NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

HIGHWAY ACCIDENT REPORT

AUTOMOBILE COLLISION WITH AND COLLAPSE OF THE YADKIN RIVERBRIDGE NEAR SILOAM, NORTH CAROLINA

FEBRUARY 23, 1975

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16. Abstract

About 9:25 p.m. on February 23, 1975, an automobile struck a vital structural member of the Yadkin River Bridge near Siloam, North Carolina. The collision occurred in heavy fog. Following the impact, the bridge collapsed and both the automobile and the bridge fell into the river. Six more vehicles vaulted into the collapse zone within a 17-minute period. Four persons were killed and 16 were injured.

The National Transportation Safety Board determines that the probable cause of the bridge collapse was the penetration of the timber railing by the vehicle and its subsequent impact with and crushing of a vital structural member of the bridge truss. The timber railing was not adequate to sustain impact at posted speeds.

The report contains five recommendations to the Department of Transportation to improve the safety of bridges on public roads.

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FOREWORD

The accident described in this report was investigated under the authority of the Independent Safety Board Act of 1974. The North Carolina Department of Transportation and Safety, the North Carolina State Bureau of Investigation, the North Carolina Rescue Squad, the Federal Highway Administration, the National Bureau of Standards, the National Highway Traffic Safety Administration, the United States Army Corps of Engineers, and the engineering consulting firm of Modjeski and Masters cooperated with the Safety Board's investigation.

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HIGHWAY ACCIDENT REPORT

Adopted: April 22, 1975

AUTOMOBILE COLLISION WITH AND COLLAPSE OF THE YADKIN RIVER BRIDGE, NEAR SILOAM, NORTH CAROLINA, FEBRUARY 23, 1975

SYNOPSIS

About 9:25 p.m. on February 23, 1975, an automobile struck a vital structural member of the Yadkin River Bridge near Siloam, North Carolina. The collision occurred in heavy fog. Following the impact, the bridge collapsed and both the automobile and the bridge fell into the river. Six more vehicles vaulted into the collapse zone within a 17-minute period. Four persons were killed and 16 were injured.

The National Transportation Safety Board determines that the probable cause of the bridge collapse was the penetration of the timber railing by the vehicle and its subsequent impact with and crushing of a vital structural member of the bridge truss. The timber railing was not adequate to sustain impact at posted speeds.

FACTS

The Accident

About 9:25 p.m. on February 23, 1975, a white 1973 Thunderbird was traveling southbound about 40 mph on State Route 1003 near Siloam, North Carolina. The roadway was wet from misting rain and shrouded in fog, which reduced visibility to 2-to-3 car lengths.

The Thunderbird approached the Yadkin River Bridge and entered the truss roadway. After entering the truss, the driver lost control of the vehicle. One hundred and forty-one feet after the vehicle entered the truss roadway, the left front fender of the vehicle contacted the left bridge rail. The left wheels did not contact the curb and only minor damage was sustained by the left front fender.

The vehicle then moved to the right, and the right front of the bumper and fender struck and penetrated the right timber bridge railing about 40 feet from the south exit of the truss. The right tire climbed the curb, and the right front end of the bumper contacted a pair of 7/8-inch vertical hanger rods which supported a floor beam, located 25 feet from the truss' south exit. One of the pair was snagged by the bumper and was broken. The right front wheel then dropped to the outside of the curb as the vehicle continued along the bridge. At the end of the bridge, the vehicle struck the truss' southwest end post, which supported 25 percent of the bridge's dead weight at the pier. (See Figure 1.) The speed of the vehicle as it struck the end post was estimated to have been about 30 mph. As the vehicle bumper struck the end post, the end post's structural cross section began to crush; then, because of the combination of the reduced structural cross section, the horizontal force of the vehicle, and the dead load of the bridge, the end post began to bend and move. As the end post moved southwesterly, the vehicle rotated clockwise. Its left rear struck and broke the east bridge rail, and the tire and wheel struck and broke the curb. The vehicle continued to rotate until its left rear wheelwell contacted the southeast end post.

The bending and subsequent collapse of the southwest end post created stress levels in members near the center of the truss that caused their failure and the collapse of the truss into the river. (See Figure 2.) The vehicle fell into the water with the south end of the bridge truss and sank, upright, near the pier face. The water covered all but a small area of the roof and the rear window. The rear window broke during the collision and allowed the driver to escape.

Another southbound vehicle (No. 2) vaulted into the collapse zone and struck the upright truss, resting in the river, near joint U1W;1/ this impact caused that portion of the truss to collapse further. The vehicle remained upright and came to rest on top of the collapsed structure. The vehicle occupants survived the crash.

Two northbound vehicles (Nos. 3 and 4) vaulted into the collapse zone and came to rest upside down. No. 3 contained four occupants, two of whom drowned. The driver of that vehicle went for help after he reached the shore. No. 4 contained two occupants who reached the roof of the Thunderbird to await rescue.

1/All labeled joints and members are depicted in Figure 3.

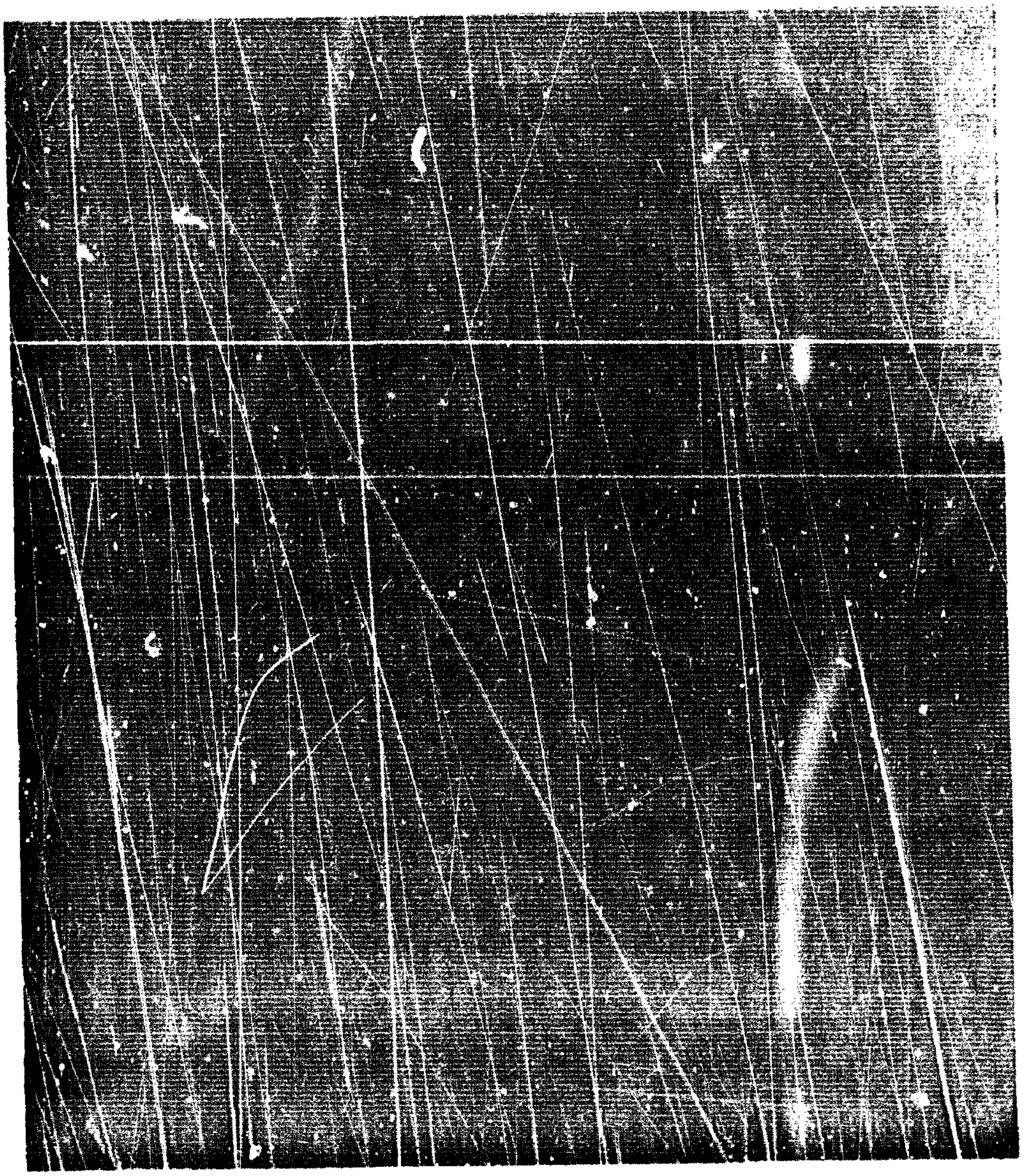

Figure 1. The arrow indicates the southwest end post that was struck by the Thunderbird.

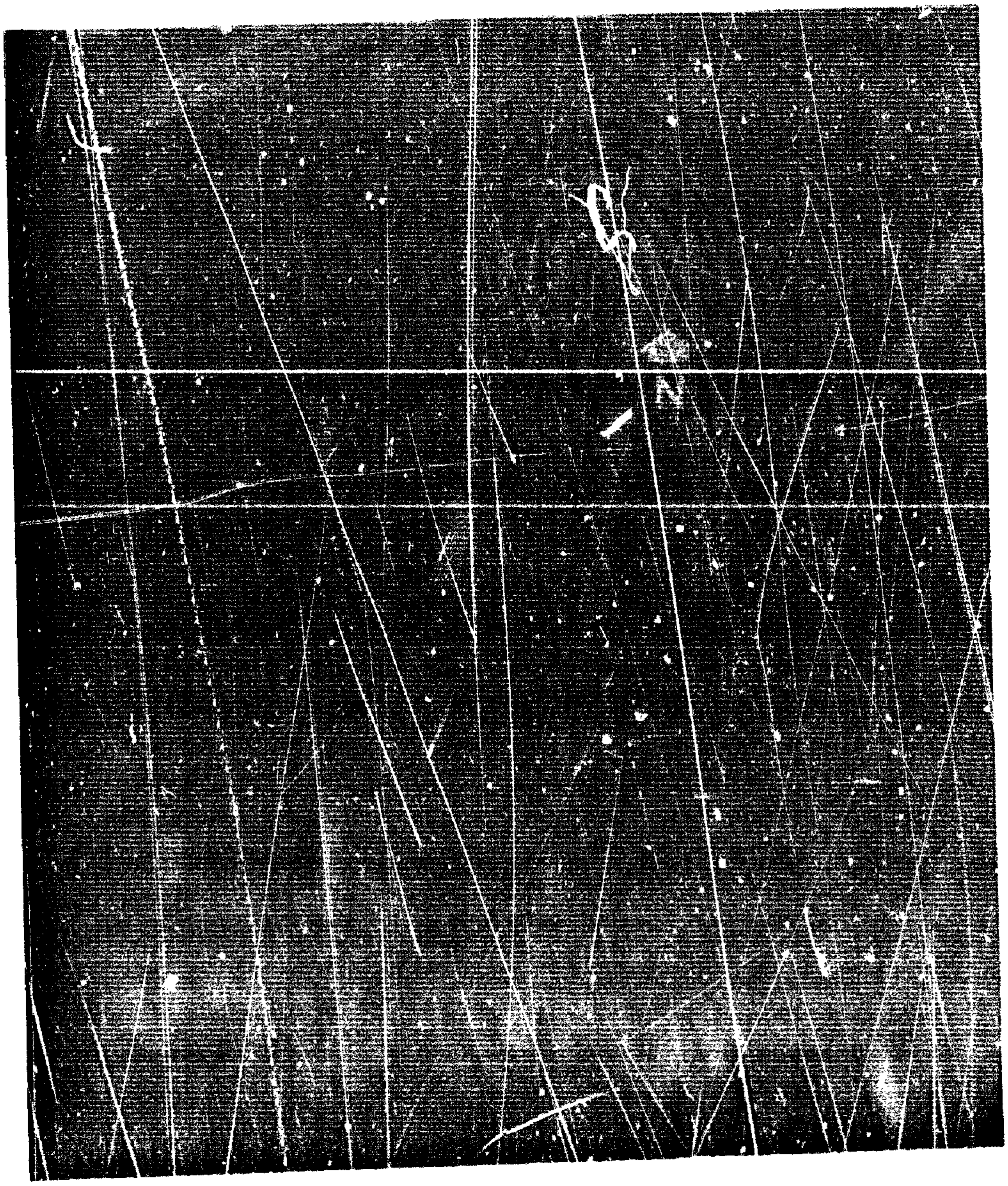

Figure 2. Aerial view of collapsed bridgo.

Another southbound vehicle (No. 5) vaulted into the collapse zone and came to rest upside down on the collapsed truss. Water entered the vehicle to a depth of about 1 foot. Two of the occupants died.

The driver of No. 6, which was behind No. 5, attempted unsuccessfully to stop and his vehicle slid into the collapse zone. All of the occupants of No. 6 survived. One of them was able to reach the bank and roadway to warn other traffic of the hazard, but not before a seventh vehicle vaulted from the north approach and came to rest upside down on No. 5.

A nearby resident, advised of the hazard by the driver of vehicle No. 5, closed the south approach to the bridge.

The bridge collapse and the entry of the vehicles into the collapse zone occurred within a 17-minute period. Four persons were killed and 16 persons were injured.

Accident Site

The accident occurred on State Route 1003, 1/4 mile south of Siloam, North Carolina. The posted speed limit is 55 mph. No requirement for reduction in speed was posted on or near the bridge. An advisory sign, posted 650 feet north of the bridge, read "One lane bridge." A similar sign was posted on the south approach.

State Route 1003 is a two-lane, asphalt-surfaced road which bears north and south in the vicinity of the Yadkin River Bridge. The roadway is part of the Federal-aid secondary system. The surface of the asphalt roadway in the vicinity of the bridge demonstrated a high skid resistance. The bridge's roadway surface was timber; it was not paved nor was it covered with skid-resistant material. The roadway was 20 feet wide, except on the bridge, where it narrowed to one lane 11 feet 2 inches wide.

Witnesses to this accident indicated that vehicles entering the bridge usually slow to 25 mph or less because the roadway narrows to one lane and because the driver's view of the bridge roadway is partially obstructed on both approaches to the bridge. The slowing of the vehicle enables a motorist to judge if a vehicle from the opposing direction has entered or is about to enter the bridge.

The roadway is marked with white stripes along the edges and with a yellow centerline in the lengths where two lanes exist. The centerline markings stop before the lanes narrow to one, near the bridge. The white edge stripes continue to the bridge, where they terminate.

Approaching the bridge from the north, the roadway has a 5-degree curve to the left. The roadway grade during the last 225 feet before the truss is a 4-percent upgrade. Three hundred feet before the bridge, the roadway starts to narrow. Approaching the bridge from the south, the road narrows 390 feet before the bridge. The roadway grade during the last 200 feet before the bridge is a 3-percent upgrade. From either approach the bridge is visible for 1/4 mile on a clear day. The roadway surface of the truss was about 30 feet above the water surface at the time that the bridge collapsed. The river bottom at its lowest point was 36 feet below the deck.

Weight limit signs, reading "Weight limit 7 tons," were posted at the entrances to the bridge.

No skid test had been performed on the bridge's timber roadway surface before the accident. After the accident, skid tests were performed at seven locations on the approaches to the bridge using a skidtrailer (ASTM Method E274). The average skid numbers (SN) were $SN_{20}61$ (tested at 20 mph) and $SN_{40}54$ (tested at 40 mph). A British Portable Tester was used at the same seven locations and provided an average frictional resistance reading of 68.8.2/

The British Portable Tester provided an average reading of 73.6 for five locations on the side spans and an average reading of 49.2 for five locations on the truss.

No research data was found to correlate the test results of the British Portable Tester with values that would be obtained using the skidtrailer (ASTM Method E274) on timber surfaces. Limited research indicates that, at low speeds, a correlation can be made for asphalt and cement concrete pavements. The same research report indicated that correlations between rough and smooth surfaces can have substantial variations. It is not clear in which category the timber surface would be classified.

On the day that the bridge collapsed, a light rain had started in the late afternoon and was subsequently followed by a heavy fog. Witness statements indicated that visibility at the time of the accident was reduced by heavy fog to between 40 and 60 feet near the bridge. There was sufficient moisture to wet the surface of the roadway and to cause some motorists to use their windshield wipers. There was no wind at the time of the accident.

The traffic accident record from January 1969 to February 23, 1975, indicated that four accidents occurred on the bridge. These accidents

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2/The speed of pendulum on this tester is about 7 mph.

involved one vehicle which lost control, two head-on collisions, and a rearend collision. The roadway surface was wet at the time of all four accidents.

The Bridge

The bridge was 385 feet long and consisted of five spans. (See Figure 3.) The center span was a 225-foot steel through truss. Its length extended across the river and was supported by concrete piers. The truss-bearing plates were bolted at the north pier and rested on a cluster of rollers on the top of the south pier. The rollers allowed the structure to expand and contract under changing temperatures. Anchor bolts, imbedded in the south pier and extending through the base plates, were designed to limit excessive movements of the truss.

The approach spans consisted of two 40-foot spans at each end of the truss.

Creosote-treated timber curbs, 10 1/4 inches high, were installed on both sides of the bridge roadway surface. The bridge railing consisted of two 2-inch by 6-inch wood members supported by 4-inch by 6-inch timber posts at 6-foot centers. The railing was painted with aluminum paint.

The truss was believed to be designed before 1928. The truss was removed from its original location and stored. In 1937, the State began to erect the truss over the Yadkin River at Siloam. The project was completed and opened to traffic in 1939.

The maintenance inspection reports for 1972 and 1974 indicated that excessive high loads on some trucks had damaged the overhead portal bracing on the bridge. A local resident stated that a truck had struck the portal bracing on the south end of the bridge on the upstream side about 2 years before the bridge collapsed. The police had no report on file concerning that accident.

The DOT&S furnished records of bridge inspections performed in 1964, 1969, 1972, and 1974. These reports were the only official inspection records.

The 1974 report gave a much lower rating to most structural elements than did the previous reports. The decking, the portal bracing, and a broken joist on an approach span received critical ratings. The truss alignment, end posts, truss verticals, a loose anchor bolt at the L9

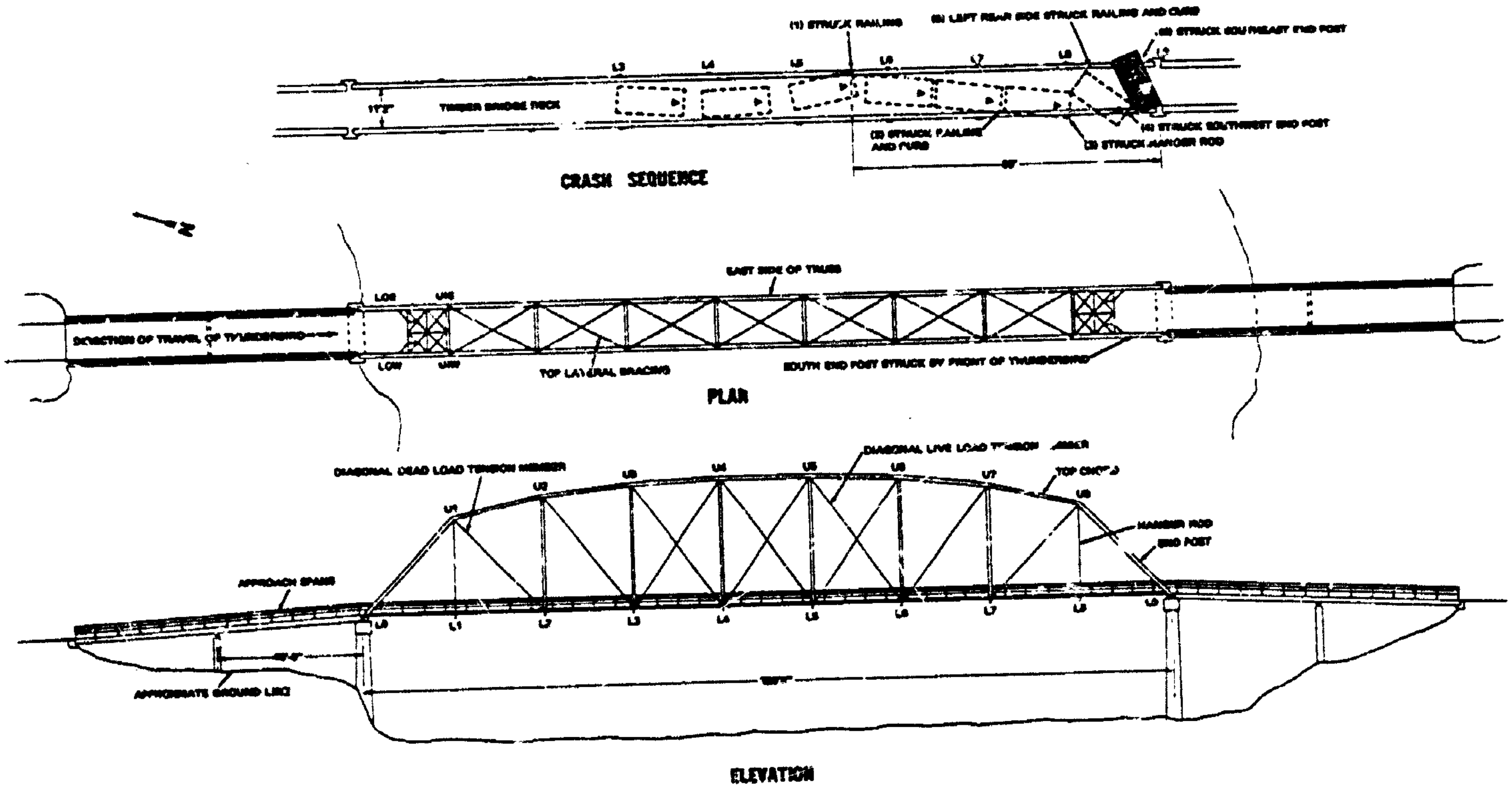

Figure 3. Drawing of Yadkin River Bridge near Siloam, North Carolina, with vehicle crash sequence.

bearing, and the structure's response to live loads received poor ratings. The report noted the nature of damage to the portal bracing as well as a 2 1/2-inch downward bow in the U8E-L9E downstream end post and a 4-inch upward bow in the U8W-L9W upstream end post. The report summarized, "Truss needs damaged members repaired," and stated "Truss is being overloaded terribly. Tractor trailers, dump trucks, etc."

A painting record for the bridge was not available. State officials indicated that the bridge was probably last painted in 1970.

The DOT&S had repaired the decking and joist on the approach spans immediately before the collapse. No repairs were made to the truss nor had there been any analysis to determine if changes were needed in the weight limit. DOT&S officials stated that the lack of analysis resulted from insufficient staff to make a timely review of inspection reports received from the inspection teams. The staff in the headquarters office was being increased based on a budget request approved by the State legislature shortly before the bridge collapsed.

Bridge Damage

During one of two floods which occurred after the bridge collapsed, the structure rolled over and came to rest at a 45-degree angle from the north pier. The north end of the structure rotated about the point where one of nine remaining cables had been attached after the bridge collapsed to stabilize the structure against normal currents.

Substantial damage was inflicted on the structure, particularly from L5 to L9. That portion had maintained good integrity during the collapse, but it became twisted severely during its movement downstream.

Most of the curb and the bridge rail were lost in the floods. A part of the curb and part of the bridge rail were lost immediately after the collapse. Some decking was lost during the collapse as well as in the floods.

The removal of the bridge and the layout of the components was completed on April 2, 1975. (See Figure 4.)

Before the floods, white paint marks were found on the underside of the end post members U8E-L9E and U8W-L9W and on one of a pair of tension rods that supported the deck. No scuffing of the inside-vertical face of the curb was apparent on the timber curb that remained between L7W and L9W. Only 30 feet of the 50 feet of curb between L7W to L9W remained at the accident site before the flood.

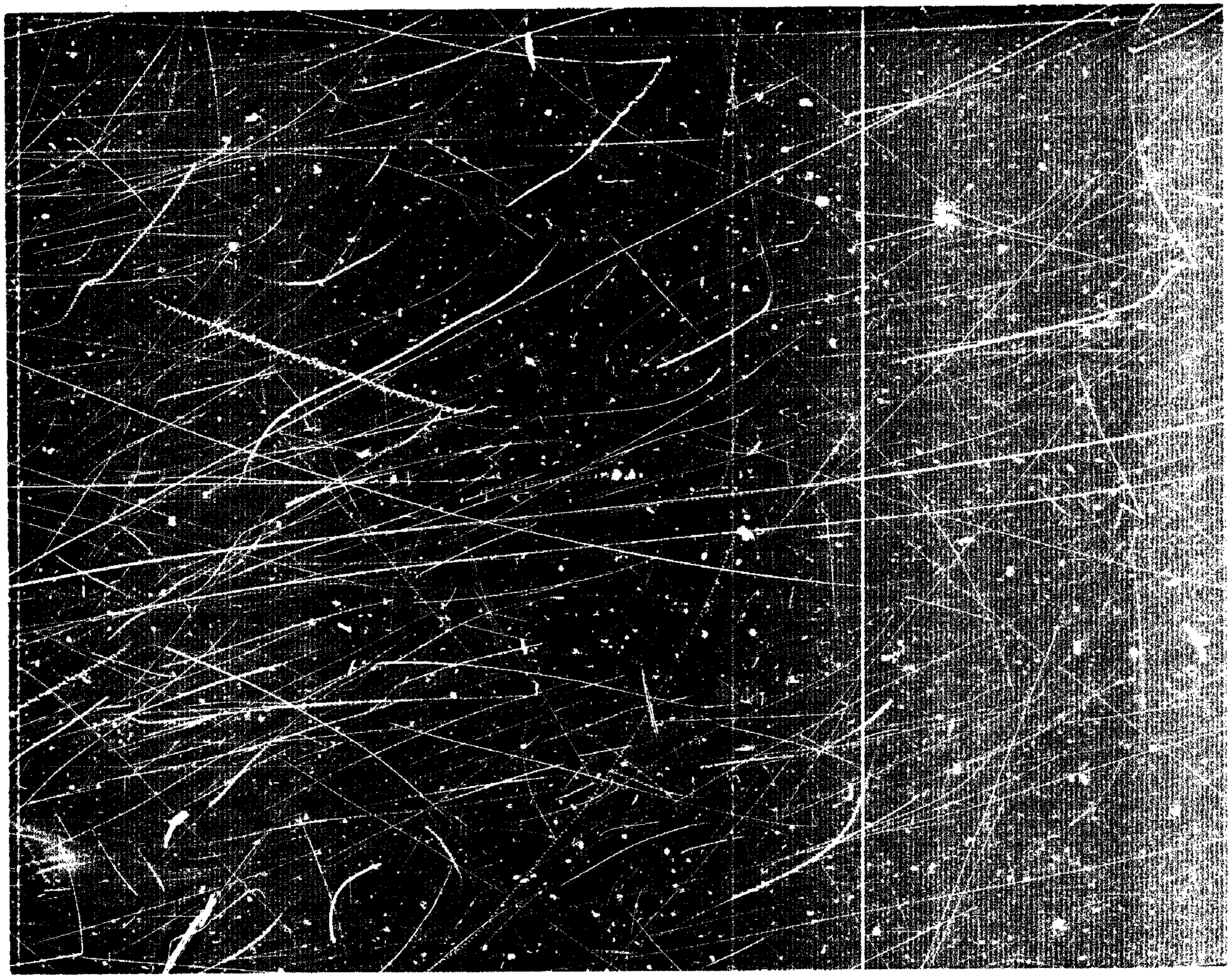

Figure 4. View of members of the bridge reassembled in layout yard. Arrow indicates end post U8W-L9W at the south end of the truss.

Broken pieces of automobile rear window glass were found on the pier top at the bridge's southeast corner, which supported end post member U8E-L9E. Headlight glass was found on the top of the southwest corner of the pier. Pieces of white fiberglass auto trim molding were found on the deck of the approach span which was adjacent to the south end of the truss.

On the river bank, southwest of the south end of the truss, several pieces of the bridge railing and glass from an automobile headlight were found.

Vertical Hanger Rod--One of the pair of vertical hanger rods (L8W-U8W) that supported the floor beam was broken.

Top Chord--The top chords U2-U3 (E and W) were fractured completely at their connections to the pin at joints U2 (E and W).

End post U8W-L9W was bent to an angle of 70 degrees between the bottom surfaces of the member (about the lateral axis) and the L9 end had rotated clockwise an estimated 25 degrees to a vertical longitudinal plane through the member. (See Figure 5.) The center of the bend was located 21 inches above the top surface of the deck. The sides of the end post were collapsed toward the outboard side of the member.

Top Lateral Bracing (Horizontal Plane)--Tension rods on the top of the truss (U3E-U4W and U4E-U5W) were shown to have been broken before the flood, which occurred after the bridge collapsed but before it could be dismantled. No other similar member was broken.

Bottom Lateral Bracing (Horizontal Plane)--An inspection of the lateral bracing rod L8E-L9W and other evidence revealed that it was not broken and that it was attached properly when the bridge collapsed.

Interviews with witnesses who traveled over the bridge between 0 and 9:25 p.m. revealed that no unusual condition existed at the south end of the truss where the L9 bearing assembly was located.

Diagonal Live Load Tension Members--The cross sections of tension members L3E-U4E and L4E-U5E were found to have been fractured completely. The L4E-U5E member contained aluminum paint in varying amounts on a portion of the fractured cross section.

Anchor Bolts at Piers--Seven anchor bolts sheared, pulled out, or pulled through the truss base plate. One bolt had failed before the bridge collapsed, according to the maintenance report.

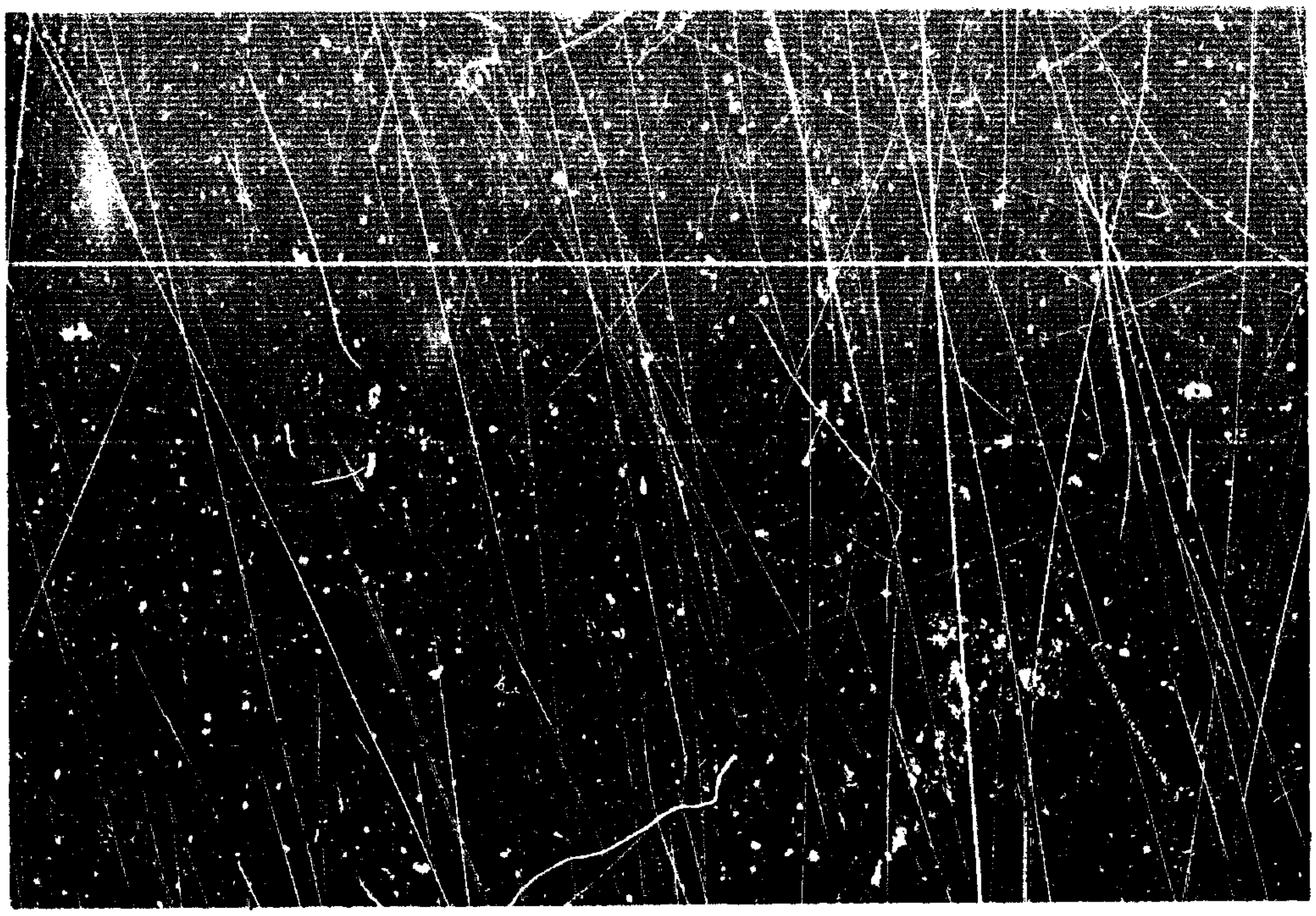

Figure 5. Damaged end post U8W-L9W, lying on the barge deck following salvage from river. Arrow A indicates bearing assembly that supported the end post at the pier and Arrow B indicates point struck by Thunderbird where bending occurred and collapse of the truss was initiated. Arrow C indicates the 13-inch bottom width of the end post.

Damage to Vehicle No. 1

The right side of the bumper contained a 7/8-inch-wide vertical indentation with fractures on the front face near the bottom surface. The bumper was broken loose from its connections to the two shock-absorbing columns. The columns were bent about 90 degress toward the right. (See Figures 6 through 9.)

To the left of the bumper centerline were two parallel diagonal indentations about 13 inches apart. (See Figure 6.) They extended onto the hood of the vehicle and were equal in width to the outside dimensions of the bottom width of the end post.

The vehicle radiator was displaced to a position against the engine. The wheel base was found to have been shortened 6 1/2 inches on the left side and 3 inches on the right.

The right front tire sidewall surface contained scuff marks. The color of the marks was similar to the black creosote preservature paint on the timber curbs.

The left front wheel contained no scuff marks that would indicate that it had contacted the curb. The wheel cover was undamaged and on the wheel.

The rear wheel cover was missing. The wheel rim contained light abrasions on a portion of its outer radius and had several small timber chips lodged just inside the rim's edge. The sidewall of the tire was split and there was a small cut at one end of the split.

An analysis of the tire damage showed that the tire failed because of a cutting action rather than an impact or blowout, and that such cutting occurred while the wheel was rolling or rotating slowly. The wheel rim and tire did not exhibit any evidence of having rotated significantly after the tire was deflated.

Vehicle Drivers

The Thunderbird was driven by the owner, a 46-year-old resident of Winston-Salem, North Carolina. He held a valid North Carolina operator's license. The driver was the only occupant of the vehicle at the time of the accident.

The driver's traffic record indicated three convictions as follows:

Reckless Driving	4/23/73
Speeding, 115 mph in a 65-mph zone	6/26/72
Speeding, 75 mph in a 65-mph zone	10/8/71

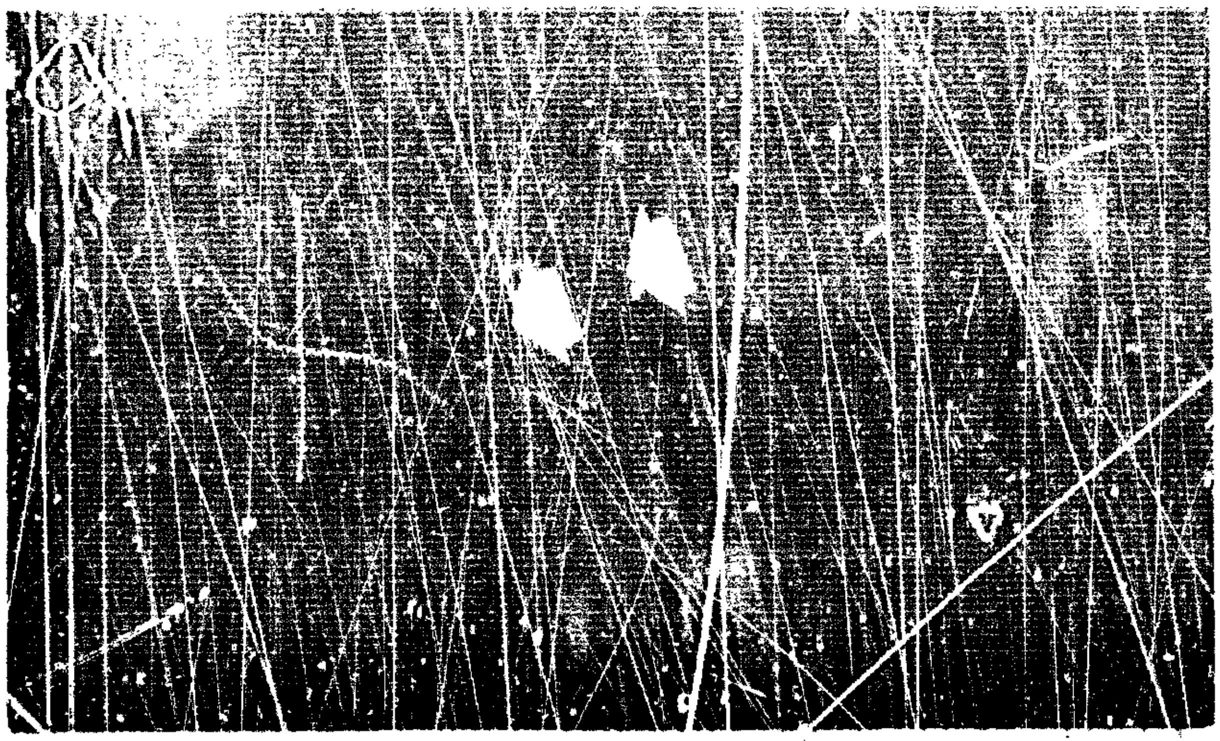

Figure 6. Front view of the 1973 Thunderbird, showing damage and the parallel indentations (arrows) that correspond to the width of the southwest end post.

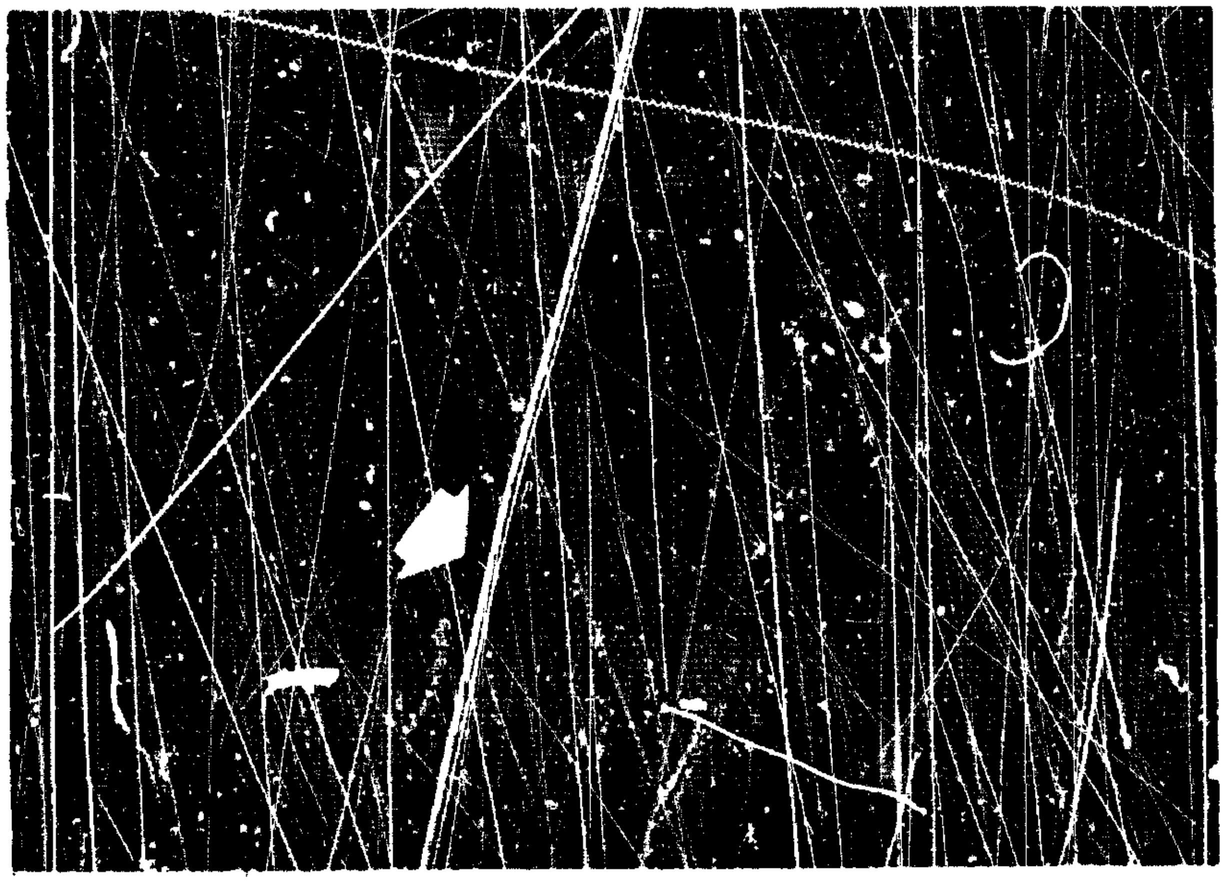

Figure 7. Damage to the right front side of the Thunderbird; the arrow indicates an indentation with silver paint marks, left from contact with the bridge rail.

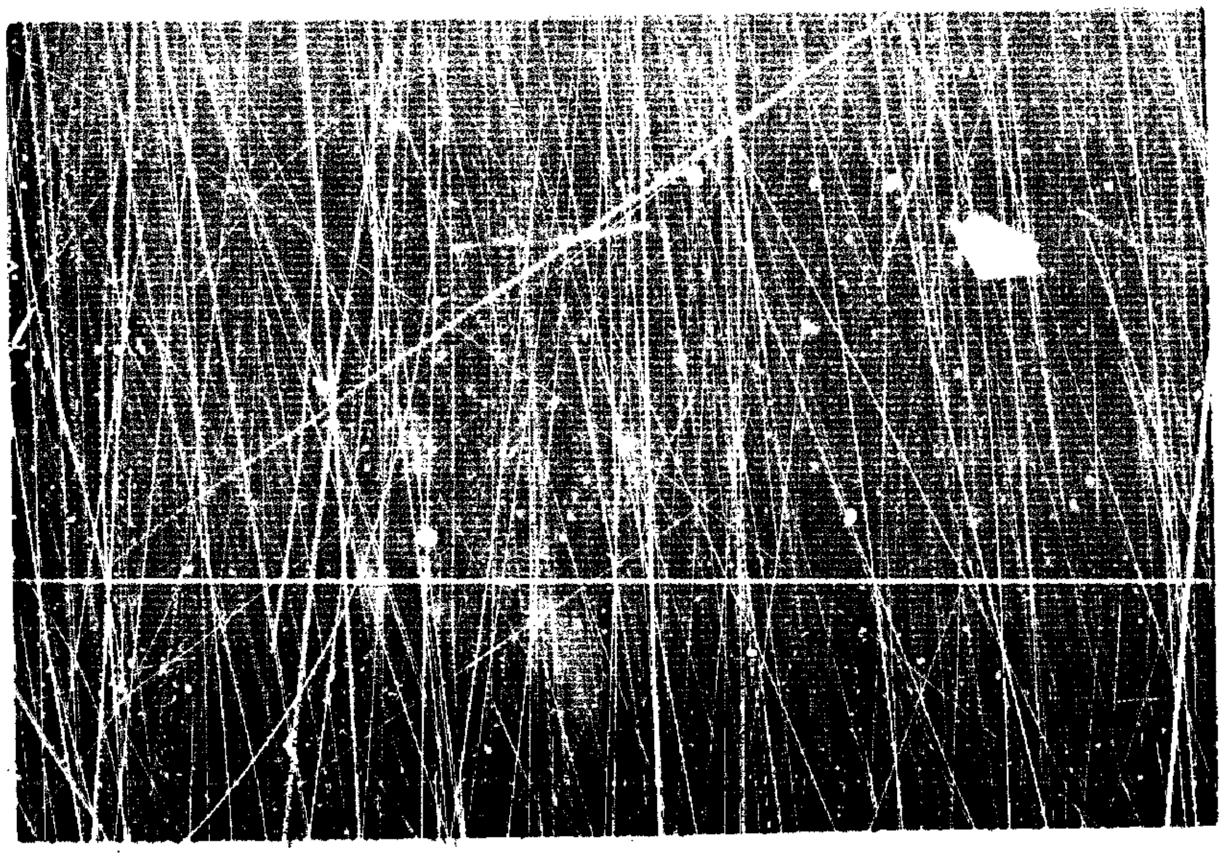

Figure 8. Right side and rear view of the Thunderbird; arrow indicates timber bridge rail protruding through wheelwell.

Figure 9. Left side and rear view of Thunderbird with damage resulting from contact with the southeast end post (arrow).

No tests were given to determine sobriety.

The driver was familiar with the road and the bridge from previous trips in the area. He had driven the Thunderbird infrequently.

The driver stated that he was wearing the seatbelt at the time of the accident. The chest restraint harness was not being used and was found in its stored position after the accident.

The driver's injuries consisted of a strained back, minor lacerations, and bruised intestines.

The driver stated that he was traveling about 35 to 40 mph as he approached the bridge and that he slowed the vehicle before entering the truss to see if opposing vehicles were on the bridge. He did not estimate his speed on the bridge, but he suggested that 20 to 25 mph would be a safe speed. He said that the bridge seemed to sway after he entered it and that the Thunderbird was difficult to control. He could recall hitting his head on something, such as the side window or front window, and then falling toward the river. He could not recall any other events relative to the collapse and did not indicate that reduced visibility had affected his control of the vehicle.

A witness reported that the Thunderbird overtook and passed his vehicle at 40 to 45 mph about 1/3 mile from the bridge.

The driver of vehicle No. 3 was familiar with the roadway. His vehicle was the first to vault from the south span. He stated that visibility was poor and that the roadway was wet. He estimated that he was traveling 25 to 30 mph and that he slowed as he approached the first spans of the bridge. After he entered the side spans, he observed the truss to be missing and he applied his brakes, but his vehicle continued to the end of the second side span and dropped over the edge. The driver indicated that he believed he could have stopped the vehicle if he had had 5 more feet of roadway. The vehicle's point of rest suggests that the vehicle was reaching 0 velocity as it fell from the bridge side span.

The driver of vehicle No. 6 was traveling to the bridge because he had heard shouts for help. He said that there was heavy fog and misting rain and that the road was wet. He was following vehicle No. 5. He said that he was traveling about 30 mph as he approached the bridge and that he slowed to about 20 mph as he entered the first span. He stated that he was about 4 to 5 car lengths behind No. 5 and as that vehicle neared or reached the point of collapse, he saw the vehicle's brakelights go on He was about 1 car length onto the first span when he saw the brake lights; he immediately braked and slid toward the collapsed area to a near-stop before his vehicle went over the end of the span into the collapse zone.

Calculations for vaulting speed indicate that the speed of vehicle No. 5 was at or under 25 mph as it left the end of the bridge span and the speed of No. 6 was about 3 mph as it left the bridge span.

ANALYSIS

The analysis of the events that led to the bridge's collapse and to the vehicles' vaulting into the collapse zone was made by utilizing two approaches and a number of techniques within each approach.

The first approach was to reconstruct the events by the use of physical evidence including photographs, laboratory analysis of physical evidence, and testimony. The second approach was to utilize a stress analysis of the truss using a computer program.3/

The stress analysis was used to verify the load rating requirements for the truss under conditions where the structural damage reported in the 1974 maintenance report was considered.

Other computer analyses considered the effects on the truss stability of the failures that were found in individual members during the investigation. The effects of these failures were analyzed in various combinations and sequences.

The Federal Highway Administration utilized its Highway Vehicle Object Simulation Model (HVOSM) computer program to analyze how the Thunderbird's stability would have been affected if diagonal members L4E-U5E and L3E-U4E had broken before or during the vehicle's entry onto the bridge, rather than as a result of the vehicle's impact with the bridge members. The expected deflections of the roadway were furnished from the stress analysis.

The structural analysis supported the analysis derived from the physical evidence. From both analyses, the following accident sequence was reconstructed.

Accident Sequence

The thrust of the southwest end post, under impact by the Thunderbird, created high stress levels in numerous members of the truss and a misalignment of the top chord as the top of the south end of the structure moved outward in a southwesterly direction.

3/Modjeski and Masters, "Final Report of the Yadkin River Bridge Collapse Investigation," September 1975.

With the failure of the southwest end post, three top laterals (U3E-U4W, U4E-U5W, and U5E-U6W) were stressed to levels of expected failure and diagonal L4E-U5E, which contained a large flaw or crack that reduced its cross section, was stressed to 6 times its yield point. Member L4E-U5E probably failed first, followed by top lateral members U4E-U5W and U3E-U4W. The failure of diagonal L3E-U4E probably occurred after the other failures.

The failures of diagonal L4E-U5E and of lateral U4E-U5W were sufficient to distort the top chord; this caused a torsional hinge to develop in the middle of the truss. The south half of the truss then could rotate rather freely without resistance from the north half. The south half continued to move westward or clockwise and the north half remained in a vertical position because of its weight and the restraint imposed by the anchor bolts attaching the truss to the pier.

As the top of the south half of the truss rotated clockwise, the center of the structure was no longer stable and started to descend downward. The south end, supported by rollers and minimally restrained by three corroded anchor bolts, moved off the south pier northward and then downward towards the river. With the south end off the pier and moving downward, the north end started to move to the southwest, pulling three of the four anchor bolts from the concrete pier. The north end dropped from the pier and the timber deck came to rest against the pier face. The northernmost 75 feet of the truss came to rest in a vertical position; the truss configuration was maintained from L0 to L3. From L3 to L5, the top chords rested at an angle to the south half of the truss, which was lying horizontal in the river with the west bottom chord on the river bottom.

Vehicle No. 2 was the first vehicle to vault into the collapse zone. It probably struck the upright truss on the northwest end post immediately north of joint U1W. The impact caused the unstable truss sections to collapse downward and southward. The top chords came to rest near the timber deck, completely fracturing the top chords at joints U2E and U2W. The vehicle speed was calculated to have been between 25 and 30 mph as it left the roadway.

Vehicles No. 3 and No. 6 almost stopped successfully. Calculations showed that if the skid number of the roadway deck was increased by 10, the surface of the roadway deck would have provided enough resistance for the vehicles to have stopped safely.

Inventory Load Rating

The inventory rating of a bridge is a measure of the vehicle weight that the structure can carry safely for an indefinite period. The posted weight capacity of bridges usually is based on their inventory ratings. The inventory rating analysis provides for a factor of safety so that a bridge can carry loads heavier than the inventory rating, without failure, for limited periods.

The truss was analyzed to determine stress levels on structural members that would be caused by various theoretical vehicle loadings traveling across the span in order to establish an inventory rating. Of particular interest were (1) the effects of the earlier damage on the end post and (2) the effects of the large crack in diagonal L4E-U5E.

The partial factures of the cross section of L4E-U5E had reduced the inventory rating to 3.5 tons. The damage to the end post further reduced the inventory rating to 2.2 tons. A 2.2-ton weight limit would have been marginally safe for the passage of automobiles. The actual posted limit was 7 tons.

Stress Analysis

Diagonals and Laterals--Top laterals U3E-U4W and U4E-U5W and diagonals L3E-U4E and L4E-U5E were found to be broken following the collapse. The L4E-U5E diagonal had been fractured partially long before the accident. The structure was analyzed for stability under the condition that all of these members were removed from the truss. The weight of the Thunderbird was located at critical points to give the maximum stresses that would have to be carried by these members. The analysis indicated that the bridge would not have collapsed, nor would severe distortion to the structure have occurred, if it had not been struck by a vehicle.

The maximum deflections of the truss, with the absence of two laterals and two diagonals cited above, were analyzed with the vehicle at the most critical location (front wheels at point L4); the vertical deflection was 1/2 inch. Bridge structures normally deflect when vehicles (live load) are moving on the roadway. The FHWA standards, as contained in currently adopted American Association of State Highway Officials (AASHO) specifications, permit as much as a 3 3/8-inch deflection on a truss with a span length of 225 feet.

End Post--The evaluation of stress levels indicates that diagonal L4E-U5E sustained the most stress during the collapse because of its reduced cross section from the earlier fracture. However, if that member had had a full cross section, the lateral U4E-U5W would have reached a critical stress and would have been the first to break. With the lateral breaking first, the stresses would have increased in the diagonal to a level to cause failure even with a full cross section present.

Therefore, the final result would have been the same regardless of the presence of the fractured cross section in diagonal L4E-U5E, and only the sequence of failure of the two members would have been affected.

Impact Forces on End Post--Damage to the Thunderbird, the speed necessary to mount the curb, and the speed necessary to carry pieces of headlight glass and bridge debris to points on the river bank suggest that the Thunderbird could have been moving about 50 mph when it struck the end post. Some slowing of the vehicle probably occurred when it contacted and destroyed the 40 feet or more of the bridge rail and when it struck and broke the hanger rod.

While the exact G-force levels cannot be determined with available data, the speed of the Thunderbird was sufficient to create G-forces well above the 7.8 G's determined to be critical to the end post in the undamaged condition. The damage to the Thunderbird and to the bridge would suggest a speed range on the bridge of 30 to 40 mph. The upper limit would be consistent with the speed observed by a witness and cited by the driver of the Thunderbird on the approach to the bridge.

Anchor Bolts--The anchor bolts were found to be substandard in size when compared to current or past AASHTO specifications.4/ (The AASHTO bridge specification standards have been adopted by FHWA.) Analysis determined that a standard installation of anchor bolts would not have prevented the truss from collapsing into the river.

Vehicle Stability

The Safety Board analyzed what effect the roadway's deflections would have had on the Thunderbird's stability, given the hypothesis that laterals U3E-U4W and U4E-U5W and diagonals L3E-U4E and L4E-U5E had broken when the Thunderbird reached point L4 and given a 1 1/2-inch vertical deflection on one side of the deck. The analysis indicated that the deflection would not have affected greatly the path of the vehicle. The vehicle would have moved about 2 1/2 inches laterally toward the low side of the roadway in 135 feet of travel from panel point 1 to panel point 6. Therefore, even if the four structural members had been broken, the effects on the moving vehicle would have been minimal and not sufficient to cause loss of vehicle control.

Witnesses traveling across the bridge immediately before it collapsed reported no unusual motion or vibration of the bridge that would suggest that the bridge was unstable. The reason the vehicle struck the bridge cannot be determined.

4/"Standard Specifications for Highway Bridges," American Association of State Highway Officials, Eleventh Edition, 1973.

Driver Visibility and Reaction

Based on the statements of witnesses, a driver's visibility at the bridge was between 40 and 60 feet. The speed at which a driver could perceive, react, and stop safely, given 40 feet of visibility and a dry, high skid-resistant surface normally would be about 15 mph. Given 60 feet of visibility, the normal safe speed would be 20 mph. These safe speeds would be even less given a wet road and a possible longer perception time caused by a driver's disbelief that the road could be missing.

The speed of the vehicles that vaulted into the collapse zone was estimated to be 20 to 30 mph as they approached the bridge. At these speeds, the opportunity to stop safely under the existing conditions was marginal.

Vehicles usually slowed to about 25 mph to cross the bridge under normal conditions. If there had been no fog, most if not all of the six vehicles might have stopped safely.

Road Skid Resistance

The bridge's roadway surface could not be tested with the skidtrailer after the accident and it had not been tested before the accident. There is no information pertaining to the skid resistance of timber surfaces or to the correlation between skidtrailer test values and the British Portable Tester values on timber surfaces. Therefore, the Safety Board could not conclude whether the timber roadway surface of the approach spans and of the truss span were above or below the FHWA minimum recommended values included under Highway Safety Program Standard 12.

Older bridges may have numerous hazards--for example, they may be narrow or be only one lane--which may make emergency maneuvering and stopping necessary. Therefore, it may be beneficial at such locations to establish skid number values higher than the minimum values recommended by FHWA.

While the exact number of bridges with untreated timber decks is not known, the number is sufficient to warrant further investigation to determine whether these bridges meet minimum standards and whether these minimum standards are adequate.

DOT&S Bridge Inspection

The inspection of the bridge as performed by the North Carolina DOT&S team in December 1974 adequately reflected the structural condition of the bridge as could be determined by visual inspection procedures, assuming that the fracture in diagonal L4E-U5E was covered with paint.

Action on Inspections--The DOT&S had not reviewed the 1974 maintenance report with regard to the structural steel damage and its effects on the inventory rating. The DOT&S stated that the report had not been reviewed because of a personnel shortage. DOT&S had received authorization in 1974 legislation for increased personnel for bridge inspection and analysis, and it was hiring additional personnel when the bridge collapsed at Siloam. The DOT&S now estimates that it has sufficient personnel to inspect and analyze the Federal-aid bridges in accordance with the Federal requirement for inspections every 2 years, but it does not have enough personnel to inspect North Carolina's nonFederal-aid bridges with the same frequency because of inadequate funds.

In 1975, the DOT&S completed a computer program that provides a structural analysis of each State bridge; this permits an inventory rating for each bridge to be completed rapidly when an inspection report is received. DOT&S also has purchased a limited number of sonic test devices to detect flaws and fractures. It plans to purchase strain gauge devices and recorders that can be attached to a bridge to study stresses under live loading. These gauges and recorders will furnish data to aid in understanding and analyzing the distribution of loads in individual members of a bridge's structure.

The DOT&S has a program funded and underway to improve traffic barriers on older bridges so that they will be more resistant to vehicles that could strike vital support members. They also have developed a low-cost device to detect bridge failures that would allow the roadway to drop and to warn motorists with flashing lights. DOT&S plans to install this device on at least 100 selected structures.

The Safety Board believes that the North Carolina DOT&S, with support from the State legislature, is responding to the problems of bridge structures with a program which is of national significance.

Bridge Barrier Rails

Bridge barrier rails that allow a vehicle to penetrate and strike structural members vital to the bridge's stability are of substantial concern. The bridge railings on most older bridges offer little resistance to an encroaching automobile. A vehicle may vault from a bridge if it penetrates the railing. Equally serious is the possibility that a bridge may fail if its vital structural elements are above the deck and are struck by a vehicle.

To improve bridge railings on older rural bridges in order to protect structural support members will be difficult for two reasons. First, the roadway widths on most of these bridges are substandard; this limits the space for adequate railings because railings would further decrease the roadway widths. Second, the structural design of the bridges is not adequate in many instances to accommodate adequate railing systems that can absorb the high energies that are transmitted when the railing is struck by a vehicle.

While posting reduced speed limits will help in some instances to reduce impact energy, experience shows that there are some locations where drivers do not reduce their speed even if reduced speeds are posted. Drivers generally make their own determinations as to safe speeds, and they respond to perceptions of hazards that are different than those upon which laws are based; consequently, posted speed limits are not a total solution.

In 1974, the Safety Board recommended in a highway accident report[5/] that the FHWA:

> Expedite a program to improve, where feasible, substandard bridge-rail systems on existing bridges to increase resistance to pocketing or penetration by impacting vehicles...

The FHWA currently has a research program to inventory existing railing types and to determine several adequate configurations of railing for retrofitting bridges. The program does not specifically address the problem of protecting bridge structural members. DOT&S requested the aid of FHWA in a program to upgrade traffic barriers on through truss bridges where railings are determined to be inadequate. One problem of retrofitting railings on older bridges is that general designs and criteria must be adjusted to individual bridges based not only on their original design but more importantly on their structural condition, which often has deteriorated over the years.

Any study of railings also should consider the effects of wide truck loads that may be higher than the normal railings, thus permitting contact with structural members. The southeast end post of the Yadkin River Bridge had been struck and damaged by such a load.

National Bridge Hazards

There are about 560,000 bridges in the United States, of which about 230,000 are in the Federal-aid system. Based on State bridge inventories,

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5/Highway Accident Report, "Wilmeth Cattle Company Truck/Bridge/Transportation Enterprises, Inc., Bus, U. S. 60-84, Fort Sumner, New Mexico, December 26, 1972," NTSB-HAR-74-1.

about 32,400 Federal-aid bridges are considered unsafe. Of those, 7,000 are unsafe because they have structural defects and 25,400 are unsafe because they are functionally obsolete, due to inadequate width, vertical clearance, approach alignments, or other factors. The FHWA estimates that about 125 bridges collapse each year. FHWA also estimates that it would cost $10.4 billion to replace all unsafe bridges. At the present rate of funding, it would take 80 years to replace these 32,000 bridges.

There are no inspection and inventorying requirements for bridges on nonFederal-aid roads, although bridges on these routes constitute more than half of all bridges on the nation's roadways. The nonFederal-aid roads, for the most part, are under the jurisdiction of State, county, and municipal governments. Many of these jurisdictions have difficulty simply in providing funds for thorough inspections of all their bridges, and would have much more difficulty in replacing deficient structures. Congress recognized safety needs on nonFederal-aid roads and provided funds under 1973 legislation; however, such funds were small compared to the need for such funds.

To appraise accurately the potential safety hazards at bridges on all roadways will require a comprehensive safety inspection program. It should not be expected that such inspections will occur without Federal leadership and funding.

The cost to replace all the critically deficient bridges on the Nation's roadways represents a large financial burden. It is not reasonable to expect that all such deficient bridges will be replaced quickly. Consequently, it is important to identify, by thorough inspection, the degree of hazard that exists at each bridge in order to identify those which need remedial measures or preventive actions the most. Such measures and actions could include closing a bridge, posting for reduced safe load limits, improving traffic controls and roadway delineation, improving bridge railings and approach traffic barriers, adding failure warning systems, increasing skid numbers of bridge and approach road surfaces above currently recommended minimums, and making other minor-to-moderate structural changes that could extend the life of the structures or prevent their collapse.

Bridge Collapse Investigations

The National Highway Safety Program Standard No. 18, "Accident Investigation and Reporting," provides that States shall establish multidisciplinary accident investigation teams to conduct investigations of a selected number of accidents. Few States have implemented such a program.

Multidisciplinary investigation teams could investigate failures of roadway structures to obtain valuable information (1) to support policy and procedure determinations for bridge inspections and (2) to determine the priorities in bridge improvements.

CONCLUSIONS

1. The driver of the Thunderbird lost control of his vehicle for reasons that could not be determined.

2. The bridge truss did not experience any abnormal movements that would have contributed to the driver's loss of vehicle control.

3. The timber bridge rails were inadequate to redirect the vehicle or to prevent it from penetrating structural components of the bridge at shallow angles and at speeds under 40 mph.

4. The truss' collapse was caused by the impact of the Thunderbird on a vital structural member, producing damage sufficient to reduce the required structural shape of the member.

5. The repair of the previously damaged end post and diagonal would not have prevented the collapse, although such damage did present a potential hazard for continued long-term use by vehicles weighing more than 2.2 tons.

6. The size or structural condition of the bridge's substandard anchor bolts did not contribute to the severity of the truss' collapse.

7. Further testing and research is required to determine the adequacy of timber roadway surfaces, without additional skid-resistant treatment, to meet FHWA recommended minimum requirements for skid-resistance.

8. The presence of traffic control devices that would warn of a missing or damaged roadway would eliminate or minimize the danger to approaching vehicles after the collapse of a bridge structure.

9. The vehicles that vaulted into the collapse zone were traveling too fast to respond adequately under the existing visual and road surface conditions.

10. The safety and usefulness of older bridges can be enhanced with better bridge railings and traffic control devices.

11. The number of hazardous bridges in the Nation is unknown since a majority of bridges are not required to be inspected and inventoried.

12. A successful bridge inspection and inventorying program for bridges not on the Federal-aid system will require mandatory Federal standards and Federal funds.

13. The safety of bridges can be improved by the identification, through inspections, of partially failed or damaged bridge components; by the correction of these defective components; and by the the dissemination of the results of such actions.

PROBABLE CAUSE

The National Transportation Safety Board determines that the probable cause of the bridge collapse was the penetration of the timber railing by the vehicle and its subsequent impact with and crushing of a vital structural member of the bridge truss. The timber railing was not adequate to sustain impact at posted speeds.

RECOMMENDATIONS

As a result of its investigation of this accident, the National Transportation Safety Board submitted the following recommendations to the Secretary of Transportation:

"Develop and publish, as a part of the FHWA research program, guidelines for the structural retrofit of bridge railings on existing bridge structures to protect vital structural members from impact by vehicles.

"Include under the National Bridge Inspection Standards and under Highway Safety Program Standard No. 12, 'Highway Design, Construction and Maintenance,' a requirement that bridge inspection reports be analyzed and evaluated within a specified time period, and that any changes in load limits be posted promptly.

"Include under Highway Safety Program Standard 12, 'Highway Design, Construction and Maintenance,' a requirement that all bridges on public roadways be inspected for safety under the same criteria established for bridges on the Federal-aid system under the National Bridge Inspection Standard.

"Institute a program in cooperation with the States which provides for the investigation, by multidisciplinary accident investigation teams, of the following:

a. All bridge collapses on public roadways,

b. Accidents involving vehicles that have struck traffic barrier railings on bridges and damaged structural members vital to the bridge's stability.

The number of such investigations should be sufficient to identify how such characteristics affect the severity of accidents.

"In cooperation with the States, perform a sufficient quantity of skid tests on timber roadway surfaces to establish if such surfaces can normally meet the recommended skid number values contained under Highway Safety Program Standard 12, 'Highway Design, Construction and Maintenance.'"

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ WEBSTER B. TODD, JR.
Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ ISABEL A. BURGESS
Member

/s/ WILLIAM R. HALEY
Member

/s/ PHILIP A. HOGUE
Member

April 22, 1976