Case Histories of Scour Problems at Bridges

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ABSTRACT

Ten case histories of scour problems at bridges are presented to provide a review of the various factors contributing to the problems, corrective actions taken, and the influence of the events on current design practices. Designing bridge foundations to resist scour is still a technical area that requires engineering judgment by experienced bridge and hydraulic engineers, and evidence indicates that additional attention to designing for scour is needed. Analyzing case histories is encouraged as a means of understanding the conditions and events that contribute to bridge scour and ways to avoid or alleviate scour problems.

Scour is an elusive subject because of its complexity. Formulas and mathematical models are still based primarily on theoretical approaches and laboratory tests because of the lack of verifiable field data. Accurate field measurements have been difficult to obtain because of the severe three-dimensional flow patterns that occur at bridges during flooding, and the problems and costs associated with recording instruments or with attempts to get skilled personnel at bridge sites during periods of peak flow.

The stream characteristics, bridge constriction flow pattern, soil and water interaction, and resulting scour will be unique for each bridge crossing as well as for each flood. The evaluation of scour potential at a bridge site, therefore, remains more of an art than a science, requiring a background in river mechanics along with additional inductive skills for making field investigations.

The current approach and emphasis given to evaluating scour varies considerably among highway agencies. Some agencies support highly qualified staffs that make detailed field and office evaluations of scour, whereas others rely on design rules of thumb, with or without the benefit of a field site review.

How much time and effort should be devoted to field and office studies of scour in the design of a bridge? What constitutes a reasonable scour study? What data need to be collected and how should they be analyzed? Engineers tend to respond to these questions with a level of effort commensurate with the perceived risk involved at each bridge crossing. Constraints such as time schedules, budgets, and available personnel may also influence decisions regarding the level of effort that should be applied.

One approach to answering these questions might be: Do bridges perform satisfactorily under design conditions? This may be a tough question to answer because the hydraulic design load is rarely applied. Designers, therefore, often do not have feedback to assess the effectiveness of their designs. This point needs to be emphasized because of the almost unbelievable energy and force of rampaging flood waters.

What should the objective be for accommodating the design hydraulic load? The principles of economic (risk) analysis recognize that bridges and their approaches may be overtopped occasionally without severe damage and that designs that provide for overtopping of the roadway may be economically desirable. These same principles are applied, however, with the assumption that bridges will be well founded and will not suffer major scour damage or settlement from floods well in excess of those anticipated in the bridge design. This approach to foundation design is based on the concept that incremental costs to provide for scour protection for rare events are small in comparison with the consequences of bridge failure.

How well do our nation's bridges compare with this standard? Do they collectively withstand rare floods without damage from scour? Unfortunately data are not collected systematically so that a conclusive answer can be given to this question. The evidence cited in the paragraphs that follow indicates that significant numbers of bridges might be expected to experience distress from scour during future flood events.

A 1973 study for the Federal Highway Administration (FHWA) (2) analyzed 383 bridge failures caused by catastrophic floods and reported that 24 percent of the failures involved pier damage, and 72 percent involved abutment damage. Many of the bridges surveyed, however, were small, single-span structures that failed during Hurricane Agnes in 1973.

A second more extensive study reported by FHWA (1) in 1978 indicated local scour at bridge piers to be a problem about equal to that experienced at abutments. The most common problems included (a) local scour at bridge piers and piled up debris and drift and (b) damage to riprap and erosion of abutment spillthrough slopes with or without the exposure of the pile-supported footings.

FHWA also reported that damage to bridges and highways from major regional floods in 1964 and 1972 amounted to about $100 million per event, and the average loss during this period was estimated at $50 million a year (2). A recent review of FHWA expenditures on emergency relief (ER) projects indicates that flood damage to bridges and highways has been averaging about $75 million annually. This represents only a portion of the total costs to highway systems caused by floods because it includes only highways in the federal-aid system that are involved in declared emergencies. Furthermore, it does not include indirect costs to the public due to temporary closures and detours.

Approximately 85 percent of the 571,000 bridges in the National Bridge Inventory System are built over waterways. The majority of these bridges span rivers and streams that are continually adjusting their beds and banks. Some of these bridges, especially those on the more active streams, can be expected to experience future problems with scour as a result of the natural processes that cause realignment of streams.

CASE HISTORIES

The case histories that follow have been selected to illustrate the types of problems that need to be identified and accounted for in designing bridge abutments and piers. Some of these examples also help to illustrate the difficulty of identifying potential scour problems at the design stage.

State and FHWA bridge and hydraulic engineers have been helpful in supplying information and commentary regarding these case histories. Their assistance is gratefully acknowledged. Continued reporting of future case histories through forums such as TRB is highly desirable to keep designers informed about problems and solutions to scour problems at bridges.

Background

Most transverse flood-plain encroachments involve a combination of highway embankment and bridges and create a constriction in the flood plain for peak flows (Figures 1 and 2). Flow velocities through bridge constrictions are normally greater than the upstream and downstream channel velocities. This difference helps to establish conditions for scour. Scour is commonly classified as (a) general scour or constriction scour (Figures 3 and 4), (b) local scour (Figures 5 and 6) at piers or abutments, and (c) lateral erosion (Figures 7 and 8). Lateral erosion is commonly caused by realignment of the stream and erosion of its banks in the reach of the bridge crossing. The following case histories illustrate the consequences of these types of scour phenomena.

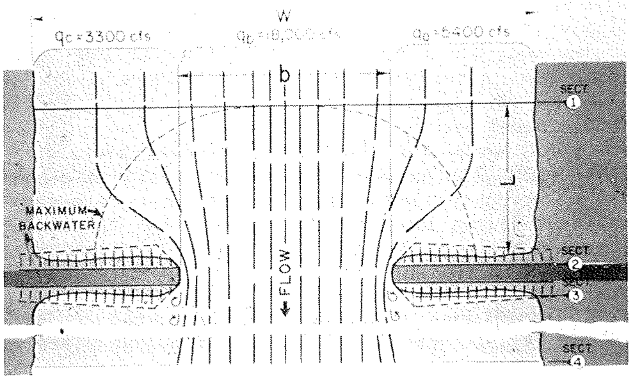

FIGURE 1 Flow lines for a typical stream crossing.

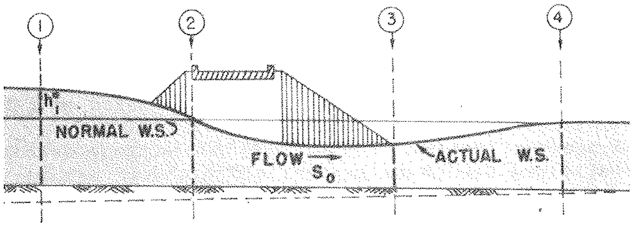

FIGURE 2 Illustration of water surface profile through a bridge constriction.

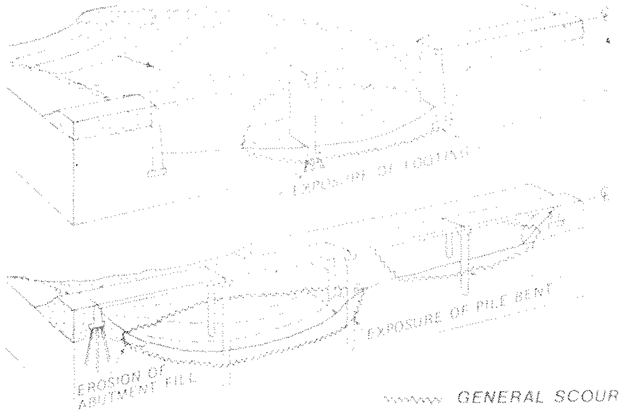

FIGURE 3 Diagram of general scour at a bridge crossing.

I-29 Bridges Over the Big Sioux River Near Sioux City, Iowa

The dual Interstate bridges over the Big Sioux River were five-span, (96, 120, 120, 120, and 96 ft) plate-girder designs 556 ft long supported by rein-

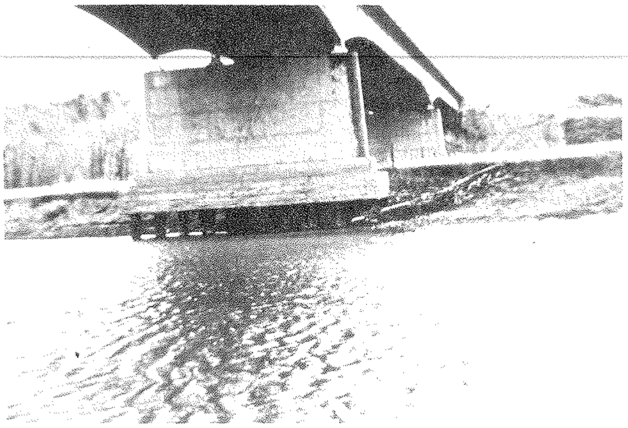

FIGURE 4 Illustration of general scour.

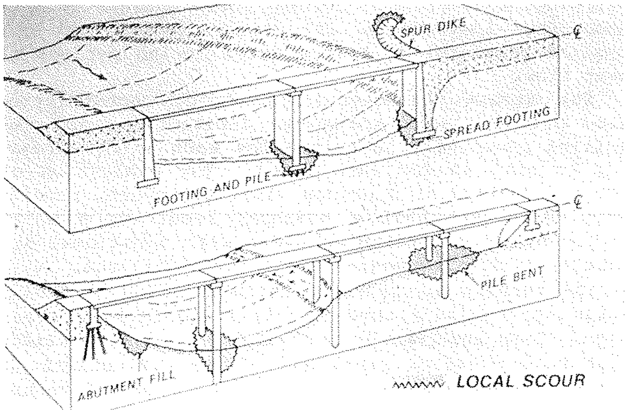

FIGURE 5 Diagram of local scour at bridge piers and abutments.

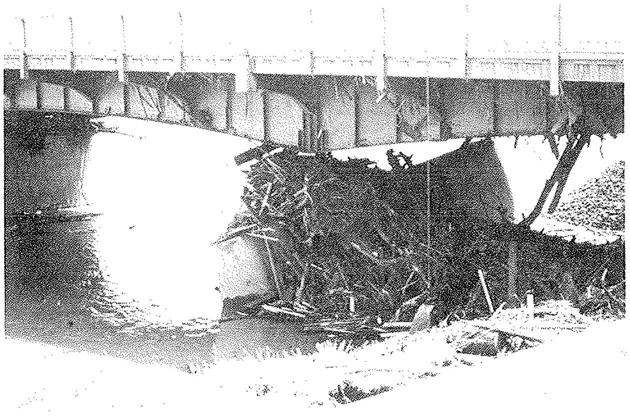

FIGURE 6 Settlement of bridge pier due to local scour.

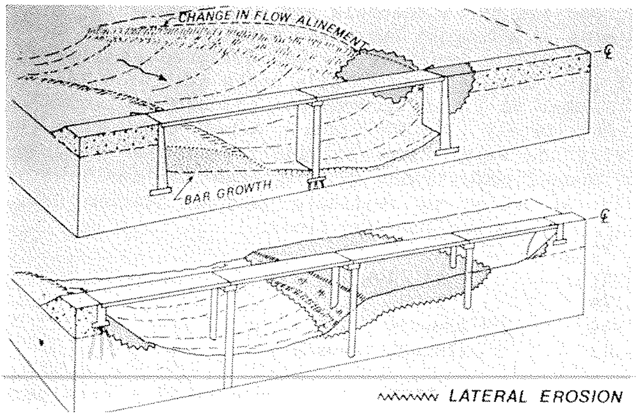

FIGURE 7 Diagram of lateral erosion resulting from realignment of a stream.

FIGURE 8 Illustration of abutment damage caused by lateral movement of stream.

forced concrete piers on continuous footings and timber piles ranging in length from 25 to 34 ft. They were opened to traffic in 1961.

The upstream structure failed during a spring flood on April 1, 1962. Fortunately the bridge was closed immediately after failure so there was no loss of life. Subsequent analysis identified several factors contributing to the failure.

1. Direct cause of failure was due to undermining of pier number 3 by scour.
2. The bridge was located on a bend in the river, and the opening was not normal to the direction of flood flow; instead the flow was at an angle of 25 to 30 degrees to a line normal to the centerline of the crossing. (The design was apparently based on plans for a future channel modification project.)
3. The hydrologic design of the bridge was based on a Q_{50} flow of 42,000 cfs at an elevation of 1,096 ft. The design assumed that the Missouri River, immediately downstream, would also be in flood stage and would create an abnormal stage in the Big Sioux. The 1962 flood was estimated at 54,000 cfs. Flood stage in the Missouri River was about 6 ft lower than the design elevation of 1,096 ft, resulting in a much steeper water surface gradient and a smaller waterway to carry the flows in the Big Sioux River.

This combination of factors resulted in a much smaller waterway to carry the flood flow, a steeper channel gradient and higher velocity, greater flows than anticipated, and finally a bridge with piers skewed adversely to the direction of flood flows.

Corrective Action

All piers of the downstream bridge were underpinned with steel H piles and the scour holes backfilled. The upstream bridge was redesigned and replaced by a three-span structure with single-column round shafts on steel pile supports. Round piers were used to minimize the problem of alignment with the flood flow. This redesigned structure has served satisfactorily and successfully withstood a flow of 81,000 cfs on April 9, 1969.

Significance

Extensive studies were made of the conditions that contributed to the collapse of the Big Sioux River Interstate bridge. A key factor in the success of this effort was the complete cooperation of the state highway agencies of Iowa and South Dakota. The data gathered and conclusions reached from this study were widely disseminated and discussed at that time. The insight gained from the analysis of this failure has been used by many bridge and hydraulic engineers to reinforce the need for careful and reliable hydrologic and hydraulic data in the design of river crossings. These insights include the need to

- Provide a favorable crossing location on a flood plain.
- Align piers with the direction of flood flow and assess the advantages of round piers.
- Carefully coordinate planning for highway projects with channel improvement projects.
- Evaluate performance of a bridge subjected to a range of flows, including flows in excess of the design flow.
- Carefully analyze assumptions for establishing design tailwater conditions and evaluate bridge performance for a possible range of tailwater conditions.
- Evaluate the effect of variable soil conditions in assessing scour.

I-80 N Over the John Day River Near the John Day Dam, Oregon

The main spans of the I-80 N crossing of the John Day River were designed as simple span deck trusses, approximately 200 ft long. The piers in the river were designed to be founded on rock or on piles driven to rock. During construction, the contractor experienced extreme difficulty in excavating the tightly packed or partially cemented gravels in the riverbed. After an evaluation of the problem, including taking borings, the contractor was permitted to place the spread footing on the gravel rather than continue the excavation to rock.

A major factor in this decision was the concurrent construction of the John Day Dam across the Columbia River. Because the I-80 crossing of the John Day River would be located within the pool area behind the dam, it was anticipated that scour would not be a problem once the pool was established. The bridge was completed in September 1963 and the pool behind the dam was expected to be filled within 2 to 3 years. On December 22, 1964, the flood of record occurred on the John Day River before completion of the dam. The river pier foundation experienced serious scour; this resulted in the loss of the pier and two spans.

Corrective Action

A replacement pier, founded on rock, was constructed and the spans replaced at a cost of $880,000. The reconstructed bridge has not experienced any further problems with scour.

Significance

Changes in the field to bridge foundation designs in waterways need to be carefully assessed for the possible consequences of scour. Spread footings placed on alluvial material in a river channel or flood plain are vulnerable to scour. Special design studies to evaluate the scour potential should be made before selection of this type of foundation in a river or flood plain. Rock or pile foundations are normally appropriate for river piers.

Events such as the failure of the John Day Bridge lend credence to the validity of Murphy's Law (if something can go wrong, it will go wrong at the worst possible time). A conservative approach to the design of bridge foundations in waterways is usually warranted.

US-15 Over SR-417 Near Irwins, New York

This highway separation structure was not designed to convey flow because it was at a considerable distance from and above the anticipated flood flows of the Canisteo River. Yet during the Hurricane Agnes flood of 1973 this crossing served as a relief structure for flow in the flood plain. The abutments, which were supported by spread footings, were undermined by the flow through the structure to a depth of 3 to 5 ft and to a maximum lateral distance of about 10 ft under the edge of the spread footing.

Corrective Action

The highway was closed to traffic and temporary timber crib supports were provided for the superstructure. The voids under the spread footing were grouted, the cross section of the local road was restored to its preexisting condition, and the road reopened for normal traffic service. Prompt action by the New York Department of Transportation limited the time Route 15 was out of service to about 4 to 6 weeks. This included the time required to replace the back wall and beam seats of one abutment.

Significance

This case provides an example of the unexpected nature and range of possible problems with structures on flood plains. The damage was unexpected because the highway crossing was not designed as a hydraulic structure and was considered to be above the elevation of anticipated floods. The Hurricane Agnes flood of 1973 was estimated to be greater than the 100-year flood in this region.

New York's decision to restore the preflood condition at the site is viewed as an exercise in risk assessment. That is, the low potential for a recurrence of flooding was not considered to warrant placement of riprap or other special treatment at this bridge.

I-10 Crossing the Pearl River Near Slidell, Louisiana

I-10 crosses the Pearl River flood plain on a series of embankments and bridges; the bridges are designated as the West Pearl bridge, the Middle Pearl bridge, and the East Pearl bridge. The timbered flood plain is several miles wide at the crossing, and the analysis and determination of flood flows across the three channels and the intervening flood plains is a complex hydraulic problem.

The Middle Pearl bridge was designed as a series of 70 ft simple spans on pile bents with pile lengths of about 50 ft to accommodate a flood of record of approximately 125,000 cfs. After completion in 1972, the Pearl River bridges experienced a series of annual peak floods greater than the design flow and, according to available gauging station data, greater than the 100-year flood.

Year	Peak Flow (cfs)
1979	151,000
1980	174,000
1983	225,000 (approx.)

During the 1983 flood, scour undermined a pile bent on the upstream bridge of the Middle Pearl and the bridge settled at this point about 0.5 ft.

Corrective Action

The Middle Pearl bridge was closed and the I-10 traffic was rerouted. A "strong man" or structural frame was placed on the bridge and holes cut in the deck to provide a means of supporting the damaged pier until it could be underpinned.

Additional piles were driven through the holes in the deck and tied in to the existing pile bent. The cost of the emergency repair work was about $81,000. In addition, work on the I-59 bridges about 5 miles upstream of the I-10 crossing will cost on the order of $1.5 million to correct a similar bridge pier scour problem caused by the 1983 flood. Additional studies using a two-dimensional flow model are underway to determine whether additional bridges should be constructed in the Pearl River flood plain.

Significance

The Middle Pearl bridge accommodated flows of the design discharge without damage; however, the bridge was damaged when flood flows greatly in excess of the design occurred. These recent floods have been studied with the conclusion that their occurrence is random in nature and is not accounted for by any identifiable changes in the watershed since the bridge was built. This case illustrates the potential benefits of designing for scour on the basis of an economic analysis that may justify foundation designs for flood flows greater than are used in sizing the waterway of the bridge.

Another interesting aspect of the 1983 flood was its effect on the fendering system for protecting piers from navigational traffic. The fendering system for the West Pearl bridge collected debris and presented an obstacle to the passage of the flood flow. Scour depths at the pier were increased to the point where they became a matter of concern to the state. Increased nationwide attention is now being given to the need for greater protection at bridge piers on navigable waterways. When such systems are provided, they should be carefully evaluated for their influence on local pier scour.

SR-85 Over the Normanskill, Albany County, New York

SR-85 crosses the Normanskill on dual two-span steel bridges; the pier for each bridge is located near the center of the stream and founded on piles. The fine-grained layered silt soils in this region are unstable and slides are common. The Normanskill is a steep fast-rising stream, and the bridges experienced several significant floods; subsequent scour at the center pier reached depths of up to 10 ft.

The scour also undermined the riprap on the south abutment slope and caused sluffing of the backslope in this area.

Corrective Action

Polyfilter woven fabric (70 mesh) was placed on the streambed and banks upstream of and through the SR-85 crossing. Medium stone fill was then placed over the filter cloth to hold it in place and to protect the banks, the spill through abutments, and the piers from the scouring velocities of the Normanskill. A lightweight soil was used to backfill the south abutment slope. This work was done in 1970 at a cost of $70,000 and is considered to be completely successful because no further problems have been experienced at this location. Installing the filter cloth in the bed of the Normanskill was difficult because of the unstable bank and abutment slopes and the fast moving water.

Significance

Selecting the proper type of filter cloth and placing it carefully on the streambed and banks is considered to be a major factor in the success of this repair effort. Also, where feasible, a more desirable alternative to placing a pier near the center of a small, fast-moving stream may be a three-span arrangement that removes the pier obstruction from the center of the channel and facilitates passage of flood waters and debris.

SR-33 Crossing the Homochitto River Near Rosetta, Mississippi

During a period extending from the 1930s to the 1950s, the U.S. Army Corps of Engineers did considerable work on channel modifications to the lower Homochitto River. One reach of the river near Deloroso was reduced from a 20-mile meandering channel to a 9-mile channel with a relatively straight outlet to the Mississippi. The river responded to these changes by degrading its bed (up to 19 ft near Deloroso). At Rosetta the river changed from a slow moving 96-ft wide channel in clay to a 328-ft wide channel in sand, which has meandered over a 3,000-ft flood plain (6). The consequences have been severe to highways and facilities crossing the Homochitto and its tributaries, and damages and bridge replacement costs are approaching $10 million.

Headcutting as a result of channel modification projects is a relatively common problem on streams near the Mississippi River. Similar problems are affecting bridges over the Obion River and its tributaries, the Forked Deer River and its tributaries, and probably other channelized streams in western Tennessee (4).

Corrective Action

In 1974 the SR-33 bridge collapsed and the Mississippi State Highway Department spent $8,000,000 to construct a new 1,500-ft bridge. The new bridge was designed to span a major portion of the flood plain rather than to try to stabilize the existing channel banks, and the north abutment was designed as a pier so the bridge could be lengthened in the future. Attempts to control degradation and meandering of the channel have been generally unsuccessful. The channel moved laterally a distance of 300 ft during the 1974 flood that destroyed the bridge.

Significance

This case provides a graphic illustration of the severe consequences that can result from channel modification projects. When the flow regime of a stream is changed by steepening the stream slope, aggradation and degradation of the streambed and lateral movement of the banks can be expected to occur upstream and downstream over an extended period of time as the stream attempts to readjust to the changed conditions. Many bridges have failed because of headcutting of unstable streams.

It is extremely important that unstable streams like the Homochitto be identified during design so appropriate measures can be incorporated in the design to protect the structure from anticipated scour. Field reviews of proposed bridge crossings are an important element of the design process.

There is, as yet, no final resolution of the problem at this site. The north abutment and approaches may still be vulnerable to attack by the river during future floods.

I-10 Crossing the Gila River, South of Phoenix, Arizona

In October 1983, heavy sustained rains in Arizona and subsequent flooding damaged many highway bridges, including several Interstate structures. The south approaches to the I-10 crossing of the Gila River were breached and several hundred feet of embankment were removed by the floodwaters.

The loss of embankment is attributed primarily to surface mining in the Gila River flood plain just downstream or west of the I-10 crossing. When the floodwaters overflowed the stream banks of the Gila and entered the depressions created by the surface mine, the flow pattern in the river changed abruptly. A significant portion of the floodwaters was diverted to the south, into the mining area, and severe degradation and headcutting began almost immediately. When the headcutting reached the highway, it undermined the embankment and abutment backfill, cutting the highway in two but leaving the abutment undamaged.

Corrective Action

Even before the floodwaters receded, state highway personnel had begun to repair the damage. Traffic was moving across the Gila River in less than 10 days. Quarry stone was brought in and placed to a depth of 6 to 8 ft to bring the embankment above the receding floodwaters and to provide a solid base for the embankment fill. The rest of the fill was then placed and asphaltic concrete pavement used on the approaches up to the bridge abutment. These temporary repairs cost about $700,000 in ER funds. Additional costs for permanent repairs and channel realignment are anticipated over the next few years.

Significance

Sand and gravel mining operations can present a hazard to highway facilities, especially in some of the western states. Existing legislation provides for few controls on surface mining operations, leaving transportation facilities and river control structures vulnerable to the unstable soil conditions created by mining operations. Millions of dollars are being spent to protect or repair highway bridges from the effects of mining, as in the present example, and such efforts often provide only temporary relief.

Lacking effective statewide legislation to control mining operations, state highway agencies may have few options other than to (a) repair and rehabilitate in an attempt to protect against anticipated scour (e.g., drop structures) or (b) buy easements to protect structures from the unstable soil conditions of surface mining operations. Additional efforts are needed at the state level to develop legislation that provides for reasonable protection of bridges and other public works facilities from surface mining operations.

SR-28 Over Esopus Creek Near Kingston, New York

An inspection in 1982 revealed that a scour hole had formed at pier 1 of this 223 ft, four-span prestressed box beam bridge. The main channel of the stream had shifted to the east about 50 ft so that flows impinged on the pier at an angle of 15 to 20 degrees and a scour hole 5 ft deep had formed.

Corrective Action

The pier foundations are supported by cast-in-place piles 20 to 30 ft long, so the structure was not considered at the time of the inspection to be in immediate danger of settlement or damage due to the developing scour holes. The stream channel was realigned for a distance of about 300 ft upstream to reestablish a smooth flow pattern through the bridge. The scour holes at the piers were filled in with stone. The stream is being carefully monitored by maintenance personnel. If the scour holes recur, consideration will be given to placing heavy stone fill (minimum 150 lb stone) in the scour hole up to the level of the top of the pier footing. The costs of the corrective action to date have been relatively low, consisting primarily of personnel and equipment time for state maintenance forces. Scheduling of corrective work was affected by the need to obtain approval from environmental protection agencies.

Significance

The strict environmental requirements for work in streams, especially good fishing creeks like the Esopus, may present a problem when attempting to correct deficiencies under emergency or near emergency conditions. Highway agencies need to develop special working arrangements with the state and federal regulatory agencies so corrective work can be expedited when a severe scour problem occurs.

In this instance, immediate action was taken to get knowledgeable people from the state central office and regional office to inspect the problem and agree on a solution. A response of this type is most important and deserves special emphasis and recognition. Some bridge failures might have been averted if greater attention had been given to minor scour damage caused by smaller floods before scour damage by the major flood destroyed the bridge.

The National Bridge Inspection Program provides a positive means for identifying incipient scour problems. It is important that bridge inspectors conduct a thorough examination of the waterway piers and abutments during the bridge inspection.

SR-121 Crossing the Mackinaw River Near Peoria, Illinois

During the period 1957 to 1981, following construction of the bridge, a pronounced meander developed upstream, causing the river to move laterally a distance of about 200 ft toward the north abutment. The piers, originally skewed 20 degrees to line up with a straight channel reach, were now receiving flood flows at an adverse angle. One overbank pier experienced severe scour caused by the angle of attack and piled up debris. The scour exposed the pier footing and half the length of support piling.

The development of the meander was attributed to clearing of trees and construction of levees for farming in the vicinity of the bridge. The drainage area of the Mackinaw River is approximately 1,000 square miles at this point. A series of heavy rains in 1980 and 1981 accelerated the bank erosion and lateral movement of the stream toward the north abutment.

Corrective Action

During the winter of 1982, the Illinois Department of Transportation constructed a series of nine stone training dikes or wing dikes of varying lengths along the outside bends of the river for approximately 1000 ft upstream of the bridge. The largest dike, placed near the north abutment, was 140 ft long. Fill was placed behind this dike to restore the cross section near the bridge to the approximate dimensions of the original plan.

The work was designed under emergency conditions to construct the dikes before the spring floods. The biggest problem was obtaining approval of the Section 404 permits for work in the river. The dikes were designed and constructed at a cost of $300,000 using guidance provided by the U.S. Department of Transportation (5). The dikes have been tested by several large floods over the past 2 years and they are performing as planned.

Significance

Early and expeditious action was taken by the state to correct a developing problem. The state chose to spend a significant amount of money ($300,000) to attempt a permanent solution to stopping the development of the meander instead of merely treating the scour at the piers themselves.

Approximately 85 percent of the nation's half-million bridges are over waterways, and it is to be expected that significant numbers of the bridges each year will be subject to potentially severe scour conditions as the streams they cross adjust their bed and banks over time. A careful inspection program and timely corrective action of identified problems are needed to avoid damage to the bridges from scour. Perhaps the most difficult aspects of this problem are the decisions of (a) when to take action and (b) how extensive the repairs need to be.

Debris and ice can have a significant effect on local scour at bridge piers and result in greater scour depths than might be predicted by existing scour formulas.

I-5 Bridge Over the Toutle River Near Castle Rock, Washington

I-5 crosses the Toutle River on a single-span (309 ft) tied-arch steel bridge with vertical abutments. The Toutle River has a steep gradient, flows with high velocities, and carries a tremendous amount of drift and debris from the slopes of Mount St. Helens. In the design of the I-5 bridge, these factors were a consideration in providing a hydraulically efficient opening. The north abutment was founded on piles driven to rock, and the south abutment was founded directly on rock. The construction was completed in 1969.

On May 18, 1980, the Mount St. Helens eruption created a tremendous discharge of mud, water, and debris roughly estimated at three times the previous flood of record. Few bridges were able to survive this event. Two upstream bridges that did remain were the Coal Bank bridge (Route 504) over the Toutle River and the Kidd Valley bridge over the South Fork of the Toutle River. In each case, one of the road approaches to the bridge was low so that flow-on of the flood plain overtopped the roadway and relieved the pressure on the bridge.

The I-5 and SR-99 bridges both withstood the flood even though almost all the flow had to pass under these bridges. This is attributed to their favorable hydraulic flow characteristics and that both bridges were founded on rock or on piles driven to rock. The I-5 bridge experienced damage to the riprap slope protection at both abutments, some minor pavement damage near the south abutment, and damage to several structural support braces on the superstructure caused by battering from debris.

Corrective Action

Traffic was temporarily detoured to the west for more than 100 miles (one way) until damage to the bridge was evaluated. Because the damage was minor, the bridge was put back into use almost immediately so that I-5 could serve as a major transportation corridor for the recovery efforts following the Mount St. Helens disaster. Heavy rock riprap was replaced around both abutments. The cost of the repairs amounted to approximately $200,000 in ER funds.

Significance

The design features associated with the I-5 crossing of the Toutle River that enabled the bridge to pass a flood of major proportions while suffering only minor damage are

- A hydraulically efficient opening with no piers in the river and generous vertical clearances above the river, offering minimal obstruction to the flood flows and the tremendous volume of debris in the river, and
- Both abutments are solidly tied into or founded on rock.

The only minor bridges on the Toutle River surviving the flood were those with low road approaches. Overtopping of the road approaches relieved the flood pressure on the bridges. This is considered to have been a major factor in their ability to withstand the flood flow. Consideration should be given to designing road approaches for overtopping, wherever practicable, to provide additional protection for the bridge.

GENERAL CONCLUSIONS

1. The interaction between a bridge and a stream is a complex one involving many variables. Although more is being learned about this relationship, no one proven or standard method or approach is available to a designer at this time.

2. Application of the concepts of economic (risk) analysis can be helpful in assessing the extent of scour protection to be provided. It is almost always cost effective to protect foundations from scour for events with greater recurrence intervals than are used in the design of waterway openings. Damage to bridge and highway elements (e.g., spur dikes, riprap, roadway approaches) from rare flood events can usually be repaired and traffic service restored rather quickly as long as the structure itself is not damaged.

3. Information helpful in analyzing the behavior of a river and its probable effects on a bridge can be obtained from field inspections, aerial photography, flood experiences of nearby structures, and other historical data as well as from scour prediction formulas and mathematical models. All available information should be considered.

4. Some structures that failed during the occurrence of a rare flood had suffered distress during previous events of lesser intensity. It is important that personnel involved in inspecting bridges, assessing flood damage, or making repairs know when to get assistance from bridge and hydraulic engineers. Good rapport between designers, bridge inspectors, and maintenance personnel will help to ensure that adequate repair of scour damage is accomplished so as to minimize the vulnerability of the structures to future flood events.

Designing bridge foundations remains a technical area that requires use of sound engineering judgment to (a) evaluate field conditions and (b) apply state-of-the-art knowledge of river mechanics to arrive at a cost-effective foundation design. Both of these aspects should be applied in design on a case-by-case basis to a degree commensurate with the potential risks and consequences of the loss of the bridge from scour. This approach to design should help minimize the future occurrence of the types of problems set forth in this paper.

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