April 1989 Hatchie River US-51 Bridge Failure

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The FHWA assisted in the National Transportation Safety Board (NTSB) determination of the cause of the collapse of the spans of the northbound US-51 bridge over the Hatchie River on April 1, 1989. The collapse resulted in five vehicles going into the river and eight people being killed. The bridge site, field observations, stream stability, analysis of aerial photographs, model studies, and foundation analysis are discussed.

Spans of the northbound US-51 bridge over the Hatchie River, referred to as the “old bridge,” collapsed on April 1, 1989. Five vehicles went into the river and eight people were killed as a result of the collapse. The National Transportation Safety Board (NTSB) initiated an investigation into the cause of the collapse and requested that the FHWA be a party to that investigation. FHWA actions to assist the NTSB determination of the cause of the collapse of the bridge are described.

BRIDGE SITE

The bridge site is located about 10 mi north of Covington, Tennessee, where US-51 crosses the Hatchie River (see Figure 1). At this crossing, the northbound lanes are carried over the floodplain of the Hatchie on the old bridge, which was built in 1936, and the southbound lanes are carried on the new bridge, which was designed in 1974 and built thereafter. The old bridge was approximately 4,200 ft long and consisted of 137 simple spans of 28 ft 6 in. over the floodplain and six longer spans over the main channel (see Figure 2). The main channel spans were supported on foundations significantly deeper than the floodplain spans. The bottom of footing elevation was approximately at elevation 223 for Piers 1 to 7 and at elevation 237.9 for pier 70 (Figure 3). Each bent had two columns. Each column had independent footings with five untreated timber piles in each footing that were 20 ft long. This bridge is approximately 1,000 ft long. It has 12 bents and 13 spans. The 11 interior spans are 76 ft 9 in. and the two end spans are 77 ft 7 in. The new bridge, similar to the old bridge, has foundations in the main channel that are much deeper than those located on the floodplain. Bents 6 through 8 have bottom of footing elevations at about 226.2 ft, while the remainder are at elevation 240 ft. Each bent has three columns. Each column has an independent footing that is 8 ft 6 in. square and six prestressed concrete piles that are 30 ft long.

FIELD OBSERVATIONS

The author and J. Sterling Jones of the FHWA were on the site during the week beginning April 3, 1989. They participated in all phases of the investigation with Joseph Osterman, NTSB investigator-in-charge, and Lawrence E. Jackson, NTSB highway group chairman. The major activities of the week were monitoring recovery, data gathering, interviewing the bridge inspection crew, site reconnaissance by boat, and underwater inspection with the FHWA Demonstration Project 80 (DP 80) team and boat.

Monitoring Recovery

Most of the week was spent with the recovery operation shown in Figure 4. The recovery of vehicles was extremely difficult.
because of the sequence of the collapse. Altogether, three spans (77 through 79) similar to Span 80, which is shown in Figure 4, collapsed into the river along with Bents 70 and 71. Apparently, Bent 70 collapsed first with Spans 77 and 78. Three vehicles fell through the opening and landed on the north bank under Span 79. A truck (tractor-trailer) was apparently next to fall through the opening. The truck struck Bent 71 and apparently caused it to collapse across the tractor.

Span 79 fell on top of these vehicles. The last vehicle to fall in was recovered from the channel near the original location of Bent 70.

Figure 5 shows the collapsed section of the bridge as it appeared from the direction that traffic approached it. Skid marks were apparently left by the truck before it went through the opening. State troopers checked levels on the span that was standing on the south side and found no measurable slope.

FIGURE 3 Concrete Bents 1 through 135 (NTSB 1990).

FIGURE 4 Recovery operation.

FIGURE 5 Collapsed spans viewed from direction of traffic.
which suggests that Pier 7 at the north end of that span did not settle. Pier 7 is supported by the deeper foundation of main-channel type. In order to recover the vehicles, Span 79 had to be broken apart. Small sections of the deck and supporting integral girder were freed from the span by jack hammering a slot in the concrete and cutting the reinforcing bars. These pieces were deposited either on the north bank between the old and new bridges or east of the old bridge. The three vehicles (green Pontiac, grey Toyota, and grey Ford) were recovered in this manner. To get to the truck, the remainder of the west facia girder was cut away and deposited with the other debris. The remainder of the span was just east of the old bridge (Figure 6). Recovery operations were then suspended on Thursday until divers could document the location of the west column of Bent 70, which was lying across the truck. Figure 7 shows the pier cap of Bent 71. The west column extended from the pier cap to the left across the truck. The front left truck tire is visible in Figure 7 and the front right hub is located to the right with the front axle in between. The back wheels of the truck were on Span 78 near where the diver is standing. Friday morning, divers from Collins Engineers, Inc., recorded the location of the column (see underwater survey). The column was then lifted off the truck, and the truck was hoisted onto a trailer. Recovery was complete by Friday afternoon.

**Data Gathering**

The major sources of background information were the Tennessee Department of Transportation (TDOT), the U.S. Geological Survey (USGS), and the Corps of Engineers (COE). An additional source of information was Herb Murphy, a diver. The TDOT provided the most recent inspection report (1987) both of the old and new bridges and full-sized bridge plans. These documents were the primary reference documents used during the week. Later, all existing inspection reports (of 1971, 1979, and 1985) were provided along with the hydraulic study for the reach.

Harry Doyle, Jr., Chief of the Memphis subdistrict of USGS, met with the team on site and negotiated a statement of work for a stream stability study of the reach of the Hatchie River in the vicinity of the bridges. Findings of this study are discussed later. It was noted that the flow was out of the main channel for the entire week. It was later determined that this flood was not a major event and had a recurrence interval of less than 2 years. Overbank flow is typical of this reach of the Hatchie River, and these types of flows are typical much of the time between November and May of each year. Overbank flow at this site is expected to be sustained for months and does not recede in a few days as with typical riverine flooding. A USGS survey crew was observed on site during the week taking velocity and cross section measurements.

The COE, Memphis office, operates a recording gauge mounted on Pier 6 of the old bridge. The COE provided printouts of daily stages and discharges from 1939 through April 3, 1989. In addition, the COE provided all existing aerial photography of the site. The flow data and aerial photography are discussed later.

Herb Murphy, a local diver, assisted in recovering bodies, recovering vehicles, and doing underwater reconnaissance of the collapsed spans. In addition, he was hired by TDOT to perform underwater inspection of the new bridge. He helped the team identify relative locations of vehicles and major bridge members. He briefed the divers from Collins Engineers, Inc., and assisted in the underwater survey of bridge members.

**Bridge Inspection**

The team interviewed the TDOT bridge inspection crew that prepared the 1987 bridge inspection report. The crew chief described the step-by-step procedures used during the inspection. They noted the soundings taken around Bent 70 (Figure 8) and described how the scour depths that are shown on the elevation view of Bent 70 (Figure 9) were determined. Apparently, a range pole was used to locate the top of footing about 1 ft underwater and stream bottom about 7 ft underwater. The footing was determined to be 5 ft thick, probably by probing. The scour depth was then calculated to be 1 ft. Because the plans show the footing to be 3 ft thick, the actual scour depth below the footing was 3 ft at the time of inspection.

The inspectors confirmed that drift had accumulated on Bents 70 and 71. The reproductions of the photographs in the

**FIGURE 6** Span 79 debris removed.

**FIGURE 7** Location of truck wreckage.
FIGURE 8 Soundings at Bent 70 (NTSB 1990).

inspection report were not clear enough to see the drift. The inspectors also confirmed the following two maintenance recommendations in the 1987 report:

1. Clear drift, and
2. Protect Piers 5 through 7 and 70 from scour.

Similar recommendations are also contained in the 1985 inspection report that was obtained subsequently. All existing inspection reports before 1985 were also reviewed, but no others contained similar recommendations.

Site Reconnaissance

Messrs. Thompson and Jones, with the assistance of the TDOT inspection crew, used the TDOT boat to assess the Hatchie River main channel using a black-and-white fathometer and a sounding weight. Cross sections were taken upstream, downstream, and at the bridges. The channel was determined to have steep banks and have water depths of 15 to 18 ft on the inside of bends and 20 to 25 ft on the outside of bends. The depth of flow in the trees at the banks varied from 6 to 8 ft. Soundings at Pier 7 indicated flow depths of about 22 ft. This would put the bottom about 39 ft below the pier cap. The total height of Pier 7 is 46 ft 8 in. Therefore, Pier 7 was assessed as safe. This assessment was later confirmed by divers from Collins Engineers, Inc. The location of the north bank in the vicinity of the bridges was established. The bank was between Piers 8 and 9 of the new bridge, about midspan. This location was a concern because Pier 9 is a floodplain pier with footings above the bottom of the stream.

Underwater Investigation

The FHWA DP 80 crew and boat were used on Friday and Saturday to survey the Hatchie River and the collapsed mem-
bers of the old bridge. The crew included divers from Collins Engineers, Inc., who located some of the collapsed bridge members and inspected Pier 7. The DP 80 boat was used both to make a black-and-white fathometer and a subbottom profiler strip chart recording of the bottom.

Collins Engineers’ findings are documented (1). Two figures from that report are reproduced for this summary: Figure 10 is an elevation view of the old bridge in the vicinity of the collapse; Figure 11 is a plan view in the same location. These two figures show the position of the members that could be located.

Figures 9 and 10 have not been updated as the result of a subsequent investigation that was accomplished when the water was only 12 ft deep. This investigation determined that the footings of Bent 70 were located on the stream bottom between Bent 70 and Pier 7. The footings were broken free both from the column and piles and were resting flat on the bottom. A pile stub was accessible on the east footing, northwest corner. This pile was measured to be 11 in. in diameter (standards called for 12 in.). The only other pile found was in the vicinity of the original location of Bent 70, east side. However, this pile was split into three parts and could not be measured. The pile material appeared to be sound. Samples were taken for analysis by the Forest Service, Forest Products Laboratory.

STREAM STABILITY

On the basis of the depth of water where recovery divers were working, and later confirmed by sounding made by FHWA’s bridge inspection demonstration project team, the north bank of the main channel was somewhere between Bent 71, which collapsed, and Bent 72, which remained standing. Figure 12, a cross section of the floodplain and bridge foundations, shows the probable progression of the north bank with time. A short reach of the channel was straightened in 1932 when the old bridge was built to improve alignment of flow through the bridge. The main channel was designed to be between Piers 5 and 6. These piers have the deeper main channel footings that are supported by concrete piles. Pier 7, which was designed to be close to the bank line, has a deep foundation. According to the plans, it is supported by untreated timber piles. The two bents that collapsed had shallower footings and pile cutoff elevations approximately 16 ft higher than the main chan-

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**FIGURE 9** Scour depths at Bent 70 (NTSB 1990).

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nel footings. As the channel bank migrated past Bent 70, the footing and the piles were exposed to the main channel flow. Having piles exposed to the flow is not necessarily a critical situation, as there are bridges that are designed to be stable with exposed piles. This particular bridge was not designed that way. For this bridge, the structural integrity of the piers as well as the supporting capability of the friction piles were in jeopardy when the bank line migrated past Bent 70.

The USGS study of stream stability of the Hatchie River in the vicinity of the old and new bridges (2) indicates that the narrowing of the floodplain by the new bridge in 1974 caused contraction scour (in the form of widening) to occur in the channel in the vicinity of both bridges. The widening is demonstrated by plotting the channel width versus time (Figure 13). The USGS study indicates that the discharges during February and March were not abnormal. The discharge at the time of collapse was approximately 8,600 ft³/sec, and this was not the peak of this flood event. The peak occurred 2 days later, on April 3, and was about 11,900 ft³/sec. This peak has a recurrence interval that is less than 2 years. In fact, it is likely to occur every year. The water surface elevation at the time of collapse was approximately 254.3 ft, and the peak was about 0.7 ft higher according to COE gauge records.

In order to determine if the channel widening or migration was either local to the bridge or occurring throughout this reach of the Hatchie River, a study was made of available aerial photography.

ANALYSIS OF AERIAL PHOTOGRAPHY

The Memphis district of the COE furnished aerial photos that covered the period from 1948 to 1984. Because many of the streams in Western Tennessee are unstable and migrate with time, significant changes in the river patterns were expected, but this instability was not the case. The Hatchie River is a stable stream. Many of the channel patterns that were evident in 1948 were still clearly visible in the 1984 photographs. Figures 14–19 are the aerial photos for 1948, 1973, 1974, 1976, 1979, and 1984, respectively. The US-51 bridge was slightly off of the 1948 photo.

The conclusion that the Hatchie River is stable was made after comparing the photographs. First, a reach of channel was selected for comparison. Because the railroad line was a common fixed feature on all the photos, it was used as a reference. The photographs were reduced and the river reach in the vicinity of the railroad was compared using the pho-
FIGURE 11  Plan view of collapsed spans.

FIGURE 12  Probable channel migration.

FIGURE 13  Channel widening.
FIGURE 14  Aerial photograph, Oct. 13, 1948 (channel $Q = 642 \text{ ft}^3/\text{sec}$, floodplain $Q = 0$).

FIGURE 15  Aerial photograph, April 2, 1973 (channel $Q = 9,218 \text{ ft}^3/\text{sec}$, floodplain $Q = 18,420 \text{ ft}^3/\text{sec}$).

FIGURE 16  Aerial photograph, Oct. 17, 1974 (channel $Q = 942 \text{ ft}^3/\text{sec}$, floodplain $Q = 0$).

FIGURE 17  Aerial photograph, Nov. 4, 1976 (channel $Q = 2,060 \text{ ft}^3/\text{sec}$, floodplain $Q = 0$).
FIGURE 18 Aerial photograph, March 6, 1979 (channel $Q = 7,001 \text{ ft}^3/\text{sec}$, floodplain $Q = 2,653 \text{ ft}^3/\text{sec}$).

FIGURE 19 Aerial photograph, Dec. 3, 1984 (channel $Q = 2,968 \text{ ft}^3/\text{sec}$, floodplain $Q = 1,289 \text{ ft}^3/\text{sec}$).

tographs of 1948, 1973, 1979, and 1985 (see Figure 20). The 1985 blowup of a small-scale aerial photograph was substituted for 1984, because the channel was clearer.

After reviewing Figure 24, it is clear that the river patterns on each side of the railroad line, which shows up on all the photos, changed little during that 37-year period.

In summary, the aerial photographs indicate that the Hatchie River was an unusually stable stream for western Tennessee. The channel migration that did occur was confined to the vicinity of the bridge (see Section 4) and is not readily discernible from a systematic study of the aerial photographs.

MODEL STUDIES

The FHWA was asked by NTSB to conduct a hydraulic model study of Bent 70. A study (3) was carried out at the FHWA Turner Fairbank Highway Research Center, Hydraulic Laboratory.

The study determined that the depth of scour for Bent 70 with the piles exposed (Figure 21) is 3.3 ft at the center pile of the upstream footing (Figure 22). The scour is about 40 percent less at the downstream footing. The model was verified by determining the scour for the square column and comparing this value (4.3 ft) with the value (5.1 ft) obtained from the pier scour equation in FHWA's Technical Advisory TS140.20, Scour at Bridges. The equation used was the Colorado State University (CSU) equation for scour at solid shaft piers.

Debris was added to the piles to simulate accumulated drift. The debris was not dense and did not appreciably increase the scour depth. In practice, if the debris was a dense clump or perhaps a solid tree trunk, the scour hole could have been much deeper.

FOUNDATION ANALYSIS

The foundation analysis was documented by Dimaggio (4). The analysis was accomplished for Bent 70 assuming that the pile material was Douglas fir, that the piles used had a 12-ft butt diameter and an 8-in. tip diameter, that the bottom was at Elevation 231, and that the piles were 20 ft in length.

The analysis indicates that with these conditions and with a little more than 4 ft of local scour, the piles do not have sufficient axial load capacity and could settle. Therefore, this is the likely mode of failure of Bent 70.

If the pile material is sound, neither lateral pile capacity nor pile buckling is a likely mode of failure. However, depending on the actual unsupported pile length, the condition of the pile material, the size of pile, and the type of pile material, these conclusions may change. For example, a pile buckling failure could occur if the pile diameter is reduced 25 percent from 12 to 9 in.

Bent 9 of the new structure was also analyzed because the north bank is approaching this bent. Bent 9 was determined to be close to unstable for the conditions outlined. Therefore, the floodplain bents of this structure should have countermeasures to protect the foundations from scour.
FINDINGS AND RECOMMENDATIONS

The following observations are preliminary and may change with subsequent findings from the recovery of the bridge wreckage that is scheduled for December or from the NTSB hearings that are scheduled for November 28 and 29.

Finding. The floodplain pier foundations were located at a higher elevation than the channel pier foundations and the channel banks were unconstrained. Either of those conditions by itself poses no particular risk if the stream is stable. However, in combination with an unstable stream reach, the foundation in this case was at risk.

Recommendation. Channel pier foundations and adjacent floodplain pier foundations both should be located below the channel thalweg, unless the channel banks are armored or the channel has exhibited long-term stability and can be assessed to remain stable.

Finding. Sounding data were taken for all piers in the channel during regular inspections. This information was not transferred to a cross section plot which included pier location and foundation elevations.

Recommendation. A cross section of the channel should be plotted after each inspection. The plot should include appropriate substructure information. The cross section should be compared to those taken in previous years so that stream changes can be identified. If movement has occurred, it should be assessed by a hydraulic engineer.

Finding. The most recent inspection report identified that the streambank had moved and that scour had occurred below the footing. However, neither the project plans nor other inspection documents identified this as an unsafe condition for this structure.

Recommendation. The critical scour elevation should be identified for unprotected piers and bank migration limits identified for streams without revetment.
REFERENCES


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