9.5 Bridge Scour Or Aggradation

9.5.1 Introduction

Reasonable and prudent hydraulic analysis of a bridge design requires that an assessment be made of the proposed bridge's vulnerability to undermining due to potential scour. Because of the extreme hazard and economic hardships posed by a rapid bridge collapse, special considerations must be given to selecting appropriate flood magnitudes for use in the analysis. The hydraulic engineer must endeavor to always be aware of and use the most current scour forecasting technology.

The FHWA issued a Technical Advisory (TA 5140.20) on bridge scour in September 1988. The document "Interim Procedures for Evaluating Scour at Bridges" was an attachment to the Technical Advisory. The interim procedures were replaced by HEC-18 (1991, 1993, 1995). Users of this manual should consult HEC-18 for a more thorough treatise on scour and scour prediction methodology. Companion FHWA documents to HEC-18 are HEC-20, "Stream Stability at Highway Structures," and HEC-23 “Bridge Scour and Stream Instability Countermeasures.”

The inherent complexities of stream stability, further complicated by highway stream crossings, requires a multilevel solution procedure. The evaluation and design of a highway stream crossing or encroachment should begin with a qualitative assessment of stream stability. This involves application of geomorphic concepts to identify potential problems and alternative solutions. This analysis should be followed with quantitative analysis using basic hydrologic, hydraulic and sediment transport engineering concepts. Such analyses could include evaluation of flood history, channel hydraulic conditions (up to and including, for example, water surface profile analysis) and basic sediment transport analyses such as evaluation of watershed sediment yield, incipient motion analysis and scour calculations. This analysis can be considered adequate for many locations if the problems are resolved and the relationships between different factors affecting stability are adequately explained. If not, a more complex quantitative analysis based on detailed mathematical modeling and/or physical hydraulic models should be considered. This multilevel approach is presented in HEC-20 (and Chapter 7, Channels).

Less hazardous perhaps are problems associated with aggradation. Where freeboard is limited, problems associated with increased flood hazards to upstream property or to the traveling public due to more frequent overtopping may occur. Where aggradation is expected, it may be necessary to evaluate these consequences. Also, aggradation in a stream reach may serve to moderate potential scour depths. Aggradation is sometimes referred to as negative scour.

All Bridge Scour Evaluation Reports, either for proposed or existing structures shall be documented in accordance with the "Bridge Scour Evaluation Report Format" found in Appendix C.

9.5.2 General Discussion ConnDOT Bridges

Prior to the early 1950’s, standard bridge design practice was typically to construct short span bridges with shallow spread footing foundations. This design practice was modified in the early 1950’s, particularly for high volume traffic routes, where the substructure was either shallow foundation on competent ledge or deep foundation (e.g. piles, drilled shafts, etc.). It is the population of bridges founded on spread footings or shallow pile foundations that are generally the most vulnerable to scour. The floods of 1938, 1955 and 1982 destroyed many of the bridges throughout Connecticut. Many of these failures were attributed to scour. As a consequence many of the bridges founded on piles survived the large storm events while those founded on shallow spread footings failed. Mapping for the major flood events experienced in Connecticut since 1927 can be found in Chapter 6, Hydrology, Appendix E.

9.5.3 Data Available Through ConnDOT Scour Program

The State of Connecticut has approximately 2373 bridges over waterways that are included in the National Bridge Inspection Standards (NBIS). Incorporating the FHWA guidelines and recommendations to address the potential for scour at a bridge, the Department initiated an ambitious scour evaluation program that has been in place since the early nineties. Below is a summary of the various scour programs conducted by the ConnDOT and the associated data available for the respective projects.

- **USGS Reports** - United States Geological Survey (USGS) conducted scour screenings on all structures not programmed for rehabilitation or replacement. Only structures on the NBIS system were included, (i.e. span widths greater than 6.1m (20 feet)). This screening process did not include culverts or structures with concrete bottom as they were considered low risk. The objective of this effort was to determine the vulnerability of a structure with respect to scour. A qualitative assessment was assigned to each bridge based on foundation information, channel stability, evidence of scour and various other variables compiled in the field. The reports provide a general overview of conditions inspected at the site.

- **Scour Evaluation Reports** - Approximately 300 bridges were evaluated for scour and assigned NBIS ratings under the Bridge Scour Evaluation Program. Each of the structures in this program was hydraulically analyzed. Scour depths were calculated from the hydraulic models. A summary of the field conditions, soil data scour depths and a recommended course of action can be found in these scour evaluation reports.

- **Comparative Scour Reports** - The Comparative Scour Program evolved by combining the information accumulated in both the USGS and Scour Evaluation reports. Remaining bridges to be evaluated in the NBIS system (and not scheduled for a project) were included in this program. NBIS ratings were assigned based on potential scour depths, with a strong emphasis on field review, history of flooding, history of scour and engineering judgement. Potential scour depths were determined by comparing the predicted scour depths of similar bridges included in the Scour Evaluation project. While these reports do not offer the comprehensive scour data found in the previous project, they do provide good information with respect to scour vulnerability, foundation information and scour history.

The data collection effort provided available information discussed above for both bridge replacements and rehabilitation projects. It will be useful in designing the foundation requirements and in developing appropriate countermeasure design. The USGS reports Scour Evaluation and Comparative Scour Reports are located in the Hydraulics and Drainage Section. An additional copy can be found in the Bridge Safety and Evaluation bridge files. Based on the conclusions noted within these documents, all bridges over water have been classified into one of three general categories, Low Risk (NBIS Item 113 rating of 8 or 9), Scour Susceptible (NBIS Item 113 rating of 4, 5, or 7*) or Scour Critical (NBIS Item 113 rating of 3 or below).

* The NBIS Item 113 rating of 7 is reserved for bridge locations at which countermeasures have been installed to mitigate a previous scour problem. If the structure is a clear span bridge

(no piers) and if the countermeasures have been designed in accordance with the procedures contained within HEC-23, the bridge may be considered "low risk." When countermeasures are placed adjacent to piers to correct a previous scour condition, the bridge is classified as "scour susceptible."

9.5.4 Scour Types

Present technology dictates that bridge scour be evaluated as interrelated components:

- long-term profile changes (aggradation/degradation) (See Chapter 7, Channels.)
- plan form change (lateral channel movement) (See Chapter 7, Channels.)
- contraction scour/deposition (HEC-18)
- local scour (See Appendix B and HEC-18)

Long-Term Profile Changes

Long-term stream bed profile changes can result from aggradation and/or degradation.

- Aggradation is the deposition of bedload due to a decrease in the energy gradient.
- Degradation is the scouring of bed material due to increased stream sediment transport capacity which results from an increase in the energy gradient.

Forms of degradation and aggradation shall be considered as imposing a permanent future change for the stream bed elevation at a bridge site whenever they can be identified.

Plan Form Changes

Plan form changes are morphological changes such as meander migration or bank widening. The lateral movement of meanders can threaten bridge approaches as well as increase scour by changing flow patterns approaching a bridge opening. Bank widening can cause significant changes in the flow distribution and thus the bridge's flow contraction ratio.

Contraction

Channel contraction scour results from a constriction of the channel which may, in part, be caused by bridge piers in the waterway. Deposition results from an expansion of the channel or the bridge site being positioned immediately downstream of a steeper reach of stream. Highways, bridges and natural channel contractions are the most commonly encountered cause of contraction scour. Two practices are provided in this manual for estimating deposition or contraction scour.

- Sediment routing practice — This practice should be considered if either bed armoring or aggradation from an expanding reach is expected to cause an unacceptable hazard.
- Empirical practice — This practice is adapted from laboratory investigations of bridge contractions in non-armoring soils and, as such, must be used considering this qualification. This practice does not consider bed armoring and its application for aggradation may be technically weak.

The same empirical practice algorithms used to evaluate a naturally contracting reach may also be used to evaluate deposition in an expanding reach provided armoring is not expected to occur. With deposition the practice of applying the empirical equations "in reverse" is required; i.e., the narrower cross section is upstream which results in the need to manipulate the use of the empirical "contraction scour" equation. This need to manipulate the intended use of an equation does not occur with the sediment routing practice which is why it may be more reliable in an expanding reach.

Local Scour

Exacerbating the potential scour hazard at a bridge site are any abutments or piers located within the flood flow prism. The amount of potential scour caused by these features is termed local scour. Local scour is a function of the geometry of these features as they relate to the flow geometry. However, the importance of these geometric variables will vary. As an example, increasing the pier or cofferdam width either through design or debris accumulation will increase the amount of local scour, but only up to a point in subcritical flow streams. After reaching this point, pier scour should not be expected to measurably increase with increased stream velocity or depth. This threshold has not been defined in the more rare, supercritical flowing streams.

9.5.5 Engineering Judgement – A discussion of the predicted local scour depths at abutments in Connecticut

The magnitude of local scour predicted at abutments is largely dependent upon the discharge intercepted by the abutment and returned to the main channel at the bridge. The predicted scour depths depend on such variables as the abutment shape, sediment characteristics, cross-section of the streambed and overbank areas and the angle of attack. The equations for local abutment scour, as presented in HEC-18, were primarily developed based upon data that has been collected in laboratory flume studies. These studies show that an increase in the projected length of an abutment into the flow increased scour. This result is caused by many factors, including an assumed uniform distribution of flow upstream of the abutment. As such, the discharge intercepted by the abutment in the laboratory is a direct function of the abutment length. This may not be the case in the field where a non-uniform flow distribution is usually experienced upstream of the abutments. This non-uniform flow distribution is caused by such factors as the relative flow depths in the main channel versus the overbank areas, and the significantly higher Manning's values that are usually representative of heavily vegetated overbank areas. The research that has been accomplished to date has not accurately replicated these field conditions. Due to this fact, the abutment scour equations are generally considered to be conservative in nature. It is important to realize that the predicted abutment scour depths would only occur in the field for conditions under which the flume experiments were conducted. The amended local abutment scour equations in Appendix B shall be used when computing local scour for abutments.

9.5.6 Armoring

Armoring may occur naturally if a stream or river is unable to move the more coarse material comprising either the bed or its underlying material. Scour may occur initially but later become arrested by armoring before the full scour potential is reached for a given flood magnitude. When armoring does occur, the coarser bed material will tend to remain in place or quickly redeposit so as to form a layer of riprap-like armor on the stream bed or in the scour holes and thus limit further scour for a particular discharge. This armoring effect can decrease scour hole depths which were predicted based on formulae developed for sand or other fine material channels for a particular flood magnitude. When a larger flood occurs than used to define the probable scour hole depths, scour will probably penetrate deeper until armoring again occurs at some lower threshold.

Armoring may also cause bank widening. Bank widening encourages rivers or streams to seek a more unstable, braided regime. Such instabilities may pose serious problems for bridges as they encourage further, difficult to assess plan form changes. Bank widening also spreads the approach flow distribution which in turn results in a more severe bridge opening contraction.

9.5.7 Scour Resistant Materials

Caution is necessary in determining the scour resistance of bed materials and the underlying strata. With sand size material, the passage of a single flood may result in the predicted scour depths. Conversely, in scour resistant material the maximum predicted depth of scour may not be realized during the passage of a particular flood; however, some scour resistant material may be lost. Commonly, this material is replaced with more easily scoured material. Thus, at some later date another flood may reach the predicted scour depth. Serious scour has been observed to occur in materials commonly perceived to be scour resistant such as consolidated soils and glacial till, as well as so-called bed rock streams and streams with gravel and boulder beds. Certain types of weathered ledge may also be susceptible to scour **(a geologist and/or geotechnical engineer should evaluate the potential for scour within a ledge formation)**.

9.5.8 Scour Evaluation Studies for ConnDOT Projects

<u>New Bridges over Waterways</u>

Level II Scour Evaluations shall be performed for all new bridges over waterways unless one or more of the following conditions apply:

- The bridge has been designed to span the entire floodplain for the superflood (500 year recurrence interval) or the critical design event if less than the 500 year flood.
- The structure foundations will be set directly on sound bedrock.
- The abutment footings will be protected with riprap designed in accordance with the methods outlined in the latest version of Bridge Scour and Stream Instability Countermeasures: (HEC-23) or successor documents. **It should be noted that the use of riprap as the sole means of providing scour protection for new bridges is discouraged and should be used only where it has been demonstrated that alternate, preferred means of designing bridges to be safe from scour related failure are not feasible.** (Refer to the Department's Bridge Design Manual for preferred foundation types).

<u>Reconstructed or Rehabilitated Bridges</u>

Generally, scour evaluations shall be performed for all bridges which are to be reconstructed or rehabilitated where significant capital investment is involved and where the bridge has been classified as scour susceptible or scour critical. A significant capital investment correlates to the following improvement categories:

- Deck replacement
- Superstructure replacement or widening
- Major repairs that involve modification to substructure units

Bridges which have been classified as scour susceptible or scour critical shall have hydrologic, hydraulic and scour evaluations performed which are sufficiently detailed to satisfy all applicable design and permitting requirements. If a detailed (Level II) scour evaluation has already been performed, the designer shall modify the results of this document as necessary to incorporate the "Modified Abutment Equations" contained in Appendix B. All necessary scour countermeasures for scour susceptible or scour critical bridges shall be incorporated into the overall project plans, as appropriate.

Scour evaluations shall not be required where structures to be reconstructed or rehabilitated have previously been classified as low risk under the Department's Bridge Scour Evaluation Program or for scour susceptible bridges which are not undergoing substructure modification and have had countermeasures installed following a Level II study.