9.6 Philosophy

9.6.1 Introduction

Any stream is a dynamic natural system which, as a result of the encroachment caused by elements of a stream-crossing system, will respond in a way that may well challenge even an experienced hydraulic engineer. The complexities of the stream response to encroachment demand that: (l) hydraulic engineers must be involved from the outset in the choice of alternative stream crossing locations, and (2) at least some of the members of the engineering design team must have extensive experience in the hydraulic design of stream-crossing systems. Hydraulic engineers should also be involved in the solution of stream stability problems at existing structures.

This section discusses qualitatively some of the design issues which contribute to the overall complexity of spanning a stream with a stream-crossing system. A much more thorough discussion of design philosophy and design considerations is found in the AASHTO Highway Drainage Guidelines, "Hydraulic Analysis for the Location and Design of Bridges."

9.6.2 Location Of Stream Crossing

Although many factors, including nontechnical ones, enter into the final location of a stream-crossing system, the hydraulics of the proposed location must have a high priority. Hydraulic considerations in selecting the location include floodplain width and roughness, flow distribution and direction, stream type (braided, straight, or meandering), stream regime (aggrading, degrading, or equilibrium) and stream controls. The hydraulics of a proposed location also affect environmental considerations such as aquatic life, wetlands, sedimentation and stream stability. Finally, the hydraulics of a particular site determine whether or not certain federal and state objectives such as floodplain use, reduction of flooding losses and preservative of wetlands can be met.

9.6.3 Coordination, Permits, Approvals

The interests of other government agencies must be considered in the evaluation of a proposed stream-crossing system, and cooperation and coordination with these agencies, especially water resources planning agencies, must be undertaken. Coordination with the Federal Emergency Management Agency (FEMA) is required when a proposed crossing encroaches on a regulatory floodway and would require an amendment to the floodway map. This is a difficult process especially in more developed areas.

Whenever practicable, the stream-crossing system shall avoid encroachment on the floodway within a floodplain. When this is not feasible, modification of the floodway itself and associated floodway maps shall be considered. The process of modifying the floodway can be difficult. If the encroachment causes additional flooding of residential structures, no map revision will be forthcoming. (See Legal Aspects, Chapter 2, Section 2.3 for additional information.)

9.6.4 Environmental Considerations

Environmental criteria which must be met in the design of stream-crossing systems include the preservation of wetlands and protection of aquatic habitat. Such considerations often require the expertise of a biologist on the design team. Water quality considerations shall also be included in the design process insofar as the stream-crossing system affects the water quality relative to beneficial uses. As a practical matter with bridges, the hydraulic design criteria related to scour, degradation, aggradation, flow velocities and lateral distribution of flow, for example, are important criteria for evaluation of environmental impacts as well as the safety of the stream-crossing structures. Environmental consequences of the bridge construction activity must also be considered (see Section 9.2.3).

9.6.5 Stream Morphology

The form and shape of the stream path created by its erosion and deposition characteristics comprise its morphology. A stream can be braided, straight, or meandering, or it can be in the process of changing from one form to another as a result of natural or manmade influences. A historical study of the stream morphology at a proposed stream-crossing site is mandatory. (See Chapter 7, Channels, Section 7.5.) This study shall also include an assessment of any long-term trends in aggradation or degradation. Braided streams and alluvial fans shall especially be avoided for stream-crossing sites whenever possible.

9.6.6 Data Collection

The purpose of data collection is to gather all necessary site information. This shall include such information as topography and other physical features, land use and culture, flood data, basin characteristics, precipitation data, historical high-water marks, existing structures, channel characteristics and environmental data. A site plan shall be developed on which much of the data can be shown. (See Chapter 1, Section 1.6.)

9.6.7 Risk Evaluation

The evaluation of the consequence of risk associated with the probability of flooding attributed to a stream-crossing system is a tool by which site specific design criteria can be developed. This evaluation considers capital cost, traffic service, environmental and property impacts and hazards to human life.

The evaluation of risk is a two stage process. The initial step, identified as risk assessment, is more qualitative than a risk analysis and serves to identify threshold values that must be met by the hydraulic design.

In many cases where the risks are low and/or threshold design values can be met, it is unnecessary to pursue a detailed economic analysis. In those cases where the risks are high and/or threshold values cannot be met, a Least Total Expected Cost (LTEC) analysis should be considered.

The results of a least-cost analysis can be presented in a graph of total cost as a function of the overtopping discharge. The total cost consists of a combination of capital costs and flood damages (or risk costs). Risk costs decrease with increases in the overtopping discharge while capital costs simultaneously increase. The overtopping discharge for each alternative is determined from a hydraulic analysis of a specific combination of embankment height and bridge-opening length. The resulting least-cost alternative provides a tradeoff comparison. If, for example, environmental criteria or constraints due to existing development result in an alternative that is different from the least-cost alternative, the economic tradeoff cost of that alternative can be given as the difference between its cost and the minimum cost provided by a LTEC analysis.

The alternatives considered in the least-cost analysis do not require the specification of a particular design flood. This information is part of the output of the least-cost analysis. In other words, the least-cost alternative has a specific risk of overtopping that is unknown before the least-cost alternative has been determined. Therefore, design flood frequencies are used only to establish the initial alternative. Thereafter, specific flood-frequency criteria such as the 50-year flood requirement for certain interstate highways and the 100-year floodplain requirements for flood insurance should be considered only as constraints on the final design selection. Deviation from the least-cost alternative may be necessary to satisfy these constraints and the trade-off cost for doing so can be obtained from the least-cost analysis.

Risk based analysis does not recognize some of the intangible factors that influence a design. The minimum design that results from this type of analysis may be too low to satisfy the site condition.

9.6.8 Scour

The extreme hazard posed by bridges subject to bridge scour failures dictates a different philosophy in selecting suitable flood magnitudes to use in the scour analysis. With bridge flood hazards other than scour, such as those caused by roadway overtopping or property damage from inundation, a prudent and reasonable practice is to first select a design flood to determine a trial bridge opening geometry. This geometry is either subjectively or objectively selected based on the initial cost of the bridge along with the potential future costs for flood hazards. Following the selection of this trial bridge geometry, the base flood (100-year) is used to evaluate this selected opening. This two step evaluation process is used to ensure the selected bridge opening based on the design flood contains no unexpected increase in any existing flood hazards other than those from scour or aggradation. With bridge scour, not only is it required to consider bridge scour or aggradation from the base flood, but also an even larger flood termed herein as the "super flood.”

Scour prediction technology is steadily developing, but lacks at this time, the reliability associated with other facets of hydraulic engineering. Several formulae for predicting scour depths are currently available and others will certainly be developed in the future. **The designer should strive to be acquainted with the "state of practice" at the time of a given analysis and use engineering judgement**.

First discussion is warranted as to what constitutes the greatest discharge passing through the bridge opening during a particular flood. Even where there are relief structures on the floodplain or overtopping occurs, some flood other than the base flood or "super flood" may cause the worst case bridge opening scour. This situation occurs where the bridge opening will pass the greatest discharge just prior to incurring a discharge relief from overtopping or a floodplain relief opening. Conversely care must be exercised in that a discharge relief at the bridge due to overtopping or relief openings may not result in reduction in the bridge opening discharge. Should a reduction occur, the incipient overtopping flood or the overtopping flood corresponding to the base flood or "super flood" would be used to evaluate the bridge scour.

With potential bridge scour hazards a different flood selection and analysis philosophy is considered reasonable and prudent. The foregoing trial bridge opening which was selected by considering initial costs and future flood hazard costs shall be evaluated for two possible scour conditions with the worst case dictating the foundation design — and possibly a change in the selected trial bridge opening.

First, evaluate the proposed bridge and road geometry for scour using the base flood, incipient overtopping flood, overtopping flood corresponding to the base flood, or the relief opening flood whichever provides the greatest flood discharge through the bridge opening. Once the expected scour geometry has been assessed, the geotechnical engineer would recommend a foundation type. This foundation type would be designed and analyzed in accordance with the governing AASHTO specifications taking into account any stream bed and bank material displaced by scour for foundation support.

Second, impose a "super flood" on the proposed bridge and road geometry. This event shall be greater than the base flood and shall be used to evaluate the proposed bridge opening to ensure that the resulting potential scour will produce no unexpected scour hazards. The "super flood" shall be defined as the 500-year flood or a designated ratio (e.g., 1.7) times the 100-year flood. Similar to the base flood to evaluate the selected bridge opening, use either the "super flood", or the relief opening flood, whichever imposes the greatest flood discharge on the selected bridge opening. The foundation design based on the base flood would then be checked against its ultimate capacity, taking into account any stream bed and bank material displaced by scour from the "super flood".

9.6.9 Preventive/Protection Measures

Based on an assessment of potential scour provided by the Hydraulic Engineer, the structural designers can incorporate design features that will prevent or mitigate scour damage at piers. In general, circular piers or elongated piers with circular noses and an alignment parallel to the flood flow direction are a possible alternative. Spread footings should be used only where the stream bed is extremely stable below the footing and where the spread footing is founded at a depth below the maximum scour computed. Deep foundations (driven piles, drill shafts, drilled piles, etc.) shall be used where it is not practical to use a spread footing foundation. Protection against general stream bed degradation can be provided by drop structures or grade-control structures in, or downstream of the bridge opening. (See Section 9.2.2.)

Rock riprap is often used, where stone of sufficient size is available, to armor abutment fill slopes and the area around the base of piers. Riprap design information is presented in HEC-18.

Consideration should be given to burying riprap under native material to accommodate Fisheries concerns. It should be noted that this is not always possible as the inspectors must be able to determine if it is in place to ensure the substructure unit is protected from the potential scour. Provide a 1.5m (5 ft) shelf for inspection purposes.

Whenever possible, clearing of vegetation upstream and downstream of the toe of the embankment slope should be avoided as it will assist in minimizing scour potential. Embankment overtopping may be incorporated into the design but should be located well away from the bridge abutments and superstructure.

9.6.10 Deck Drainage

A major responsibility of the engineer is to provide for the safety of the traveling public. There is a much greater risk of someone being in an accident on the bridge as the result of wet pavement than there is due to the catastrophic collapse of the bridge due to floods or structural failure.

Improperly drained bridge decks can cause numerous problems including corrosion, icing and hydroplaning. Whenever possible, bridge decks should be watertight and all deck drainage should be carried to the ends of the bridge. Drains at the end of the bridge should have sufficient inlet capacity to carry all bridge drainage.

The design of pavement drainage on the bridge should use the same criteria as the approach roadway. However, it should be noted that an approach roadway with a rural typical section will be more free draining than a bridge deck with parapets where the deck will confine the runoff in a manner similar to a curbed roadway section. Careful attention must be given to spread on the bridge deck.

Where it is necessary to intercept deck drainage at intermediate points along the bridge, the design of the interceptors shall conform to the HEC-12 and HEC-21 procedures.

When deck drainage interceptors are needed, a collection system will be necessary to discharge the runoff. Some considerations for this system are:

- environment concerns for discharging pavement runoff directly into a waterway
- design and maintenance of extensive drain systems attached to the superstructure
- free drops from deck interceptors
- 200-mm (8 in) minimum projection beyond lowest adjacent superstructure component
- provide erosion control under free drops unless outlet from bridge superstructure is more than 12.2 m (40 ft) above ground

9.6.11 Construction/Maintenance

Construction plans should be reviewed jointly by Construction, Environmental Planning and the Hydraulics and Drainage Section to note any changes in the stream from the conditions used in the design. Temporary structures and crossings used during construction should be designed for a specified risk of failure due to flooding during the construction period. The impacts on normal water levels, fish passage and normal flow distribution must also be considered.

The stream crossing design shall incorporate measures which reduce maintenance costs whenever possible. These measures include riprap protection of abutments and embankments, embankment overflow at lower elevations than the superstructure, and alignment of piers with the flow.

9.6.12 Temporary Hydraulic Facilities

Temporary hydraulic facilities include, among other things, temporary bridges, bypass channels, haul roads, or channel constrictions such as cofferdams. Such facilities must be capable of conveying the temporary design discharge without endangering life or property, including the structure under construction. The temporary design discharge for temporary structures and crossings used during construction is determined by the methodology indicated in Chapter 6, Section 6.15, Hydrology for Temporary Facilities.

The temporary hydraulic facilities should be designed or specified so as not to cause roadways to be overtopped or aggravate existing flooding conditions during the temporary design discharge. Hydraulic analysis of such facilities is based on the methods described in this manual. A hydraulic analysis with the temporary facility in place is required and should be compared to an analysis of existing conditions.

A flood contingency plan is required should a storm greater than the temporary design storm occur during construction. This usually starts with the engineer evaluating what path the floodwater would take should the flow exceed the capacity of the temporary system. Some considerations include:

- Is there sufficient relief so that flood levels would not significantly impact surrounding area or cause erosion and damage downstream by sudden release of the floodwater?
- If the roadway would be overtopped, what is the path, where is the low point and what is the approximate depth of flow? Is the overflow likely to cause any significant damage? If traffic is being maintained during construction are there sufficient provisions to close the road to traffic if flooded?
- How long will a temporary system be needed or any obstructions be in place? The probability of flooding increases with the length of time.

The flood contingency plan should be described in the hydraulic report and Attachment L of the DEP permit application.

The need for temporary erosion protection, scour countermeasures and, in the case of temporary culverts, outlet protection should be addressed.

Temporary hydraulic facilities should be shown on the stage construction/water handling plans. See Chapter 3, Design Development, Section 3.7.6 regarding the information to be provided.