would have been substantially reduced. Also, several generations of the caddisfly larvae would have had the opportunity to inhabit the pits created by their ancestors, reducing the need to create new pits. This would diminish the effect that the caddisfly larvae had on the piles.

The Safety Board believes that the effects of any one condition alone probably would not have caused the degree of reduction in pile cross section evidenced by the bridge wreckage. Further, it is unlikely that the caddisfly larvae in combination with the tidal currents would have substantially reduced the pile diameters without the presence of the bacteria and decay fungi. However, the bacteria and decay fungi in combination with the tidal currents may have degraded the exterior layers of the timber piles without the contributing effects of the caddisfly larvae, although this degradation would have occurred at a considerably slower rate.

Prior to this accident the MDE had not recognized the importance of the data it had collected concerning the caddisfly population in the Pocomoke River, and accordingly did not provide it to the SHA. The Safety Board believes that similar water quality data (concerning the presence of caddisfly larvae or other contaminants), collected by state environmental agencies throughout the country, can assist State highway engineers in identifying bridges that may be susceptible to underwater degradation.

Collapse Sequence of the Bridge

Based on the physical evidence, witness statements, and the computer analysis, the Safety Board concludes that the following sequence of physical events occurred, resulting in the collapse of the S.R. 675 bridge spans: Bacteria and decay fungi began to attack the untreated timber piles and condition the wood after the bridge was constructed. Following the bacterial and fungal infestation, caddisfly larvae inhabited the piles and formed pits in the pile surfaces. The constant effects of the decay fungi, bacteria,

caddisfly larvae, and tidal currents, which contained suspended sediments, worked together to reduce the cross sectional area of the piles at pile bent 1 so that by August 1988, the cross sectional area of the piles had been reduced by an average of 35 percent. Prior to the construction of the U.S. 13 bridge in 1959, the S.R. 675 bridge was regularly subjected to heavy truck traffic. Local heavy vehicles continued to cross the bridge until April 1988, when the bridge was load posted. As a result of this traffic loading and a lack of expansion elements in the bridge, the girders in spans 1 and 3 cracked prior to 1978, increasing the loads on pile bent 1. At some point during the past several years, a truck weighing about 65,000 pounds crossed the bridge, or two large trucks with a combined weight of about 65,000 pounds passed each other at the same time while crossing the bridge, and caused an overload at pile bent 1. This condition caused at least one pile to buckle. Additional traffic loads continued to cause the other piles in pile bent 1 to buckle, and on the morning of August 15, 1988, one of the girders in span 1 cracked near pile bent 1. (Girder cracks were indicated in the UMD computer modeling) As traffic continued to cross the bridge, additional cracks appeared in the span 1 girders, the steel reinforcing bars within those girders began to bend, and pile bent 1 began to settle, forming a dip in the bridge deck. This dip was corroborated by witnesses who reported a crack in the south side of the bridge. Finally, the continued traffic loading cracked the remaining uncracked girders at pile bent 1. As a result, spans 2 and 3 acted as cantilever elements and placed additional loads on pile bent 2. Consequently, the piles in pile bent 2 began to buckle, and eventually the west side spans collapsed.

In addition to the cracks that formed in the west side girders during the collapse, the steel reinforcing bars in the girders began to bend, break, and pull out of the concrete. During this collapse sequence, the redundancy of the bridge was negated and the bridge loads were no longer transferred through the superstructure to the proper substructure members. The buckling of the piles in pile bent 1 may have occurred over a long period of time, with the actual collapse of the bridge occurring over several days. This event illustrates the advantages of a redundant structure which enables loads to be transferred from one structural member to another. Further, this accident highlights how multiple failures occurring over time may be necessary in a redundant structure before a catastrophic collapse can occur, compared with the sudden catastrophic failure that frequently occurs when just one member of a simply supported, non-redundant bridge fails, as happened in the Mianus, Chickasawbogue, and the New York Thruway bridge collapses.[57]

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[57] For more information: see Highway Accident Report--"Collapse of a Suspended Span of Interstate Route 95 Highway Bridge Over the Mianus River, Greenwich, Connecticut, June 28, 1983" (NTSB/HAR-84/03); Highway Accident Report--"Collapse of the U.S. 43 Chickasawbogue Bridge Spans Near Mobile, Alabama, April 24, 1985" (NTSB/HAR-86/01); Highway Accident Report--"Collapse of New York Thruway(I-90) Bridge Over the Schoharie Creek, Near Amsterdam, New York, April 5, 1987" (NTSB/HAR-88/02).

Bridge Design and Construction

The changes to the original bridge design made during construction helped make the structure more redundant, but at the same time they altered loads and stresses on the substructure members. Span 3, which was designed to be a one-foot thick slab fixed to the bascule pile bent and supported by rollers on pile bent 2, was instead constructed with a thin deck supported by girders and was fixed to both the bascule pile bent and pile bent 2. This departure from the design plans allowed the loads normally carried by the west side spans to be partially distributed to the much larger bascule pile bent. However, the girder and thin slab combination increased the weight of the span by about 28,000 pounds. Although the west side spans were constructed as a continuous redundant structure, examination of the bridge wreckage revealed that span 3 had little reinforcing steel in the top of the girders to resist tensile forces. This limited rebar probably allowed the girders to crack near the center of the span. Further, during construction, expansion elements in the west side spans (the rollers), were eliminated from the design. Therefore, thermal expansion of the west side spans was absorbed in span 1 near the west abutment, and as a result, span 1 cracked at this location.

During construction the improper batter of the piles in pile bents 1 and 2 helped to reduce the ability of the pile bents to resist lateral and rotational (eccentric) loads. Even though the changes made to the bridge design during construction altered the load-bearing characteristics of the superstructure and substructure, they did not contribute to the collapse of the bridge. With little maintenance, this bridge stood for 67 years, regularly carrying heavy vehicles that exceeded the 18-ton design load. The bridge was able to withstand some of the large increases in loads, because of the redundancy in the superstructure. As a result of the redundant design, the actual collapse extended over several days and provided warnings of the degraded condition of the bridge. In view of this, the Safety Board concludes that alterations made to the bridge design during its construction did not adversely affect this structure.

When the piles were driven, there was no requirement that they be treated with a preservative. In fact, the current AASHTO Standard Specifications for Highway Bridges, Section 4.3.2, allows untreated timber piles to be used in permanent construction for foundation piling when the cutoff is below permanent ground water level, as long as they are not exposed to marine borers. This specification would allow the use of untreated timber piles if the Pocomoke River Bridge was constructed today. However, as shown in this investigation, untreated timber piles exposed to water can be attacked and degraded by bacteria and decay fungi. The Safety Board recognizes that most new bridges designed with timber piles are constructed with piles that have been chemically treated. However, the Safety Board believes that the use of untreated timber piles in bridge construction should be prohibited when those piles are submerged in water.

Adequacy of the Maryland Bridge Inspection Program

Scope of Inspections. The various superstructure and underwater inspections of the S.R. 675 bridge were conducted within the FHWA-required intervals. Also, the inspectors and engineers that performed these inspections met the minimum qualifications established by FHWA. The Safety Board believes that the superstructure inspections were thorough and that they identified the majority of bridge defects located above water.

During the three underwater bridge inspections, the inspection crews were not given any guidance from SHA concerning the measurement of piles. Additionally, the crews were not provided with the available bridge plans or copies of previous inspection reports. As a result, only a few random measurements were taken of the pile diameters. The locations and elevations of these measurements were not consistent from inspection to inspection; therefore, no comparison of the data was made by the inspectors to determine changes in individual piles. Also, the inspectors were unaware of the actual diameters of the piles as installed, and thus could not readily determine the extent of any reduction that may have taken place. Further, only one increment bore sample was extracted from a pile during the 1986 inspection, and this sample was not turned over to the SHA until after the bridge had collapsed. None of the inspections had discovered the bacterial or fungal decay of the piles, or the presence of the aquatic insect larvae. However, the 1981 inspection report indicated that bark covered the submerged piles. Due to the diver's inability to see the piles, and the use of gloves during the inspection, it is likely that the pitted surface of the piles was mistakenly identified as bark. Even though the information provided to and developed by the on-site inspectors was limited, both the 1981 and 1986 inspection reports recommended repair of the untreated timber piles.

The Safety Board concludes that although several deficiencies in the methods and execution of the underwater inspections resulted in the production of limited data concerning the untreated piles, the information provided in the inspection reports and report recommendations was sufficient to alert SHA engineers of the diminished pile diameters.

Deficiencies in the Use of Inspection Data. During the review of underwater inspection reports by the SHA Bureau of Bridge Inspection and Remedial Engineering, engineers did not routinely refer to design plans or compare information from various bridge inspection reports. As a result, the remedial engineers that reviewed the data from the S.R. 675 Bridge underwater inspection reports never identified the cross section loss of the submerged piles. Had the engineers reviewed the bridge design plans, they would have discovered that the pile diameters were not provided on the plans. Further, had they compared the three underwater inspection reports, the engineers could have discovered that some of the pile diameters measured during the inspections were well below diameters required by both AASHTO and AASHO specifications. Therefore, the Safety Board concludes that during the review of underwater inspection reports for the S.R. 675 bridge, SHA engineers did not make effective use of available data to properly evaluate the substructure of the bridge.

Both the 1981 and 1986 underwater inspection reports included recommendations to the Bureau of Bridge Inspection and Remedial Engineering to repair the piles. The 1981 report indicated that in view of the size of the piles in pile bent 1, 2, 5, and 6, design calculations should be reviewed, taking into consideration the present traffic loading. During Safety Board depositions, SHA engineers indicated they were not aware of any calculations having been performed as a result of the recommendations. Additionally, there was no indication that the SHA had repaired or reinspected the piles. The Safety Board believes that if the SHA had adequately responded to the recommendations made in the underwater inspection reports, they would have detected the seriousness of the degraded condition of the piles. Consequently, the SHA could then have taken corrective measures to improve the condition of the piles, perform load calculations based on the actual pile diameters, or close the bridge. Therefore, the Safety Board concludes that SHA's failure to act on the underwater inspection report recommendations resulted in the uninterrupted and unaltered use of the bridge by vehicular traffic while the bridge substructure continued to degrade.

In 1986, when the increment bore sample was extracted from the timber pile, there were no established procedures from FHWA, AASHTO, or the SHA to examine and test the samples. Thus, if the inspector had submitted the core sample to SHA officials, a comprehensive examination might not have been conducted. Further, ice pick tests of the piles conducted during the 1986 underwater inspection did not reveal the degraded condition of the timber due to bacteria and decay fungi. The Safety Board believes that testing and microscopic examination of increment bore samples and cultures from submerged timber piles is essential to properly evaluate the condition of bridge substructures. Consequently, uniform guidelines for testing, and criteria for retrieving increment bore samples during underwater inspections of timber pile bridges should be developed.

Adequacy of Load Rating Inspections. In response to FHWA reviews encouraging the SHA to check its bridges to determine the safe load, the inventory and operating rating for the S.R. 675 bridge was calculated in March 1987 by SHA consultants, and again in May 1987 by SHA engineers. As a result, the SHA concluded that the bascule span was the weakest member of the bridge, and it subsequently recommended that the bridge be posted with a 25-ton weight restriction and a 25 mph speed limit. The bridge was finally posted in March 1988, 12 months after the first calculations had been completed.

In both sets of calculations, the bridge substructure elements were not considered, even though recommendations had been made to the SHA during the 1981 underwater inspection to determine the load capacity of the pile bents. The operating rating of the bridge was determined assuming that only one maximum-legal-load truck was on the structure at a given time. Thus, no calculations were made to determine the bridge operating capacity based on the substructure elements, to account for two fully loaded trucks on the superstructure, or to account for the actual physical condition of the substructure, nor were they required.

The Safety Board believes that because SHA did not account for these conditions in its load rating calculations, the bridge was posted with an unrealistically high weight restriction. The posted load limits would have allowed two 50,000-pound vehicles to pass each other on the bridge at the same time, thus exceeding the buckling capacity of pile bent 1. Further, the SHA failed to post the bridge for 12 months after the initial set of calculations was completed. This permitted heavy vehicles in excess of 50,000 pounds to cross the bridge for a year more than was necessary. A legally loaded truck weighing about 65,000 pounds could have caused one of the degraded piles in pile bent 1 to fail during this period of time. Thus, the Safety Board believes that the SHA should include substructure members in the load rating calculations, and it should make allowances for the current condition of all bridge elements. Further, as illustrated by this collapse, the bridge substructure can become the weakest member of the bridge, and therefore should be considered in load rating procedures. The Safety Board believes that SHA should review the load rating calculations previously made for other bridges within the State to make certain that substructure members were inspected and their carrying capacities were considered during the calculation process.

The Safety Board previously addressed the issues of load rating and underwater bridge inspection in its 1986 final report on the Collapse of the U.S. 43 Chickasawbogue bridge spans.[58] As a result of that investigation, the Safety Board issued recommendation H-86-5 to the Federal Highway Administration:

> Require State highway officials to determine the safe load capacity for all bridges. Ensure that the underwater elements of all bridges over water have been recently examined before the safe load capacity is determined. (H-86-5)

The recommendation is currently classified as open-acceptable action. It calls for the inspection of underwater bridge elements prior to load rating calculations; however, it does not require that information developed during these inspections be used in the calculations. The SHA had determined the load capacity for the S.R. 675 Bridge, and had performed an underwater inspection of the structure about two years prior to the collapse. However, the SHA did not use the information collected during this inspection to determine the safe load rating for this bridge.

The AASHTO Manual for Maintenance Inspection of Bridges does recommend that the deteriorated conditions of bridge members be considered during load rating calculations. The AASHTO Manual also recommends that computations for stresses and allowable loads consider only one maximum loaded vehicle on the bridge, and in some conditions two maximum loaded vehicles on the bridge, but in the same lane. As a bridge experiences a live load, the load is transferred to the bridge substructure through the superstructure.

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[58] For more information, see Highway Accident Report--"Collapse of the U.S. 43 Chickasawbogue Bridge Spans Near Mobile, Alabama, April 24, 1985 (NTSB/HAR-86/01)

Therefore, when two adjacent lanes experience live loads simultaneously, those loads are transferred to the substructure, and the superstructure elements surrounding each load are not significantly affected by the load in the adjacent lane. However, the substructure supporting the bridge at that location is subjected to the combined weight of both loads. The Safety Board believes that substructure elements should be evaluated during load rating calculations. Consequently, these calculations should consider two maximum loaded vehicles in adjacent lanes to accurately represent loading conditions of the bridge substructure.

Maryland State Highway Administration Organization

Following the collapse of the S.R. 675 Bridge, the SHA implemented a variety of policy and procedural changes to improve the inspection and evaluation of bridges within Maryland.

The changes implemented by SHA following the bridge collapse have improved the quality and availability of bridge inspectors. The SHA has established two additional superstructure inspection crews and has recently trained most of the SHA inspectors through a two-week FHWA-sponsored bridge inspection course. When the bridge collapsed, the inspection crew responsible for the S.R. 675 bridge was also responsible for the inspection of more than 300 other bridges biannually, as well as the additional reinspection of about 10 bridges yearly. This work load permitted an average of about one day per bridge inspection.

Although the SHA provided most of its inspectors with an FHWA-sponsored bridge inspection course, the engineers in the BI&R were not similarly trained. Since these engineers are responsible for bridge inspections in response to inspection crew requests, in addition to the review and interpretation of inspection reports, the Safety Board believes that they should also be trained in comprehensive bridge inspection methods.

The SHA indicated that underwater bridge inspection contractors will now be hired based on an evaluation of their professional ability rather than simply through a low bid method, and these contractors will be permitted to perform the load rating analysis following the inspections. Further, for fiscal year 1989, the number of quality control inspections used to verify rating procedures and to assure uniformity, has more than doubled, and the quality control inspections will include a review of the underwater inspection reports.

Although the Safety Board recognizes the significance of these changes, it believes that additional changes would further improve the quality of the program. Through the Maryland computer bridge inventory, the SHA was able to determine that 169 structures within the state contained timber piles in their substructure. However, the SHA was unable to determine which bridges contained timber piles that were submerged in water. In order for the SHA to properly identify bridges that are potentially susceptible to pile degradation, the Safety Board believes that the SHA should enhance its bridge inventory to identify timber piles by type, preservative treatment, size, and placement (submerged in water).

The SHA has further indicated that all timber pile bridges within the State are scheduled to receive a supplemental inspection that would include measurements of the pile diameters, batter and direction of piles, maximum ice pick penetration, and length of piles exposed to water. The Safety Board believes that the SHA should include the collection of these data in its regularly scheduled underwater inspections.

The Chief of the Bureau of Bridge Inspection and Remedial Engineering not only supervises the inspection crews and remedial engineers, he is the person to be notified should inspection crews discover a defect within a bridge that requires immediate repair. Additionally, the Chief is required to review each defect sheet, review and supervise bridge rehabilitation designs, and monitor municipal government compliance with NBIS. Further, SHA has indicated that the Bureau Chief will now have control of the scope and schedule of maintenance and repair work performed on State bridges. In the 1988 review of the SHA bridge inspection program, FHWA indicated a need for an increase in staff to monitor bridge repairs. Also, the FHWA recommended that a new position be created within the SHA to monitor bridge inspection of county and city bridges. The Safety Board concurs with the FHWA recommendations and believes that the SHA should go further in implementing staff improvements. Now that the SHA is placing emphasis on underwater inspections, and the responsibility for maintenance and repair of State bridges has shifted to the Bureau of Bridge Inspection and Remedial Engineering, the increased work associated with the inspections and maintenance could overwhelm the existing staff. Due to the complex nature of the underwater inspections, and the demonstrated weakness of the SHA inspection report review process discussed earlier, the Safety Board believes that the SHA should provide the engineering staff of the Bureau of Bridge Inspection and Remedial Engineering with sufficient capability to monitor underwater inspections and to perform more in-depth reviews of underwater inspection data.

Federal Oversight of Maryland Bridge Inspection Program

Recommendations from the FHWA reviews of the Maryland bridge inspection program have resulted in a variety of improvements. By 1988, all State bridges had been inspected within the FHWA required two-year cycle, and although not all municipal bridges had been inspected, the number not in compliance with the regulation had been substantially reduced. Further, load rating calculations were completed on all bridges that required this evaluation, an underwater inspection program had been established, and the inspection of municipal bridges was being monitored. The FHWA also provided the SHA with information concerning previous Safety Board bridge collapse investigations and guidance on inspection methodologies to locate deficient bridge conditions similar to those highlighted in Safety Board reports.

However, during its reviews, the FHWA did not evaluate the adequacy of the SHA's review of inspection reports or maintenance and rehabilitation of bridges in response to inspection report recommendations. Because the SHA was not performing well in this respect, the FHWA's failure to have examined this area of the SHA's procedures precluded its ability to recommend corrections that may have caused the SHA to recognize the need for corrective

action. However, both AASHTO and, more recently, the FHWA have recognized the need to correct critical deficiencies highlighted through the inspection program. Currently the AASHTO Manual for Maintenance Inspection of Bridges states, "Records should provide a full history of the structure including all recommendations for strengthening and repair along with the actions which have been taken on these recommendations." On May 13, 1988, in a memo from the Associate Administrator for Engineering and Program Development to the Regional Administrators and the District Federal Program Administrators, FHWA called attention to the need for follow-up actions to critical recommendations by bridge inspection teams:

> One element that seems to be lacking is a procedure to assure that critically needed maintenance activities or strengthening improvements identified by the Bridge Inspection Teams are made in a timely manner. Because not following through on critical maintenance or strengthening recommendations can result in the collapse or premature closing of bridges, it is essential that each State have a system which assures that necessary work is accomplished. Equally important is the need for each FHWA division office to establish an on-going process to monitor the State's accomplishments relating to critically needed bridge maintenance and strengthening recommendations.[59]

As a result of this memo, the FHWA Division Office is now assessing the review of inspection reports by SHA, and repair measures instituted as a result of SHA's review. Further, the FHWA is currently stressing the importance of responses to inspection recommendations in a series of "Bridge Management Tri-Regional Workshops."

Adequacy of SHA Concrete Testing

During the investigation of this accident, the SHA extracted 4-inch concrete core samples from the bridge wreckage. These samples were subsequently tested and revealed a low modulus of elasticity for the concrete. The Safety Board conducted a review of the test data and determined that the size of the concrete aggregate, as much as 2.2 inches in diameter, influenced the test results. To clarify this condition, Safety Board investigators asked the SHA to extract larger core samples, but the SHA did not have the equipment to take 6-inch or 8-inch concrete cores. Through an independent contractor, the Safety Board later extracted 6-inch concrete core samples from the bridge wreckage and had them tested in accordance with ASTM standards for modulus of elasticity. The resulting moduli of elasticity were much higher than the results of the original tests performed by SHA, and they revealed that the concrete did in fact have an adequate modulus of elasticity, and it was not fatigued. In examining concrete from bridges, the modulus of elasticity tests are essential to determine load distributions and fatigue conditions of the concrete. The Safety Board believes that the

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[59] See Appendix E for further information.

SHA should obtain equipment capable of extracting larger concrete core samples for testing in accordance with ASTM standards.

Missed Opportunities for Detecting Problems with the Bridge

The bridge tenders employed by the SHA were at work on the bridge both days prior to the collapse, but they did not observe the depression in the west side spans. These tenders had made a cursory inspection of the bascule on both days, but, they did not inspect the remainder of the structure. The tenders were not trained or expected to look for deficiencies in the bridge, outside of the operation of the bascule.

The S.R. 675 Bridge showed signs of deterioration and displacement at least two days prior to the collapse. On two separate occasions witnesses reported the dip in the west side spans to the Pocomoke City Police Department; however, neither complaint was thoroughly explored, nor was the SHA advised of the witness observations. One complaint was overlooked by the police dispatcher, and although the Police Chief inspected the east side spans of the bridge in response to the second complaint, he erroneously concluded that a pavement defect at the east abutment was the cause of the complaint, and he never inspected the west side bridge spans. Consequently, motorists were allowed uninterrupted use of the bridge as it was slowly collapsing. Even if police personnel had inspected the entire bridge, it is uncertain that they would have recognized the depression in the bridge deck as a potential hazard.

However, if the Police Department had notified the SHA District Office of the complaints, the SHA indicated they would have sent bridge inspectors to inspect the bridge. It is likely that they would have recognized the seriousness of the bridge deck depression, and they would have subsequently closed the bridge. Although this would not have prevented the collapse, it would have eliminated the potential hazard to motorists. Inherently, police personnel are not trained to identify or determine the seriousness of bridge defects, nor does the Safety Board believe that they should be. However, municipal governments within the State of Maryland should be encouraged to have their personnel notify the SHA when any complaint is received concerning the condition of a bridge. In response, the SHA should have inspectors who are familiar with the bridge conduct an immediate review of the complaints. In this way an accurate assessment of the bridge condition can be made.

CONCLUSIONS

Findings

1. The passenger car that crossed the bridge just prior to the collapse did not contribute to the collapse.

2. The emergency response of the police units to the scene following the collapse was timely, orderly, and adequate for this accident.

3. The bridge collapse did not result from a pre-existing deficiency in, or an overstress of the superstructure components.

4. Scouring of the soil surrounding the bridge substructure did not occur prior to the collapse.

5. The untreated timber piles in pile bents 1 and 2 were more than 50, but probably no more than 65 feet in length.

6. The reduction in cross sectional area of the untreated timber piles, their improper batter, and their additional internal degradation from bacteria, fungi, and aquatic insect larvae infestation, caused the piles in pile bent 1 to buckle under heavy vehicle loading conditions. Immediately after the buckling failure of pile bent 1, the piles supporting pile bent 2 were subjected to extreme load transfers which caused them to buckle and fail.

7. Some pile embedment may have occurred in pile bent 1 during or prior to the collapse sequence.

8. The continual effects of fungi, bacteria, aquatic insect larvae infestation (caddisflies) and the tidal currents which carried suspended sediment, worked together to reduce the cross sectional area of the submerged untreated timber piles.

9. The timber piles in pile bent 1 experienced a greater reduction in cross sectional area than the timber piles in pile bent 2 because of a combination of increased tidal current velocities, and an increased population of aquatic insect larvae at pile bent 1.

10. Had the timber piles supporting the S.R. 675 bridge been chemically treated, the reduction in pile diameters would have been less.

11. The routine collection of water quality data by State environmental agencies throughout the country can assist State highway engineers in identifying bridges that are susceptible to deterioration of their underwater elements.

12. A truck weighing about 65,000 pounds that crossed the bridge, or two large trucks (whose combined weight was about 65,000 pounds) that passed each other on the bridge at the same time, initially may have caused at least one of the deteriorated piles in pile bent 1 to buckle.

13. The redundant design of the bridge prolonged its life.

14. The changes made to the original bridge design during construction helped make the structure more redundant, but at the same time they altered the loads and stresses on the substructure members.

15. The west side bridge abutment cracked as a result of thermal expansion within the bridge superstructure.

16. The above water superstructure inspections of the S.R. 675 Bridge were adequate, and they identified the majority of the

superstructure defects.

17. Sufficient recommendations were included in the underwater inspection reports to alert SHA engineers about the reduced pile cross sections.

18. During the review of underwater inspection reports concerning the S.R. 675 bridge, State Highway Administration engineers did not make effective use of previous data to properly evaluate the condition of the untreated timber piles.

19. The SHA allowed continued use of the bridge despite the underwater inspection report that indicated the bridge substructure was in a degraded condition, and needed immediate repair, and despite the low bridge sufficiency rating.

20. Microscopic examination of increment bore samples and cultures from submerged timber piles are essential to evaluate the condition of bridge substructures.

21. Because the SHA did not have a procedure for the examination of increment bore samples, it is unlikely that a comprehensive examination of the sample taken during the 1986 underwater inspection would have been conducted if the inspecting engineer had submitted the sample to SHA officials.

22. Because the SHA was not required and did not evaluate the condition of the bridge substructure elements in its load rating calculations, and because it determined the operating rating assuming only one truck traveling across the bridge at a time, the bridge was posted with an unrealistically high weight restriction.

23. Due to the reduction in pile diameters, the submerged piles were the weakest structural element in the bridge.

24. Following the collapse of the S.R. 675 Bridge, the SHA implemented a variety of policy and procedural changes that have improved the inspection and evaluation of bridges within Maryland.

25. The SHA was unable to determine which timber pile bridges contained submerged piles, because the SHA's computer bridge inventory did not contain this information.

26. The addition of two more inspection crews should assist SHA in performing superstructure inspections thoroughly.

27. The SHA did not initially make accurate assessments of the condition of the bridge concrete because they did not possess equipment to extract the 6-inch or large core sample needed for this concrete aggregate.

28. Local police did not thoroughly investigate citizen reports of a depression in the bride deck, and did not notify the SHA of the reports. This precluded an opportunity for the SHA to close or repair the bridge.

29. Municipal governments within the State of Maryland do not routinely notify the SHA when a complaint is received concerning the condition of a State-owned bridge.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the collapse of the S.R. 675 bridge spans was the inadequate response of the Maryland State Highway Administration to deficiencies noted in the underwater bridge inspection reports. This resulted in the failure to repair or replace submerged untreated timber piles, which had deteriorated from the combined effects of bacteria, fungi, and aquatic insect larvae infestation, and abrasion by tidal currents. Contributing to the collapse was the improper batter of the timber piles and the preexisting cracks in the superstructure girders.

RECOMMENDATIONS

As a result of its investigation, the National Transportation Safety Board recommends:

--to the Maryland State Highway Administration:

Modify bridge inspection procedures to provide inspectors with "as built" plans if available, during on-site inspections. (Class II, Priority Action)(H-89-56)

Modify bridge inspection report review procedures to require reviewers to compare all inspection reports, design plans, and "as built" plans, if available. (Class II, Priority Action)(H-89-57)

Review the load rating calculations for all bridges within the State and consider the load carrying capacities of substructure members during the calculation process. (Class II, Priority Action)(H-89-58)

Reevaluate the load rating for bridges for which the substructure was not considered in load rating calculations. (Class II, Priority Action)(H-89-59)

During regularly scheduled underwater bridge inspections, require bridge inspectors to record at a minimum: incremental measurements of pile diameter, pile batter and direction, maximum ice pick penetration, and length of exposed piles. (Class II, Priority Action)(H-89-60)

Train, on comprehensive bridge inspection methods, State Highway Administration engineers who review bridge inspection reports and rate the bridges within Maryland. (Class II, Priority Action)(H-89-61)

Provide the engineering staff in the SHA Bureau of Bridge Inspection and Remedial Engineering with sufficient capability to monitor the State underwater inspection program, the quality of reports and report reviews, the underwater inspection program for county and city bridges, and bridge maintenance, rehabilitation, and repairs. (Class II, Priority Action)(H-89-62)

Require when evaluating concrete bridges, that concrete core samples be six-inches or larger in diameter to improve the analysis of these structures. (Class II, Priority Action)(H-89-63)

Establish procedures for municipal governments to notify the SHA District Maintenance Office of any reported complaint concerning the condition of a bridge structure, and develop procedures to investigate all notifications thoroughly. (Class II, Priority Action)(H-89-64)

--to the Federal Highway Administration:

Modify the Bridge Inspectors Training Manual to include information on the identification and detection of aquatic insect larvae infestation in submerged timber piles, the techniques for analyzing increment bore samples for bacteria, fungi, or other contaminants, and the need for sufficient measurements to enable complete assessment of the condition of timber piles. (Class II, Priority Action)(H-89-65)

Issue, as an interim measure, a technical advisory that discusses bacteria, fungi, and aquatic larvae infestation of submerged timber piles and the potential for cross sectional area loss of submerged timber piles as a result of these infestations. (Class II, Priority Action)(H-89-66)

Require State highway officials to include the condition of underwater bridge elements in load capacity calculations. (Class II, Priority Action)(H-89-67)

Develop guidelines and establish criteria, in cooperation with the American Association of State Highway and Transportation Officials, for testing timber increment bore samples to determine the presence of bacteria and decay fungi, and require that increment bore samples are retrieved during underwater inspections of bridges with submerged timber piles. (Class II, Priority Action)(H-89-68)

--to the American Association of State Highway and Transportation Officials:

Modify the Standard Specifications for Highway Bridges, Section 4.3.2, entitled "Limitations on the Use of Untreated Timber Piles," to preclude the use of untreated timber piles that are submerged in water. (Class

II, Priority Action)(H-89-69)

Develop guidelines and establish criteria, in cooperation with the Federal Highway Administration, for testing timber increment bore samples to determine the presence of bacteria and decay fungi, and require that increment bore samples are retrieved during underwater inspections of bridges with submerged timber piles. (Class II, Priority Action)(H-89-70)

Modify Section 2.4.2, "bents", of the Manual for Maintenance Inspection of Bridges to include information on how to identify and detect aquatic insect larvae infestation in submerged timber piles. (Class II, Priority Action)(H-89-71)

Modify Section 4.5, "Rating of Bridges, Evaluations" to require the evaluation of substructural bridge members during load rating calculations. (Class II, Priority Action)(H-89-72)

Modify Section 5.2.2, "Live Loads," of the Manual to require that computations for stresses and allowable loads consider at least one maximum loaded vehicle in each bridge lane. (Class II, Priority Action)(H-89-73)

Advise State highway officials to obtain water quality data from State environmental agencies, especially concerning locations where concentrations of aquatic insect larvae have been found, and evaluate this data in conjunction with scheduled underwater bridge inspections. (Class II, Priority Action)(H-89-74)

--International Association of Chiefs of Police:

Advise your members of the circumstances of the S.R. 675 (Pocomoke City) bridge collapse, and urge them to notify state transportation officials when a complaint is received concerning a bridge. (Class II, Priority Action)(H-89-75)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ James L. Kolstad
Acting Chairman

/s/ Jim Burnett
Member

/s/ John K. Lauber
Member

/s/ Joseph T. Nall
Member

/s/ Lemoine V. Dickinson, Jr.
Member

November 7, 1989

APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

Investigation

The National Transportation Safety Board was notified of this accident on August 18, 1988 by the news media. Investigators were dispatched from the Washington, D.C. Headquarters and arrived on the scene August 20, 1988.

Participating in the investigation were representatives from the Maryland Department of Transportation State Highway Administration and the Federal Highway Administration. The Safety Board commissioned several studies and tests from the United States Geological Survey, the Department of Agriculture Forest Products Laboratory, the Smithsonian Institution, and Froeling and Robertson Inc. to determine the events and conditions surrounding the collapse. The Maryland State Highway Administration performed the wreckage recovery, concrete tests and rebar tests; and through a cooperative agreement with the University of Maryland, the SHA performed pile testing and a computer analysis.

Depositions

On November 9, 1988, Safety Board investigators obtained depositions from representatives of the Maryland State Highway Administration and from consultants employed by the SHA. Further, answers to Safety Board interrogatory questions were obtain from other SHA consultants.

APPENDIX B

1988 S.R. 675 BRIDGE INVENTORY FORM

BRIDGE INVENTORY - APPRAISAL LOGIC ITEM LISTING 10/27/88 PAGE 0 [illegible]2

STRUCTURE # 23 004 BRIDGE

ITEM 8 STRUCTURE # 23 004 TAPE FILE STRUCTURE # 23030

STRUCTURAL DATA

4	CITY/TOWN	POCOMOKE CITY
5	INVENTORY ROUTE	PRINCIPLE ROUTE STATE HIGHWAY MAINLINE 00675
6	FEATURE INTR.	POCOMOKE RIVER
7	FACILITY CARRIED	M00675A
9	LOCATION	ON SOMERSET CO LINE
10	VERTICAL CLEARENCE	UNLIMITED
11	INTRACOUNTY MILE POST	1.95
12	SECTION #	0
18	VULNERABILITY CODE 1-9	4
19	DETOUR LENGTH MILES	1
20	TOLL CODE	ON FREE ROAD
21	CUSTODIAN	STATE HIGH.DPT.
22	OWNER	STATE HIGH.DPT.
24	FEDERAL AID SYSTEM	FA SECONDARY RURAL,STATE JURISDICTION
25	ADMINISTRATIVE JURIS.	STATE
26	FUNCTIONAL CLASS	RURAL MAJOR
201	CONTRACT #	S-011-000-000 WO-531-721-114
202	CONTRACT #	WO -102-000-000
27	YEAR BUILT -	1920 YEAR RECONSTRUCTED - 1981
203	SHA SPEC.YEAR	UNKNOWN
204	AASHTO SPEC.YEAR	UNKNOWN
28	LANES ON STRUCTURE	2 UNDER 0
29	ADT	3600
30	YEAR ADT	1977
31	DESIGN LOAD	OTHER
32	APPROACH ROADWAY WIDTH	3'SH. 24'RDWY. 3'SH.
33	BRIDGE MEDIAN	NONE
34	SKEW DEG.	0
35	STRUCTURE FLARED	NO
36	TRAFFIC SAFETY FEATURES	
	BRIDGE RAILING	MEETS ACCEPTABLE STANDARDS
	TRANSITIONS	DOES NOT MEET ACCEPTABLE STANDARDS
	APPROACH GUARDRAIL	DOES NOT MEET ACCEPTABLE STANDARDS
	APPROACH GUARDRAIL TERM	DOES NOT MEET ACCEPTABLE STANDARDS
38	NAVIGATION CONTROL	YES
39	NAVIGATION V.CLEARANCE	5
40	NAVIGATION H.CLEARANCE	65'
41	OPERATIONAL STATUS	C
42	TYPE SERVICE	HIGHWAY OVER WATERWAY
43	STRUCTURE TYPE MAIN	STEEL MOVABLE - BASCULE
44	STRUCTURE TYPE APPROACH	CONCRETE BOX BEAM OR GIRDERS - MULTIPLE
45	# OF SPANS- MAIN	1
46	# OF APPROACH SPANS	6
47	HORIZONTAL CLR. LT.RT.	24.0'
48	LENGTH MAX. SPAN	65'
49	STRUCTURE LENGTH	276'
209	# OF CONTINUOUS SPANS	0
210	TOTAL # OF SPANS	7
211	SPAN L1	S 36 S

BRIDGE INVENTORY - APPRAISAL LOGIC ITEM LISTING 10/27/88 PAGE 0 [illegible]05

STRUCTURE # 23 004 BRIDGE

1986 UNDERWATER INSP

100	SUFFICIENCY RATING	18.72%
	JURISDICTION	AASHTO SECONDARY
	COUNTY	WORCESTER
	ROUTE #	M00675A
	DIRECTION	N
	MAINLINE	1
	OVER-UNDER	UNDER
37	HISTORICAL SIGNIFICANCE	5
	NAVIGABILITY	HISTORIC
	DEFENSE SYSTEM	2

STRUCTURE # 23 004 BRIDGE

212	SPAN L2	S 36 S
213	SPAN L3	S 13 S
214	SPAN L4	S 65 S
215	SPAN L5	S 13 S
216	SPAN L6	S 36 S
217	SPAN L7	S 36 S
219	SLOPE PROTECTION	NONE
220	CUTOFF WALL	NONE
221	STRUCTURAL STEEL MAT.	UNKNOWN
50	SIDEWALK WIDTH LT. RT.	0.0' 0.0'
51	ROADWAY CURB - CURB	24.0'
52	DECK WIDTH OUT-OUT	27.0'
222	I. TO I. PARAPET	26.5'
223	SHOULDER WIDTH FT.	0'00'' 0'00''
224	WT.POSTED - KIPS	0
226	CLEAR.OVER RDWY.POSTED	NO
227	UNDERCLEAR.POSTED	NO
53	MIN. VERTICAL CLR.	UNLIMITED
54	MIN.VERTICAL UNDERCLR.	LESS THAN 10'
55	LAT.UNDERCLR.RIGHT	NOT APPLICABLE
228	FOOTING ABUT.	CONCRETE TIMBER PILES ENTIRE STRUCTURE
229	SUBSTRUCTURE ABUT.	CONCRETE CANTILEVER PREDOMINANT FEATURE
230	FOOTING PIER	CONCRETE TIMBER PILES ENTIRE STRUCTURE
231	SUBSTRUCTURE PIER	CONCRETE SOLID SHAFT ENTIRE STRUCTURE
57	WEARING SURFACE	CONCRETE
232	SUPERSTR. DECK	NO BITUMINOUS OVERLAY CONCRETE SLAB
233	SUPERSTR. DESIGN	NON-COMPOSITE ENTIRE STRUCTURE
234	CURBS WIDTH	0'03'' 0'03''
235	PARAPET	CONC.BRK.OPEN
236	RAILING NONE NONE	STEEL PICKET
237	FENCING	NONE
238	# STRINGERS ORIG.	4
240	STRINGER SPACING ORIG.	6'6'' TO 7'0''
242	BEARING TYPE	NONE
243	JOINT TYPE	NONE
244	SIGN ON STRUCTURE	NO
245	STRUCT.[illegible]LIGHTING	YES
246	PROVISION FOR LIGHTING	NO
250	STRUCTURE IN TIDAL AREA	NO
260	UTILITIES ON STRUCTURE	ELECT.
261	UTILITIES UNDER STRUCT.	NONE
262	NAME OF STRUCTURE	POCOMOKE RIVER BR.
	REMARKS CARD 7	STEEL GRID SURF. ON MAIN SPAN; DIVER FOR U.W.I.
	REMARKS CARD 8	REPAIRS TO BASCULE SPAN 1981
263	SHA SPEC. RECONST.I	1968
265	AASHTO SPEC. RECON. I	1978

INSPECTION RESULTS - CONDITION CODES

9 - NEW CONDITION
8 - GOOD CONDITION - NO REPAIRS NEEDED
7 - GENERALLY GOOD CONDITION POTENTIAL EXISTS FOR MINOR MAINTENANCE

STRUCTURE # 23 004 BRIDGE

6 - FAIR CONDITION - POTENTIAL EXISTS FOR MAJOR MAINTENANCE
5 - GENERALLY FAIR CONDITION - POTENTIAL EXISTS FOR MINOR REHABILITATION
4 - MARGINAL CONDITION - POTENTIAL EXISTS FOR MAJOR REHABILITATION
3 - POOR CONDITION - REPAIR OR REHABILITATION REQUIRED IMMEDIATELY
2 - CRITICAL CONDITION - URGENT NEED FOR REPAIR OR REHABILITATION SHOULD BE CLOSED UNTIL REPAIRED
1 - CRITICAL CONDITION - FACILITY IS CLOSED. SHOULD DETERMINE FEASIBILITY OF REPAIR
0 - CRITICAL CONDITION - FACILITY IS CLOSED AND BEYOND REPAIR

ITEM 90 DATE	301 DECK	302 SURFAC PARAPET	303 HNDRL CURBS	304 SDWLK JOINTS	305 RDWY MCHN.	306 RVBL.SPN DECK	58	311 BRGS	312 MN.SUP MEMBERS	313 PAINT DRAIN	314	59 SUPSTR	321 UNDMN SCOUR	322 ABUT	323 PIER	324 PILE	60 SUBSTR	61 SLOPE PROTECT	62 CULVERT ETC.
04/14/88	6	7	7	6	8	N	6	6	5	5	8	5	8	6	6	N	6	8	8
05/01/86	6	7	7	6	8	7	6	6	5	5	8	5		6	6	N		8	8
05/09/84	6	6	7	6	8	6	6	7	6	7	7	6	8	5	7	6	5	8	8
10/05/82	7	8	8	8	8	8	7	N	6	5	7	5	8	6	8	8	6	8	8
09/17/80	7	7	8	8	8	5	6	N	6	5	8	6	8	6	8	N	7	8	8
08/28/78	6	N	7	8	N	N	6	N	6	6	8	6	7	7	7	8	7	8	8
01/01/76	7		7	8			7		6	7	8	8	8	7			7	8	8
02/01/74	7		7	8			7		7		8	7		8	8		8	8	8
04/01/72	7		7	8			7		7		8	7		8	8		8	8	8

325	FRACTURE CRITICAL INSP.	3
63	EST.REMAINING LIFE YRS.	1
64	OPERATING RATING TONS	GROSS LOAD 00 TONS
65	APPROACH ROADWAY ALIGN	7
66	INVENTORY RATING	GROSS LOAD 00 TONS
340	INSPECTION NEEDS	EASTERN 12 BOAT DIVER FR.CRIT.
371	FRACTURE CRITICAL	YES
		DATE ITEM 325 FRACTURE CRITICAL INSPECTION
		04/14/88 3

APPRAISAL

67	STRUCTURAL CONDITION	2 HIGH PRIORITY OF REPLACEMENT
68	DECK GEOMETRY	8 EQUALS DESIRABLE CRITERIA
69	UNDERCLEAR. VERT. - LATR	5 BETTER MINIMUM ADEQUACY
70	SAFE LOAD CAPACITY	1 IMMEDIATE REPAIR NEEDED
71	WATERWAY ADEQUANCY	7 BETTER MINIMUM CRITERIA
72	APPR. RDWY.ALIGN.	7 BETTER MINIMUM CRITERIA

PROPOSED IMPROVEMENT

73	YEAR NEEDED	UNKNOW

MAINTENANCE

ITEM 351 YEAR	ITEM 361 COST	ITEM 352 TYPE

APPENDIX C

1986 SHA UNDERWATER INSPECTION CONTRACT (SPECIAL PROVISION-UNDERWATER INSPECTION)

SPECIAL PROVISIONS
UNDERWATER INSPECTION OF
EXISTING BRIDGES -10

CONTRACT NO. AW 086-292-146

UNDERWATER INSPECTION

Included:

This work shall include the complete inspection of the stream or river bottom, underwater portions of the substructure and foundation elements as well as dolphins and fender systems between the high water line and the mud line.

All findings will be reported directly to the Maryland State Highway Administration for review and acceptance with accurate scale drawings of the findings at each structure.

Equipment and Personnel:

The Contractor shall supply at his own expense, all equipment, labor, licenses, permits, and insurance required for the successful completion of this project.

The Professional Engineers(s) who will oversee and coordinate the underwater inspection shall be registered in the State of Maryland and possess a minimum of five (5) years acceptable experience in this type of work. A detailed resume, including education, experience, and background of each Registered Professional Engineer, with whom the Contractor intends to conduct the work, shall be submitted by the Contractor within fourteen (14) days following notification of low bid.

The diver(s) who will actually perform the underwater inspection shall be experienced in this type work. A detailed resume, including education, experience, and background of each diver, with whom the Contractor intends to conduct the work, shall be submitted by the Contractor within fourteen (14) days following notification of low bid. The diver shall meet the following requirements:

1. He must possess and produce upon request valid credentials showing successful completion of a regular training course given nationally recognized diving authority.

2. He must be a graduate Engineer (Civil-Structural) from an accredited university and possess at least five (5) years experience in underwater inspections with at least 500 hours of experience in underwater inspection of structures; five (5) years additional experience may be substituted for the required Engineering degree to total ten (10) years of experience in underwater inspections.

3. The diver shall be capable of recognizing signs of distress in structural members and anticipating potentially hazardous conditions.

The diver shall be completely familiar with the existing substructure on each bridge prior to performing the underwater inspection.

Failure by the Contractor to submit the required resumes shall be grounds for rejection of the bid. The Contractor submitting the lowest acceptable bid will be required to verify all resumes to the satisfaction of the Administration. Acceptance of the bid will depend upon the Administration's acceptance of the experience and background qualification's of each Professioal Engineer and the acceptance of the qualification of each diver, as well as the bid amount. The inability to meet the above requirements or to provide satisfactory verification of the submitted resumes shall also be grounds for rejection of the bid.

At least one (1) Professional Engineer and one (1) diver designated in the resumes and accepted by the Administration, shall be present at the site during all phases of the inspection, and report preparation.

The use of substitue divers and/or Professional Engineers which were not designated with submission of the bid will not be permitted without written authorization by the State Highway Administration.

Inspection Methods:

The inspection of all substructure and foundation elements shall include, but not be limited to the following:

1. Concrete Piles: Check all concrete piles for erosion, wear, abrasion, scaling, or spalling of concrete, exposure of and deterioration of any exposed reinforcing steel, and all cracking while paying particular attention for hollow piles.

2. Steel Piles: Check all steel piles for corrosion misalignment or loss of section.

3. Timber Piles: Check all timber piles for vermin such as marine borer, shipworm attack, termites, and powder-post beetles, etc.; for evidence of fungus decay; for damage by collision and/or overstressing; and for excessive weathering. All timber piling shall be sounded and, probed with a heavy duty 6" (min.) blade icepick.

The worst pile in each bent shall be selected for drilling. If a bent has more than eight (8) piles, the two worst piles shall be drilled. The hole shall be drilled perpendicular to the pile surface with a 5/16" drill bit at a depth equal to approximately one-quarter of the pile diameter. Additional holes may be necessary to determine the limits of deterioration along the length of the pile. All drilled holes with evidence of deterioration shall be probed with a heavy duty icepick with a blade of sufficient length to determine the depth of penetration. Piling with evidence of fungus decay or damage from vermin shall be further tested by use of an Increment Borer to determine depth of penetration and size of area of decay or damage. A sharp Increment Borer which extracts a core 0.2 in. (nominal) in diameter shall be used, taking care that the Increment Borer is perpendicular to the pile surface, and checks and knots are avoided. Cores extracted by an Increment Borer shall then be labeled, identified and sent to the State Highway Administration Headquarters, Bureau of Bridge Inspection and Remedial Engineering, 707 N. Calvert St. Baltimore, Maryland 21202 Test for further evaluation. All drilled and Increment holes shall be immediately plugged with treated, tightfitting wooden plugs. The wooden plugs shall be treated with a wood preservative approved by the Engineer. Care shall be used in selecting the proper diameter plugs, and in driving to avoid breaking the plug or splitting the pile.

4. Dolphins and Fenders: Examine for same deterioration as substructure piles.

5. Pier and Abutement: Check for any deterioration of concrete cracks, spalls, and for any indication of movement.

6. Scour: The river bottom beneath the bridge and around the piers, piles, and/or abutments should be checked for developement of scour holes and unintended exposure of any portion of the substructures. Additionally, if the river bottom contour is found to deviate from the contract plans in the vicinity of the subject structures, the Contractor shall accurately determine and report the extent of such deviations.

7. Underwater Cables: Check for damage to the cable, from vessels or floating objects, kinks in the cable, exposure of cable when it should be buried, and determining and plotting the exisiting location of the cable.

SPECIAL PROVISIONS
UNDERWATER INSPECTION OF
EXISTING BRIDGES -13

CONTRACT NO. AW 086-292-146

Particular attention shall be directed to the dimensions of all substructure units and their conformance to the plans provided. Any divergence from these plans shall be accurately reported.

The Contractor shall submit a proposed schedule of inspections to the District Engineer and to the Bureau of Bridge Inspection and Remedial Engineering at least five (5) days in advance of the proposed performance date, so a representative of the State Highway Administration may accompany the Contractor during his inspection operations. The Contractor shall also inform the District Engineer and the Bureau of Bridge Inspection and Remedial Engineering of any changes to the proposed schedule.

The Contractor shall be responsible for, and make good any damage caused to any pedestrian, vehicle or craft, or any person in said vehicle or craft, in which damage or injury is attributable to acts of the Contractor.

If, in the opinion of the Professional Engineer, a dangerous or critical situation exists, he shall immediately notify Mr. Geoffrey V. Kolberg, Chief, Bureau of Bridge Inspection and Remedial Engineering (Phone Number: 301-659-1175), and follow up with an accurate interim written report.

Method of Measurement and Basis Of Payment:

Underwater inspection of the bridges will not be measured for payment, but cost thereof shall be included in the contract lump sum prices bid on the pertinent Underwater Inspection items.

APPENDIX D

NATIONAL BRIDGE INSPECTION STANDARDS

CODE OF FEDERAL REGULATIONS

23 HIGHWAYS - PART 650

Subpart C - National Bridge Inspection Standards

§650.301 Application of standards.

The National Bridge Inspection Standards in this part apply to all structures defined as bridges located on all public roads. In accordance with the AASHTO (American Association of State Highway and Transportation Officials) Transportation Glossary, a "bridge" is defined as a structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening.

§650.303 Inspection procedures.

(a) Each highway department shall include a bridge inspection organization capable of performing inspections, preparing reports, and determining ratings in accordance with the provisions of the AASHTO Manual[1] and the Standards contained herein.

(b) Bridge inspectors shall meet the minimum qualifications stated in §650.307.

(c) Each structure required to be inspected under the Standards shall be rated as to its safe load carrying capacity in accordance with Section 4 of the AASHTO Manual. If it is determined under this rating procedure that the maximum legal load under State law exceeds the load permitted under the Operating Rating, the bridge must be posted in conformity with the AASHTO Manual or in accordance with State law.

(d) Inspection records and bridge inventories shall be prepared and maintained in accordance with the Standards.

(e) The individual in charge of the organizational unit that has been delegated the responsibilities for bridge inspection, reporting and inventory shall determine and designate on the individual inspection and inventory records and maintain a master list of the following:

(1) Those bridges which contain fracture critical members, the location and description of such members on the bridge and the inspection frequency and procedures for inspection of such members. (Fracture critical members are tension members of a bridge whose failure will probably cause a portion of or the entire bridge to collapse.)

(2) Those bridges with underwater members which cannot be visually evaluated during periods of low flow or examined by feel for condition, integrity and safe load capacity due to excessive water depth or turbidity. These members shall be described, the inspection frequency stated, not to exceed five years, and the inspection procedure specified.

(3) Those bridges which contain unique or special features requiring additional attention during inspection to ensure the safety of such bridges and the inspection frequency and procedure for inspection of each such feature.

(4) The date of last inspection of the features designated in paragraphs (e)(1) through (e)(3) of this section and a description of the findings and follow-up actions, if necessary, resulting from the most recent inspection of fracture critical details, underwater members or special features of each so designated bridge.

§650.305 Frequency of inspections.

(a) Each bridge is to be inspected at regular intervals not to exceed 2 years in accordance with Section 2.3 of the AASHTO Manual.

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[1] *The "AASHTO Manual" referred to in this part is the "Manual for Maintenance Inspection of Bridges 1983" together with subsequent interim changes or the most recent version of the AASHTO manual published by the American Association of State Highway and Transportation Officials. A copy of the Manual may be examined during normal business hours at the office of each Division Administrator of the Federal Highway Administration, at the office of each Regional Federal Highway Administrator, and at the Washington Headquarters of the Federal Highway Administration. The addresses of those document inspection facilities are set forth in Appendix D to Part 7 of the regulations of the Office of the Secretary (40 CFR Part 7). In addition, a copy of the Manual may be secured upon payment in advance by writing to the American Association of State Highway and Transportation Officials, 444 N. Capitol Street, N.W., Suite 225, Washington, D.C. 20001.*

(b) Certain types or groups of bridges will require inspection at less than 2-year intervals. The depth and frequency to which bridges are to be inspected will depend on such factors as age, traffic characteristics, state of maintenance, and known deficiencies. The evaluation of these factors will be the responsibility of the individual in charge of the inspection program.

(c) The maximum inspection interval may be increased for certain types or groups of bridges where past inspection reports and favorable experience and analysis justifies the increased interval of inspection. If a State proposes to inspect some bridges at greater than the specified 2-year interval, the State shall submit a detailed proposal and supporting data to the Federal Highway Administrator for approval.

§650.307 Qualifications of personnel.

(a) The individual in charge of the organizational unit that has been delegated the responsibilities for bridge inspection, reporting, and inventory shall possess the following minimum qualifications:

(1) Be a registered professional engineer; or

(2) Be qualified for registration as a professional engineer under the laws of the State; or

(3) Have a minimum of 10 years experience in bridge inspection assignments in a responsible capacity and have completed a comprehensive training course based on the, "Bridge Inspector's Training Manual"[2], which has been developed by a joint Federal-State task force, and subsequent additions to the manual.[3]

(b) An individual in charge of a bridge inspection team shall possess the following minimum qualifications:

(1) Have the qualifications specified in paragraph (a) of this section; or

(2) Have a minimum of 5 years experience in bridge inspection assignments in a responsible capacity and have completed a comprehensive training course based on the "Bridge Inspector's Training Manual", which has been developed by a joint Federal-State task force.

(3) Current certification as a Level III or IV Bridge Safety Inspector under the National Society of Professional Engineer's program for National Certification in Engineering Technologies (NICET)[4] is an alternative acceptable means for establishing that a bridge inspection team leader is qualified.

§650.309 Inspection report.

The findings and results of bridge inspections shall be recorded on standard forms. The data required to complete the forms and the functions which must be performed to compile the data are contained in Section 3 of the AASHTO Manual.

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[2]The "Bridge Inspector's Training Manual" may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

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[3]The following publications are supplements to the "Bridge Inspector's Training Manual": "Bridge Inspector's Manual for Movable Bridges," 1977, GPO Stock No. 050-002-00103-5; "Culvert Inspector's Training Manual," July 1986, GPO Stock No. 050-001-0030-7; and "Inspection of Fracture Critical Bridge Members," 1986, GPO Stock No. 050-001-00302-3.

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§650.311 Inventory.

(a) Each State shall prepare and maintain an inventory of all bridge structures subject to the Standards. Under these Standards, certain structure inventory and appraisal data must be collected and retained within the various departments of the State organization for collection by the Federal Highway Administration as needed. A tabulation of this data is contained in the structure inventory and appraisal sheet distributed by the Federal Highway Administration as part of the Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges (Coding Guide) in January of 1979. Reporting procedures have been developed by the Federal Highway Administration.

(b) Newly completed structures, modification of existing structures which would alter previously recorded data on the inventory forms or placement of load restriction signs on the approaches to or at the structure itself shall be entered in the State's inspection reports and the computer inventory file as promptly as practical, but no later than 90 days after the change in the status of the structure for bridges directly under the State's jurisdiction and no later than 180 days after the change in status of the structure for all other bridges on public roads within the State.

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[4]For information on NICET program certification contact: National Institute for Certification in Engineering Technologies, 1420 King Street, Alexandria, Virginia 22314. Attention: John D. Antrim, P.E., Phone (703) 684-2835.

Effective date October 25. 1988.

APPENDIX E

AQUATIC INSECT LARVAE INFESTATION OF SUBMERGED TIMBER

Excerpts from the Report of the effects of caddisflies on the Pocomoke City Bridge pilings. Oliver S. Flint, Jr., Department of Entomology, National Museum of Natural History, Smithsonian Institution, Washington, DC.

Caddisflies (Trichoptera) are an order of insects closely related to the moths and butterflies (lepidoptera). They have a four stage life cycle-egg, larva, pupa, adult. In general the first three stages are passed in the aquatic habitat, but the adults are aerial. The female, after mating, either descends, swimming, under the water surface to place her eggs on a suitable substrate, or drops an egg mass into the water, or places the mass on a suitable object over or next to the water. The larvae o almost all caddisflies live in freshwater, but a few exotic species live in the ocean, and some others live in damp terrestrial environments. Except for two families that are free-living, all larvae construct some sort of shelter in which they live. One group of families construct from plant or mineral particles a portable case that shelters the body. This they drag around as they move over the substrate feeding on living or dead organic matter. The second group of families construct a shelter that is fixed to the substrate. This generally consists of a silken retreat portion which serves to shelter the larva, and an anterior net of some type which strains their food from the water flowing by. In some instances there are no separate retreat and net portions, instead the entire retreat serves as a filtering bag. At the end of the larval stage, all species construct some sort of shelter for the ensuing pupa. Those that had constructed cases usually modify this and attach it firmly to, or bore with it into, the substrate, therein pupating in safety. The shelter markers also modify and strengthen the retreat portion of their shelter, generally hiding it in some crevice or irregularity in the substrate. After completion of the pupal period, the pupa cuts its way out of the enclosing shelter, swims to the surface, crawls out onto some bit of solid substrate, its skin splits and the adult emerges and flies off, to begin the cycle all over again. This type of caddisfly larvae (Hydropsyche incommada-Hagen) were discovered on the untreated timber piles of the S.R. 675 bridge.

The immature stages of the caddisflies live in all sorts of water. There are a few species in Australia and New Zealand whose larvae event live in oceanic water along the edges of the islands. Some others live in leaf litter in damp, terrestrial habitats. However, most larvae live in fresh water, either flowing of standing. Generally speaking, those that construct the portable cases are more frequently found in ponds and lakes, but many are inhabitants of fast flowing torrents. The shelter makers, however, are almost always limited to flowing water, only a few being able to inhabit wave-washed lake margins.

The larvae, which do essentially all the feeding and growing in the caddisflies, feed on all types of organic matter depending upon the species. Some are predators, feeding on various small invertebrates they encounter on the substrate. Most feed on plant matter, primarily detritus, but a few are

known to be associated with certain living aquatic plants. The detritivores obtain their food in a variety of manners. Most of those that make the portable cases actively seek out their food - leaves and sticks fallen in the water, or the algal film growing on rocks or sticks. The shelter makers require flowing water to carry suspended particulate matter into their trap nets. The size of the net meshes, and the food particles retained, varies greatly depending upon the species...

The annual life cycle vary greatly between species, and also from south to north in the same species. Probably most species in the mid-Atlantic states have a single life cycle per year. Adults generally begin emerging in spring, soon mate and lay eggs, the larvae hatch in a week of so, and the larvae grow slowly during fall and winter, rapidly completing development in later winter and early spring of the following year. After a pupal period of 1 to 2 weeks, the adults emerge to begin the cycle again. There are many variations on this cycle, with adults emerging at various times of the warmer seasons and larval growth taking place at other times. However, many species may have two generations per year; H.incommoda being reported to have two generations in Georgia (Cuney & Wallace 1980) or three in Virginia (Parker & Voshell 1982). In these situations larval growth is rapid and continuous in the warmer seasons, resulting in a series of generations during the warmer months, with larvae overwintering in a partially grown state...

In the last 15 to 20 years there has been a surge of interest in, and research on, the role of detritus (dead and decaying plant matter) in the production of invertebrate biomass (tissue mass of living invertebrate animals)... it is clear that organic matter, leaves, sticks, wood, etc., that falls into slowing water is, in general, the major source of energy available to the aquatic system. However, most of this matter when it first enters water is not attractive to detritivores [caddisflies], it must be conditioned first. This entails the invasion of the woody tissues by fungi and other microbes which break down some of the constituents. This conditioned plant matter is much more attractive as a food, and, in the case of leaves, may be rapidly consumed. Larger woody debris is much more slowly conditioned and consumed than leaves. Probably one of the more important contributions invertebrates make to the degradation of wood is the removal of conditioned wood, thereby speeding further penetration of unaffected wood by decay organism. Anderson, et al. (1978) state: "The indirect role of feeding on senescent microflora, exposing more surface area and spreading fungal spores, would enhance the role that these invertebrates play in the processing of wood."

Additional Information. The Smithsonian Institution translated two papers that described Hydropsyche larvae damage to wooden supports of bridges. In 1901, a 47 year old Finnish bridge was destroyed by demolition after the balance of the bridge was endangered. The bridge was supported with a coffer scotch pine structure, 2 to 2.5 meters high, that was submerged. Larvae were not present near the surface but it was so densely covered further down in the water that the larvae were touching each other. In 1926, a 50 year old Swiss bridge was rehabilitated do to damage by feeding insects. This bridge's substructure was built of oak and larch that had been treated with carbolineum (this may have become inactive over the years) to

protect from putrefaction. The larvae attacked tenon in mortise holes that loosened the articulation of the bridge that was about 1 meter below the water line. The tenon in the tie beam was diminished to almost half its original size. The researcher stated that the wood looked as if scarred by smallpox. Both of the researchers examined the content of the larvae and detected fragments of wood in the digestive tract.

One researcher studied the destruction of 3-inch balsam logs in cold water beaver ponds in Alberta, Canada. He predicted the half life of these logs as 57 years. This half life is similar to the life span of several other bridges that have been shortened due to the presence of caddisflies.

In aquatic environments, changes in the pH, which is a logarithmic expression in that one pH unit is 10 times more or less concentrated than an adjacent pH unit, effect the acidity or the alkalinity of the water. The pH of seawater varies between 7.2 and 8.2; water with a pH below 7 is acidic, with a pH above 7 it is alkaline. As an example, exposed steel in water with pH below 4 will be attacked slowly. However, since wood is most stable at a pH between 4.0 and 7.0 (natural pH of the growing wood), wood is more tolerant or more stable in acid than steel. Data from 1954 to 1988 shows that the pH varies in the Pocomoke River at the S.R. 675 bridge site from 5.38 to 8.6 but is usually around 6.0 to 7.0.

*U.S. GOVERNMENT PRINTING OFFICE:1990-261-991:00034