Case studies and lessons learned from recent scour-related bridge failures in the United States

CASE STUDIES AND LESSONS LEARNED FROM RECENT SCOUR-RELATED BRIDGE FAILURES IN THE UNITED STATES

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SUMMARY

Bridge failures from scour in the United States in the past 10 years have cost 25 lives, millions of dollars in replacement costs, and many more millions of dollars in the indirect cost of detours, lost commerce, and litigation. As a result of the investigation of the bridge failure over Schoharie Creek, the Federal Highway Administration recommended that all bridges over water in the United States be evaluated as to their vulnerability to failure from scour. In addition, the failures prompted an increase in bridge scour research. Three bridge failures: Schoharie Creek (I-90), the Hatchie River (U.S. 51), and Arroyo Pasajero (I-5) are described, and some of the lessons learned from these failures and the ongoing evaluation program in the United States are highlighted.

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1. INTRODUCTION

There are 575,000 bridges in the Unites States National Bridge Inventory. Eighty four percent of the bridges are over water. Stream instability and scour cause 60 percent of the bridge failures in the United States. Nationally, the annual cost for scour related bridge failures is about $30 million and flood damage repair costs for Federal-aid highways are about $50 million. Three bridge failures from scour in (1) Upstate New York, (2) Western Tennessee and (3) Central Valley California in the past 10 years with the cost of 25 lives, millions of dollars in replacement costs and many more millions of dollars in the indirect cost of detours, lost commerce and litigation illustrate the societal and financial costs of bridge failures. As the result of the investigation into the Schoharie Creek bridge failure all States are required to evaluate the scour susceptibility of all their bridges over water. This paper will briefly describe these three failures and some of the lessons learned from the failures and the States' evaluation program in the past 10 years (1988 to 1998).

2. SCHOHARIE CREEK, NEW YORK (1987) BRIDGE FAILURE

At approximately 10:45 a.m. April 5, 1987, the center span and east center span of the 540-foot-long bridge on the New York State Thruway over Schoharie Creek in Montgomery County, New York, collapsed during a near-record flood (about 1,756 m^3/s). About an hour and a half later, the west center span fell into the water (see Figure 1). One tractor semi-trailer and four automobiles fell nearly 25 m into the river after the first span collapsed, resulting in 10 fatalities.

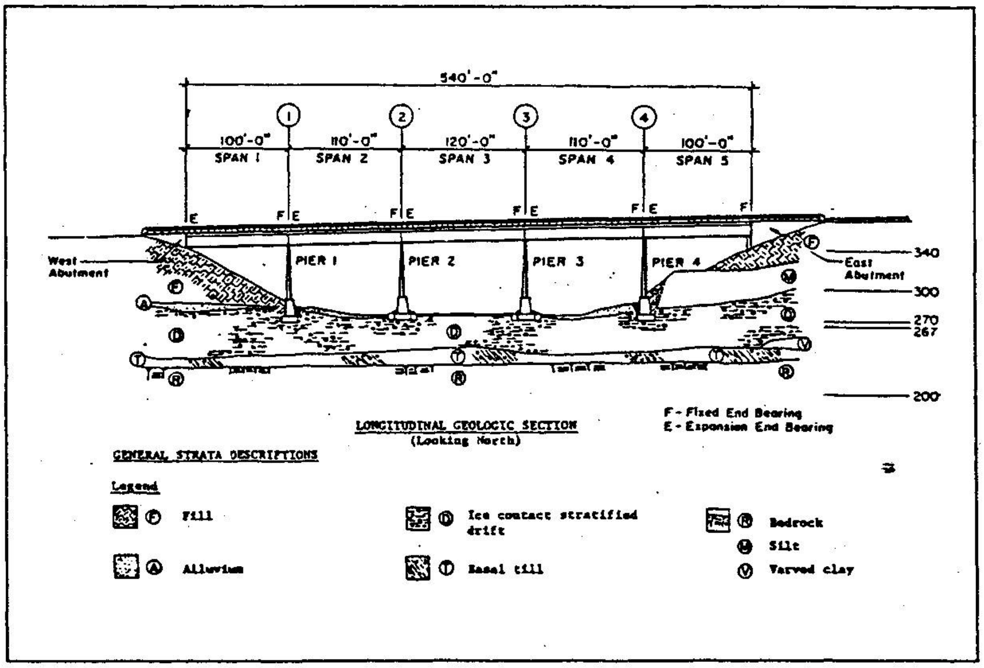

Figure 1. South elevation of Schoharie Creek bridge showing key structural features and schematic geological section.

The substructure consisted of four piers and two abutments. Each pier was a rigid frame (columns and tie beam) supported on a lightly reinforced concrete plinth (pedestal) and spread footing bearing on glacial till just below the streambed. The abutments were founded on piles driven through the embankment fill into the underlying glacial till. The piers were founded on spread footings 1.5 m deep by 5.5 m wide by 25 m long with no piles. The bridge designers assumed that the glacial till substrate was "nonerodible."

After an extensive investigation and detailed analyses, which included hydraulic computer and physical modeling [1], the U.S. National Transportation Safety Board (NTSB) [2] determined that the probable cause of the collapse of the Schoharie Creek bridge was the failure of the Thruway Authority to maintain adequate riprap around the bridge piers, which led to severe erosion (scour) in the soil beneath the spread footings. It was concluded that the 1987 flood alone probably did not cause failure of the Thruway bridge. Rather, the cumulative effect of local scour around pier 3, particularly in the last 10 years, was the most significant hydraulic factor contributing to the failure.

Using the Schoharie Creek bridge and others damaged during the 1987 flooding in New York as examples, an economic study [3] estimated that the indirect costs suffered by the general public, business, and industry because of long detours and lost production time as a result of a bridge failure exceed the direct cost of bridge repair by a factor of five.

3. HATCHIE RIVER, TENNESSEE (1989) BRIDGE FAILURE

On April 1, 1989, at about 8:15 p.m., a section (Bents 70-71) of the 1,280m-long bridge on U.S. Route 51 over the Hatchie River in Tennessee collapsed during a moderate flood (about 224 m^3/s). The accident report revealed that the collapse occurred slowly over a period of about one hour. Four passenger cars and one tractor semi-trailer plunged into the river, resulting in 8 deaths.

The bridge substructure consisted of main channel piers and floodplain bents supported on piles about 6.1 m long (Figure 2). There was about a 4-meter difference in elevation between the pile cap for the main channel piers and the pile cap of the shallower floodplain bents. A post-failure investigation revealed the following rates of channel migration into the north bank of the river at the bridge: 1931 to 1975 - 0.24 m/yr; 1975 to 1989 - 1.37 m/yr; and 1981 to 1989 - 0.58 m/yr [4].

The NTSB determined that the probable cause of the collapse of the northbound U.S. Route 51 bridge spans was the northward migration of the main river channel, which the Tennessee Department of Transportation failed to evaluate and correct. As with the Schoharie Creek failure, the lack of structural redundancy in the design of the bridge spans contributed to the severity of the accident [4].

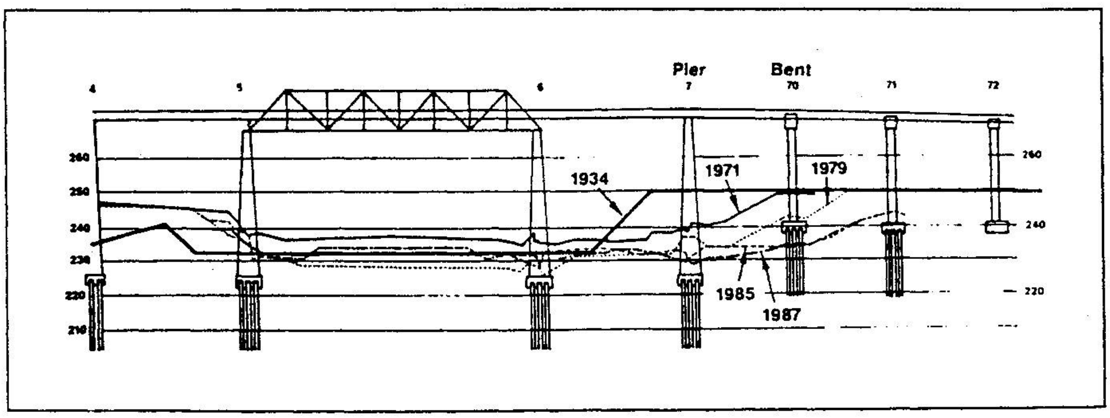

Figure 2. Channel cross section change at the Hatchie River bridge, Tennessee.

4. ARROYO PASAJERO, CALIFORNIA (1995) BRIDGE FAILURE

On March 10, 1995 the I-5 bridges over Arroyo Pasajero near Coalinga, California failed with the loss of 7 lives. The flow was 773 cms with about a 75-year return period. The bridge was constructed in 1967. The foundation of the bridge was 3 bents, each consisting of six 406 mm cast-in-place columns spaced approximately 2.3 m on centers. The abutments were vertical wall with wing walls. The columns were embedded 12.5 m; but the columns only had steel reinforcement for 5.2 m below the original ground. The bents were at an angle to the flow, that in 1995 was estimated to be from 15 to 26 degrees.

A flood in 1969 lowered the stream bed 1.83 m and damaged one column. In repairing the damage a web wall 2.44 or 3.66 m high, 11.6 m long and 0.6 m wide was constructed around the columns to reinforce them. The elevation of the bottom of the web wall was not established. The angle of attack of 15 to 26 degrees was not a factor in local pier scour when the bents were composed of columns but the web wall changed that.

An investigation [5] determined that long-term degradation was 3 m and contraction scour was calculated as 2.6m. Local pier scour, as determined from a model study, ranged from 2 to 2.7 m. The 2.0 m of scour occurred in the model study when the web wall was above the bed and 2.7 m of scour occurred with the web wall at the bed. A minimum potential total scour depth of 7.6 m would result in the column bents having 4.9 m of remaining embedment, but would have exposed 2.4 m of the columns without steel reinforcement. The force of water and debris on the exposed column sections without steel reinforcement caused them to fail.

5. LESSONS LEARNED

These bridge failures, as well as the scour evaluation program and research projects that were initiated after the Schoharie Creek bridge failure resulted in the following lessons learned in the past ten years (1988 to 1998):

- Bridge failures are expensive. In most cases the indirect costs are many times larger than the direct costs of bridge replacement.
- It is dangerous to consider stream bed material as "non erodible." Sedimentary rock may be erodible in high velocity turbulent flow. Even bed rock may be eroded over time.
- Stream instability is an important consideration in bridge evaluation and design, and in many cases stream instability can significantly increase scour potential at a bridge.
- The evaluation of the vulnerability of bridges to scour, design of scour countermeasures and the design of new bridges should be conducted by an interdisciplinary team of hydraulic, geotechnical, structural and bridge engineers.
- Bridges should be evaluated and designed to be safe from the 100-year flood or a smaller overtopping flood if it puts more stress on the bridge. The appropriate geotechnical safety factor should be used in the design for this flood event. The foundation design should be checked for safety from a super flood with a geotechnical safety factor of 1. The magnitude of the 500 year flood is suggested for the super flood.
- Inspection is an important factor in bridge safety and inspectors must be adequately trained to recognize potential stream instability and scour problems.
- Communication between bridge inspectors and decision makers in Highway Agencies is a critical aspect of bridge safety. As noted by the NTSB, "Unfortunately, in the bridge inspection program, itself, there is a lot of paper work being filled out but not, in many cases, adequate follow through to correct the problems being identified."

- The HEC-18 [6] equation for determining local scour at bridges is the best available. However it appears to give excessive scour depths for wide piers.
- Pressure flow scour at bridge piers can increase scour depths by a factor of two to three. Pressure flow occurs when the lower bridge chord and deck become submerged. Preliminary methods for estimating pressure flow scour are given in HEC-18 [6].
- Flume studies and field experience show that the scour on an abutment caused by the upstream horseshoe vortex is twice as deep for vertical wall abutments than for spill through abutments.
- Although some of the flow conditions are different, scour at bridges over tidal waterways can be analyzed using the same equations and methods for non-tidal (riverine) bridges.
- Riprap is not a permanent countermeasure for pier scour. It can be used to protect existing bridge foundations from scour in conjunction with a scour monitoring or inspection program. New or replacement bridges must be constructed with foundations that are stable considering the total scour prism without the use of riprap.
- Instruments were developed for the real time measurement and monitoring of scour depths at piers and abutments by NCHRP Project No. 21-3 [9]. Monitoring of scour depths can be used to determine when scour at a bridge foundation becomes critical enough to close the bridge.

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