Section 39 - Scour At Bridges

39.1 General Criteria

1. In addition to the information presented within this Section, the specific guidance provided in Subsection 2.6 of the *AASHTO LRFD Bridge Design Specifications* should be referred to. As stated therein, the *AASHTO Model Drainage Manual* may be referred to for guidance and references on design procedures and references to hydrologic and hydraulic designs computer software.

   Additionally the following Hydraulic Engineering Circulars (HEC) reports provide guidance that should be used in performing a scour analysis:

   HEC 18 – *Evaluating Scour at Bridges*. Procedures for designing new, replacement and rehabilitation of bridges to resist scour are presented.

   HEC 20 – *Stream Stability at Highway Structures*. Guidance for identifying stream instability and for the selection and design of appropriate countermeasures to mitigate damage to bridges is presented.

   HEC 23 – *Bridge Scour and Stream Instability Countermeasures*. Bridge scour and stream instability countermeasures that have been implemented by various State Departments of Transportation are identified in this Report. Also, design guidelines for the countermeasures are provided.

2. Foundations of new bridges, bridges to be widened or bridges to be replaced, shall be designed to resist scour for a 100 year flood criteria, or a flood of a lesser interval, that may create the deepest scour at bridge foundations. A bridge may be in an inundated condition when the design flood for bridge scour occurs. This shall be referred to as the "Design Flood for Bridge Scour".

   For existing bridges, the design flood criteria shall be the 100 year discharge, or a discharge of a lesser interval that is expected to produce the most severe adverse condition. However, the past history of floods at a particular location shall be evaluated to determine if a greater interval is justifiable to establish a flood discharge rate.

3. The foundation design shall be checked for a 500 year check flood, or if information for a 500 year flood is not available, 1.7 times the discharge rate of a 100 year flood. This shall be referred to as the "Check Flood for Bridge Scour".

39.2 Preliminary Scour Analysis

1. Data Collection and Review Process. To perform a Scour analysis of an existing bridge location or for planning construction of a new bridge, data collection should include the following:

   a. Office Data Collection

      1.) Data on the waterway's history with respect to flooding and, if available, a Preliminary Scour Evaluation Report

      2.) Contract plans, As-built drawings, Aerial Surveys, Drainage area

      3.) Photographic documentation

      4.) FEMA Flood Insurance Studies from NJDEP

5.) Bridge Evaluation Survey & Underwater Inspection Report, if any, from a local owner or the NJDOT

6.) Foundation Reports and Boring logs

7.) Existing Hydrologic and Hydraulic models, if available from NJDEP

b. The NJDOT Structural Evaluation Unit should be contacted for obtaining information and documents on performance of scour analysis of existing bridge structure locations.

2. Identifying Scour Analysis Variables

Specific bridge scour variables or parameters shall be identified for a mathematical scour analysis. Such variables or parameters shall include the following:

a. Hydrologic & Hydraulics Analysis

1.) Hydrologic Analysis – Refer to Subsection 2.6.3 of the *AASHTO LRFD Bridge Design Specifications* for guidance. Determine the drainage area from USGS maps or other appropriate sources. List available flood records. Determine design flood discharge and discharges for other frequencies. Plot flood frequency and stage-discharge-frequency curves for the site.

2.) Hydraulic Analysis – Subsection 2.6.4 of the *AASHTO LRFD Bridge Design Specifications* and Chapter 9 of the *AASHTO Highway Drainage Guidelines Manual* provides guidance in the hydraulic design of a stream crossing. The *AASHTO Highway Drainage Guidelines Manual* defines technical aspects of hydrologic and hydraulic design and presents a stream crossing design procedure that may be followed. The following guidance should also be used for a hydraulic analysis.

a.) In the event of recent floods or shifting of a stream, an old hydraulic study should not be considered reliable. A new study should be carried out. The HEC-RAS, "*River Analysis System, Users Manual*", 1995, published by the U.S. Army Corps of Engineers, or WSPRO software may be used. Existing studies performed by FEMA, the U.S. Army Corps of Engineers, U.S. Soil Conservation Service and NJDEP may also be assessed.

b.) The allowable velocity for a bridge location and the permissible backwater should be determined. This information may then be compared with computed velocities and backwater using HEC-RAS or WSPRO. The scour depth for a proposed bridge and, if economical, for an existing bridge should be estimated. Refer to item 3.) below for backwater criteria.

c.) When a dam exists upstream of a bridge, the design flood for the dam and its spillway shall be considered when performing the scour analysis.

d.) For criteria on bridge waterway sizing, refer to Subsection 2.6.4.3 of the *AASHTO LRFD Bridge Design Specifications*. Also, the NJDEP Technical Manual for Land Use Regulation Program Bureaus of Inland

and Coastal Regulations, Stream Encroachment Permits should be referenced to verify permitted requirements.

3.) Backwater elevation criteria

a.) As per current NJDEP requirements, if projects are located in the Central Passaic Basin of the State, the permissible backwater rise and fill shall be, without exception, for both bridge replacement or new construction, zero.

b.) At other locations throughout the State, if an existing bridge structure, in a waterway, is to be replaced then the permitted water elevation rise shall be zero either upstream or downstream of the bridge structure.

Also, at other locations throughout the State, if new construction of a bridge structure is planned, then a 0.2 foot water elevation rise is permitted. For both new construction and bridge replacement scenarios, 20% net fill of the waterway location is permitted. For certain, as deemed necessary situations, an exception for additional fill may be granted.

b. Stream Stability

The NJDEP publication "*Technical Manual for Land Use Regulation Program, Bureau of Inland and Coastal Regulations Stream Encroachment Permits*", HEC 18 and HEC 20 Reports may be used to determine stream stability variables.

c. Geotechnical Considerations

The following data should be assessed in determining geotechnical impacts on the scour analysis:

1.) Review subsurface information that is provided in the Geotechnical Report.

2.) Evaluate historic scour related conditions and potential scour holes at the bridge site.

3.) Soil classification – Based on laboratory tests for grain size samples, classify the soil.

39.3 Performing A Scour Analysis

1. The following types of analyses should be conducted in the overall scour analysis of a bridge:

   Level 1- Qualitative assessment of Stream stability, including lateral stability, vertical stability and determining the profiles and plan formations of streams and rivers. (Refer to HEC 20)

   Level 2- More detailed quantitative analysis, including hydrologic, hydraulic and scour analysis to assess scour vulnerability. (Refer to HEC 18)

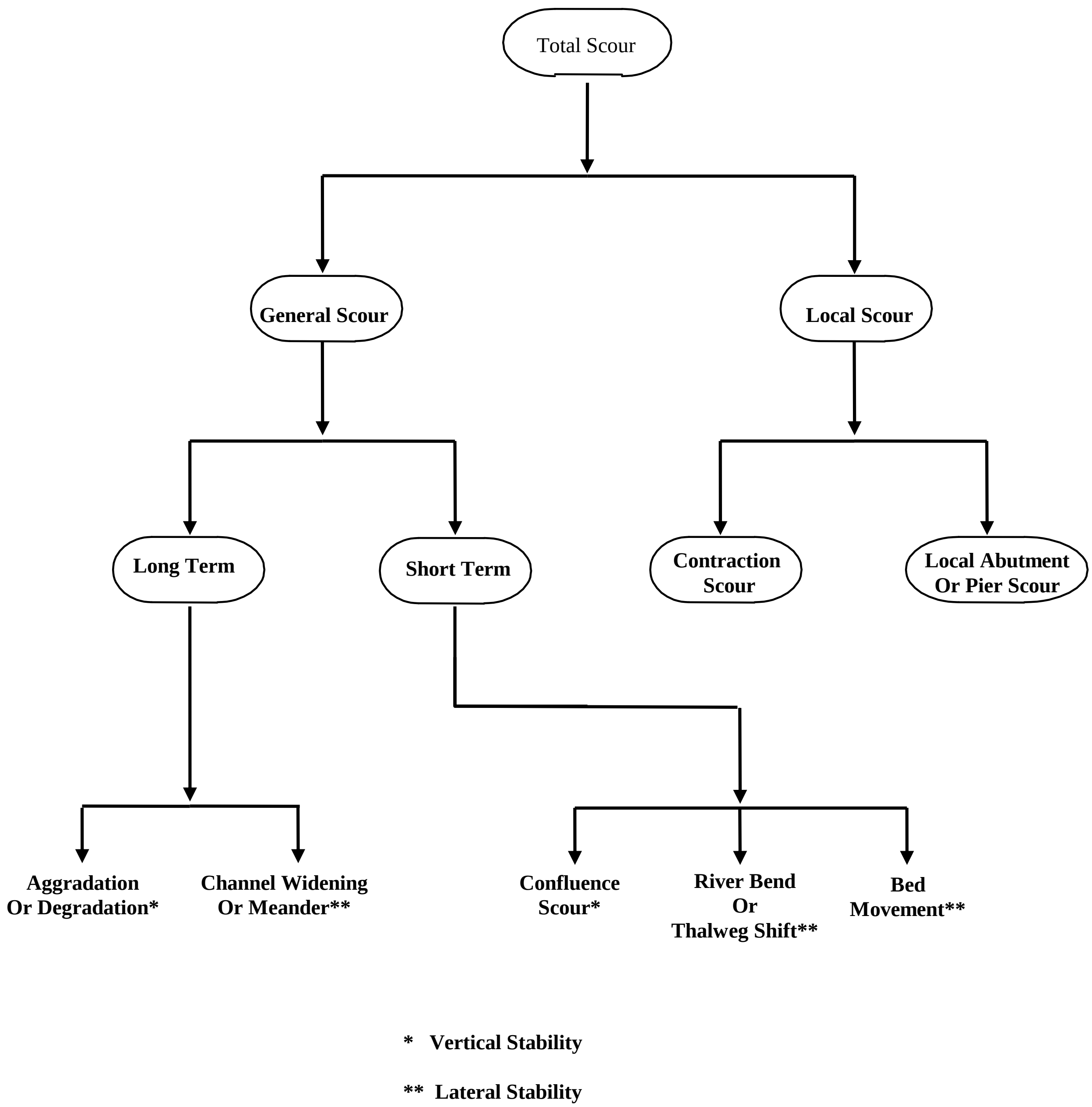
   Level 3- Bridge scour design of stream instability countermeasures. (Refer to HEC 23)

2. If the determined estimated scour depth that must be addressed in the design process seems excessive, an evaluation of the site should be made. The

evaluation should include a flood history assessment as well as any evidence of scour occurrence.

The evaluation can be used as a basis to recommend a reduction of the determined scour depth. A percentile reduction recommendation may be submitted to the Manager, Structural Engineering for approval.

3. The following flow diagram may be utilized to assess the impact of scour and scour components on a bridge structure site.



Notes:

1. Long term scour is based on the concept that long term streambed elevation changes can take place over the time scale of several years during the life of a

bridge, due to aggradation or degradation. Also, natural or man-induced causes may affect the reach of a river in which the bridge is located.

2. Aggradation involves the deposition of material eroded from the channel or watershed upstream of the bridge.
3. Degradation involves the lowering or scouring of the longitudinal profile of a channel. The bends of meandering channels may move laterally in the vicinity of the bridge, causing the channel to widen and create lateral erosion and scour.
4. If bridge inspection records of cross sections of the stream at the bridge site are maintained over many years, long term scour can be calculated from streambed elevation changes. Projections of scour based on a long-term trend can be made.
5. Common Countermeasures used for aggradation are channel improvements by dredging or cleaning.
6. Countermeasures for degradation are channel lining with concrete pavement, increasing a bridge opening width or vegetation planting.

Upon determination of the effects of scour impact, a summary of scour depth may be prepared as presented in the following Table:

Table 39-1 Scour Depth Summary at Abutment/Pier

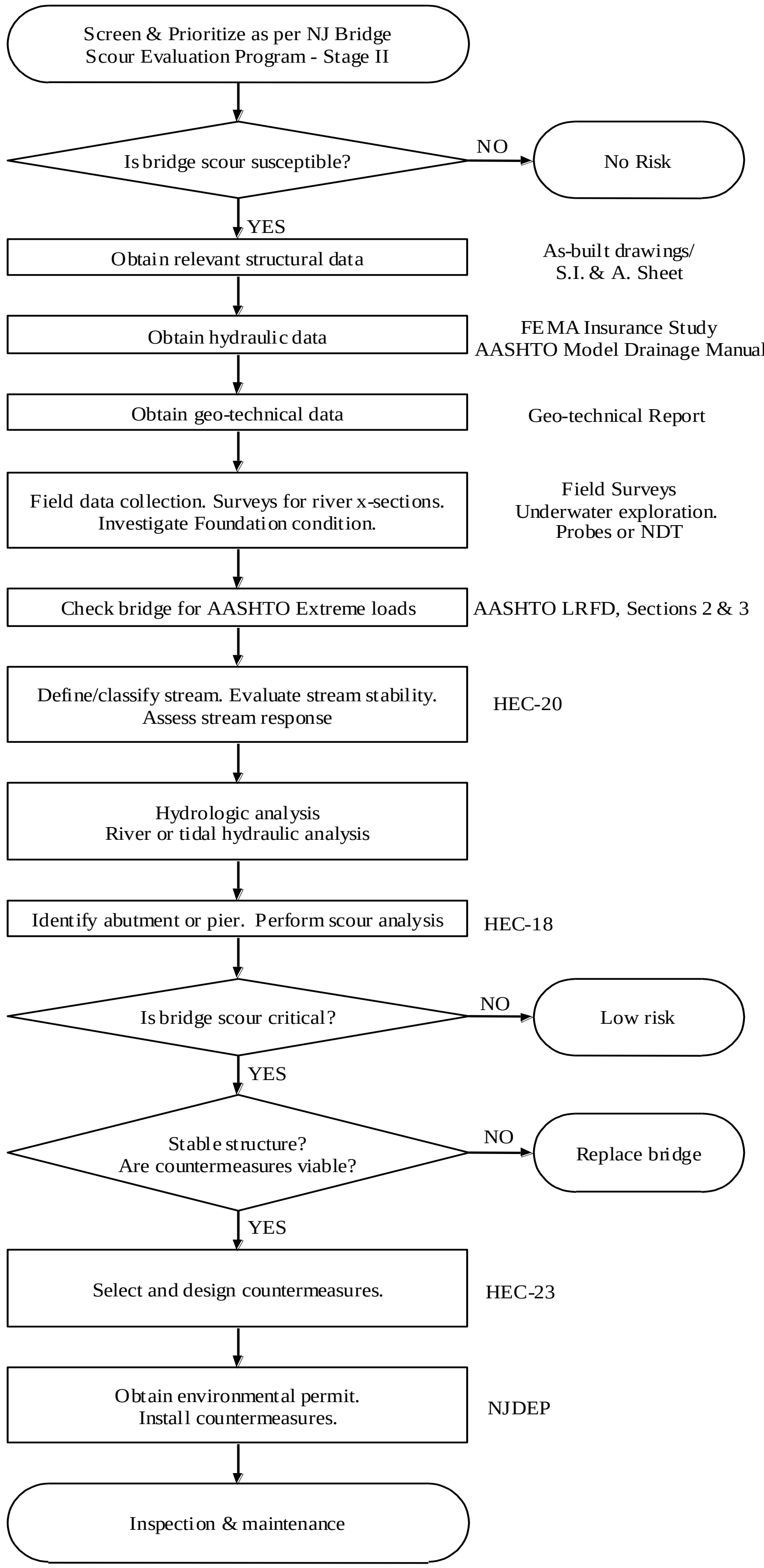
Discharge Frequency	**Computed Scour Depths in Feet**					**Proposed Elevations**	
	Long term Scour	**Short term Scour**	**Contrac tion Scour**	**Local Scour**	**Total Scour**	**Top of Footing**	**Bottom of Footing**
50 Year							
100 Year							
500 Year*							

* If 500 year Discharge is not available, use Q500 = 1.7 x Q100

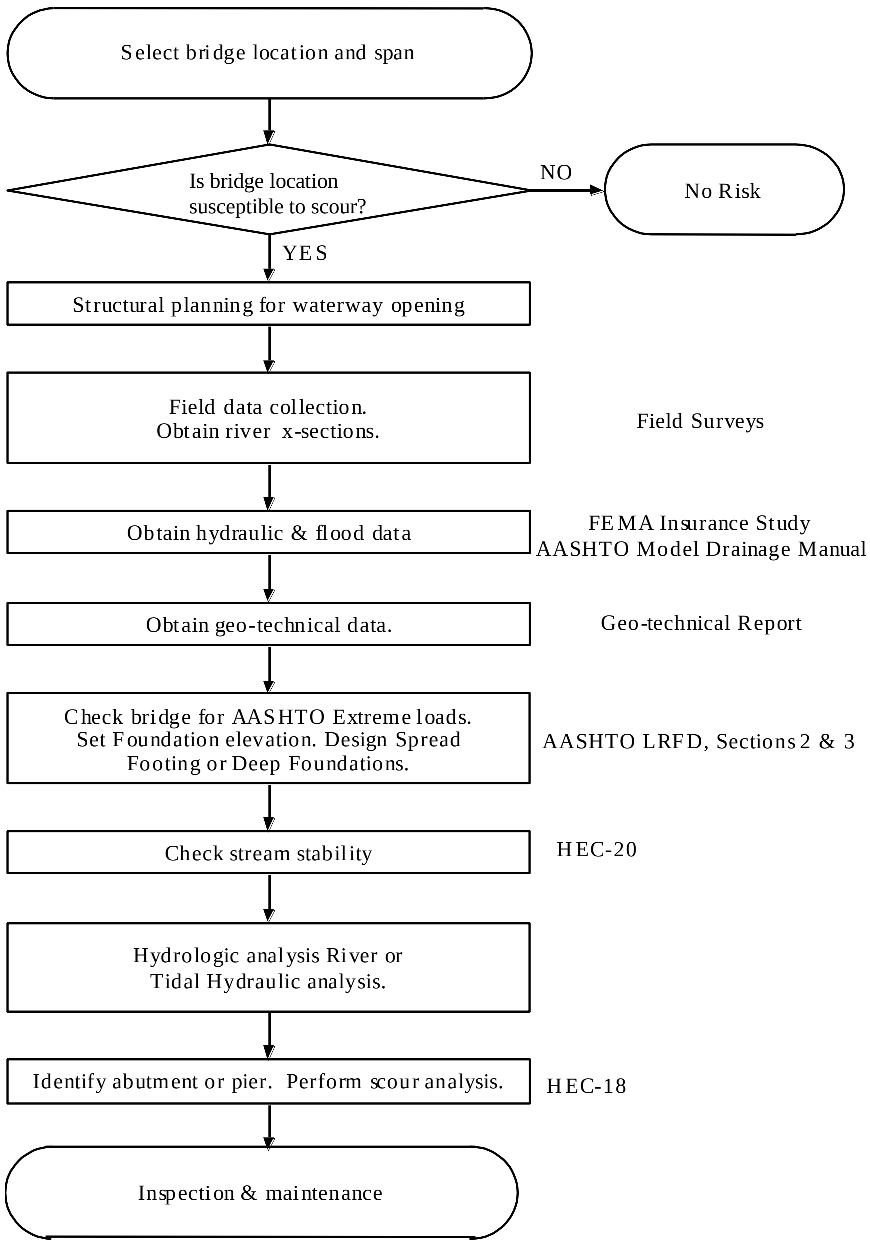
39.4 Flow Diagrams For Detailed Scour Evaluation

The following flow charts may be followed in developing a comprehensive scour analysis:

1. Existing Bridges and Bridges to be Widened



2. New Bridges and Bridges to be Replaced



39.5 Design Guidance

The following guidance may be followed in developing scour resistant bridge designs:

1. If it is determined from established inspection procedures, that all streambed material in the computed scour prism has been removed and is not available for bearing or for lateral support, an existing bridge should be considered for replacement.

2. The preliminary submission shall include a Hydraulic and Scour Report. The Report should establish a design procedure for scour resistance. The following structural elemental information should be addressed in this Report:
   a. Superstructure
      1.) The bridge superstructure and the general elevation of approach roadways shall be above the maximum flood level of 100 years or other designated critical flood.
      2.) For streams that carry a large amount of debris, the elevation of the lower chord of the bridge shall be at least 2 feet above the freeboard for a 100 year flood.
   b. Abutment and Wingwalls
      1.) The design of abutments and wingwalls shall be considerate of the potential that the channel may shift and that scour may occur during the life of the structure.
      2.) Design loads shall be based on the *AASHTO LRFD Bridge Design Specifications*, Section 3, Extreme Events I (including water loads (WA) for scour depths based on mean discharges).
   c. Piers
      1.) Location of piers in small streams should be avoided. Small streams are susceptible to flooding during localized rain storms. Erosion of a pier's foundation may occur.
      2.) The number of piers in any stream channel shall be limited so that ice forces and potential for local and contraction scour are minimized.
      3.) In order to reduce drift build up, piers shall be aligned with the flow direction.
      4.) Design loads shall be based on the *AASHTO LRFD Bridge Design Specifications*, Section 3, Extreme Events II (including water loads (WA) for scour depths based on mean discharges).
      5.) Piers subject to tidal conditions shall be protected on all sides by means identified in Section 19 of this Manual.
      6.) If there is a hazard of ice and debris buildup, multiple pile bents shall be avoided.
      7.) A solid wall or hammerhead pier is preferred to a column bent or pile bent pier. For scour estimation, evaluate a bent pier as a solid pier. Circular or elongated pier shapes shall be preferred to rectangular shapes.
   d. Foundation Planning Based on Scour Analysis
      1.) Scour Depth Considerations
         a.) Subsection 2.6.4.4 of the *AASHTO LRFD Bridge Design Specifications* may be referenced for guidance concerning bridge foundation design concepts.

b.) Foundations shall be designed for the condition that all stream bed material, in the 100 year scour prism above the total scour line, has eroded and is not available for bearing or lateral support.

3. Spread Footings on Soil

   a.) Use spread footings only where the stream bed is extremely stable.

   b.) Place top of footing at the scour depth that is determined by the Check Flood for Scour.

4. Spread Footings on Erodible Rock

   a.) Consult an Engineering geologist for rock erodibility.

   b.) Estimate the potential scour depth and place the bottom of footing 6 inches below that depth.

   c.) Place the final footing in contact with the sides of excavation and fill the excavation above the footing with riprap.

   d.) Blasting shall not be permitted for rock excavation.

5. Spread Footings on Non-erodible Rock. For highly resistant rock such as granite and non-erodible limestone, place the bottom of the footing on a clean rock surface 0.5 feet below the bedrock and consider doweling for increased lateral restraint.

6. Deep Foundations

   a). When a stream bed is not stable, piles should be considered.

   b.) For driven piles or drilled shafts with footings or caps, place the top of the footing below the stream bed at a depth that is equal to the estimated sum of long term degradation and contraction scour.

   c.) Consideration should be given to using a lesser number of longer piles as compared to a greater number of shorter piles. This will develop higher bearing loads. This approach will provide a greater factor of safety against pile failure due to scour, at little or no increase in cost.

   d.) If, due to an increase in unsupported pile length that is measured up to the total scour depth line, pile stability shall be checked for column action requirements. Additional lateral loads due to stream pressure, currents, debris and ice loads should be considered in the pile design.

   e.) For stub abutments, piles shall be carried at least 3 feet below the thalweg elevation.

   f.) When piles cannot be driven, drilled shafts or caissons shall be used.

39.6 Scour Countermeasure Development Procedures

1. Selection and Design of Scour Countermeasures for Existing Bridges

   a.) Scour countermeasure methods shall provide vertical and lateral channel stability and minimize or eliminate aggradation, degradation, lateral erosion and local scour.

   b.) Such methods to structural features may include:

      - driving sheet piling to protect existing footings or

- driving sacrificial piles to deflect flow and induce deposition in a local scour hole at piers.

2. The Department has completed a Research project titled *Handbook of Scour Countermeasure Designs*. Detailed guidelines on developing permanent countermeasures are provided in the Final Report. The Final Report may be downloaded from the following NJDOT Research website:

   www.state.nj.us/transportation/refdata/research

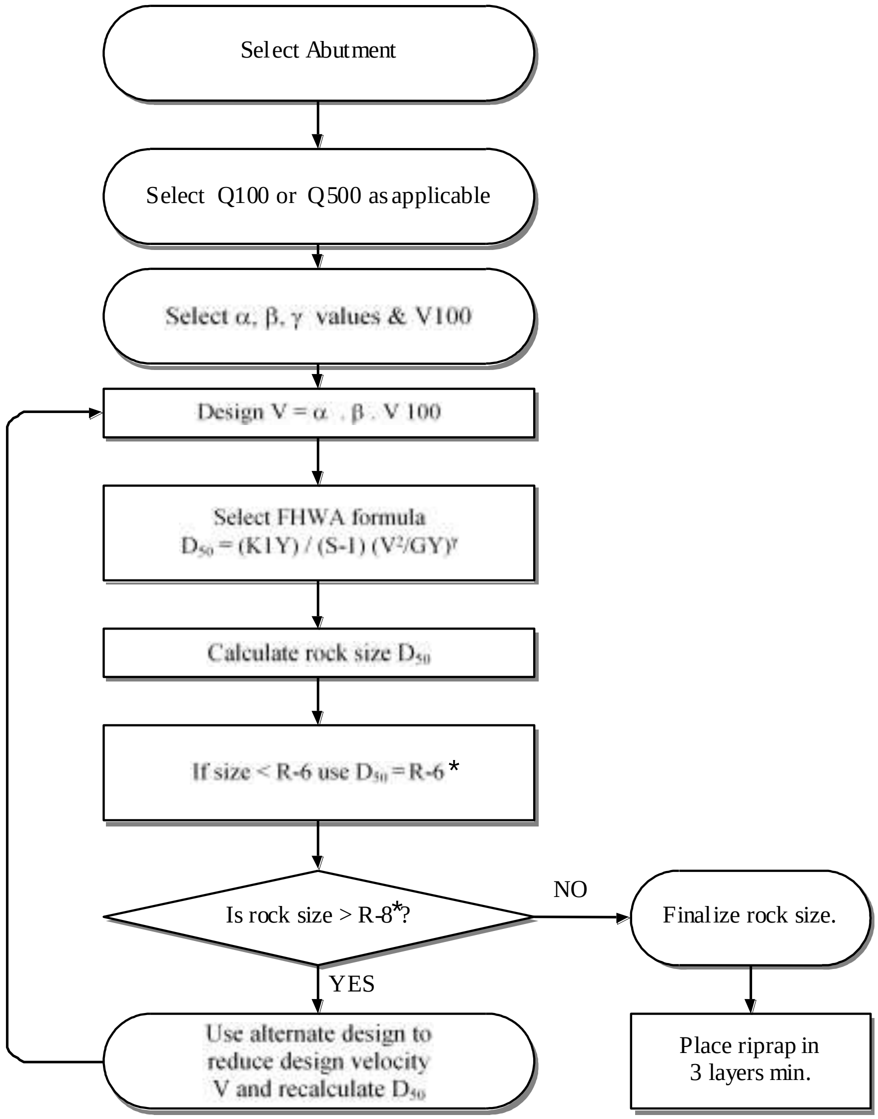
   Designers are encouraged to study the Final Report for possible use of the Report's recommendations.

3. Using Riprap as a Temporary Countermeasure

   a.) Limitations of riprap: Although natural riprap is the most commonly used armoring, it requires monitoring since it is not held in position similar to other types of armoring; such as, articulated concrete blocks, grout filled bags, gabion or reno mattress.

   b.) Riprap should only be considered as a temporary countermeasure when retrofitting an existing bridge. Alternate countermeasures as described in HEC-23 and in this Section; such as, heavier armoring, river training measures, channel improvements, modifying the structural features including monitoring, shall be adopted.

   c.) The following flow diagram may be followed in designing a riprap system for abutment protection:



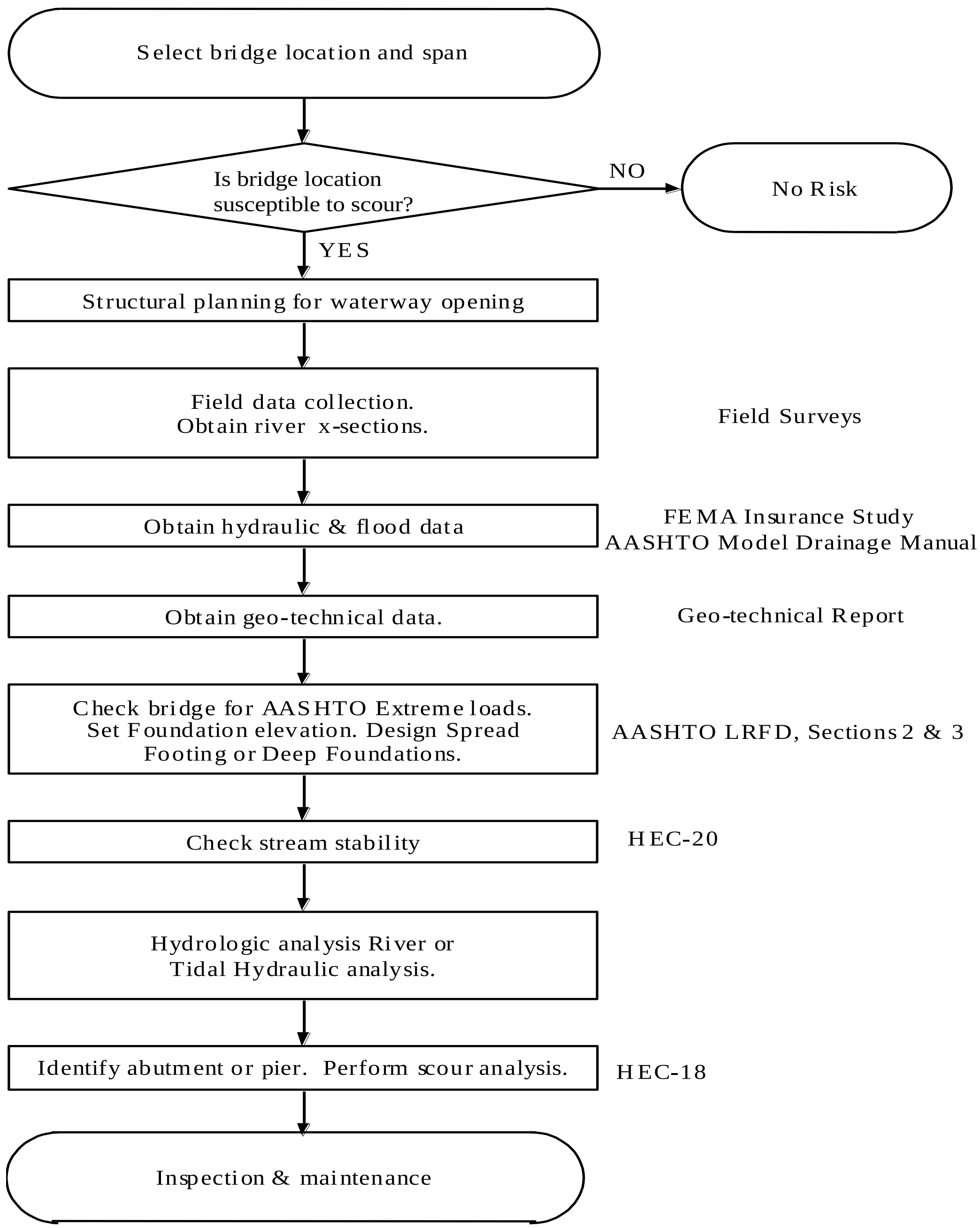
* NCSA Classification

Riprap at Abutment on Spread Footing (on soil).

NOTES:

1. If rock exists at a depth lower than the design depth, place bottom of footing at 6" below rock surface.
2. Set design depth = 1/2 scour depth if only riprap countermeasure is used.

d. The following flow diagram may be followed in designing a riprap system for pier protection:



e. Rip-Rap Layout Procedures

1.) Riprap grading – Designate 50 percent of stones in a layer to be equal or greater than the specified size (D_{50}). The specified size can be calculated by hydraulic considerations using FHWA formulae (see flow diagrams above). The remaining 50 percent of the stones can be of a smaller size than the (D_{50}) to fill the smaller voids between the stones.

2.) Maximum stone size in a layer < 1.5 D_{50} .

3.) Minimum thickness of each layer = 1 foot.

4.) Minimum number of layers = 3.

5.) Width of a riprap layer on a footing, at the river side of an abutment or around the pier shall be the maximum of the following:

2 x (width of abutment or pier at base) or

(1 foot + d cot θ), where d is the design scour depth at the abutment or the pier and θ is the angle of natural repose for the soil, as obtained from the Geotechnical Report.

6.) Place riprap around the footings with the slope starting at a distance of 1 foot from vertical face of the footing.

7.) Before placing riprap, check that the excavation line that is located adjacent to the abutment and around the pier meets OSHA safety requirement for the type of soil.

8.) The top of riprap shall be below the river bed to avoid encroachment of the river, or dislodging of the stones by floating debris, ice or currents.

9.) If a riprap design is based on a scour analysis, use a reduced design depth d = y/2, Where y = computed scour depth.

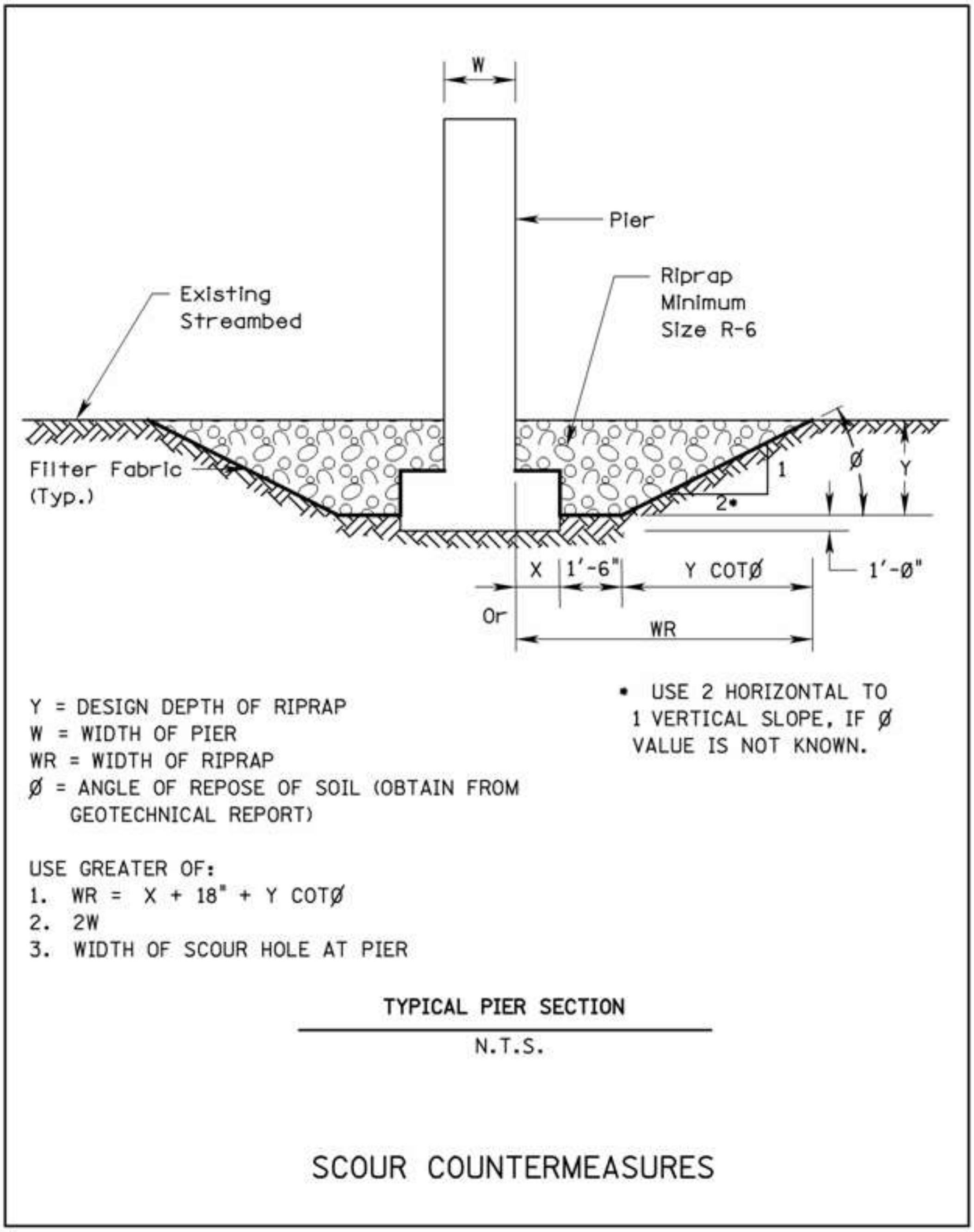
10.) If the design depth "d" is greater than the available depth between riverbed elevation and bottom of footing, and the rock is not available within depth "d", or if the computed D_{50} size > R-8, alternate countermeasures will be required.

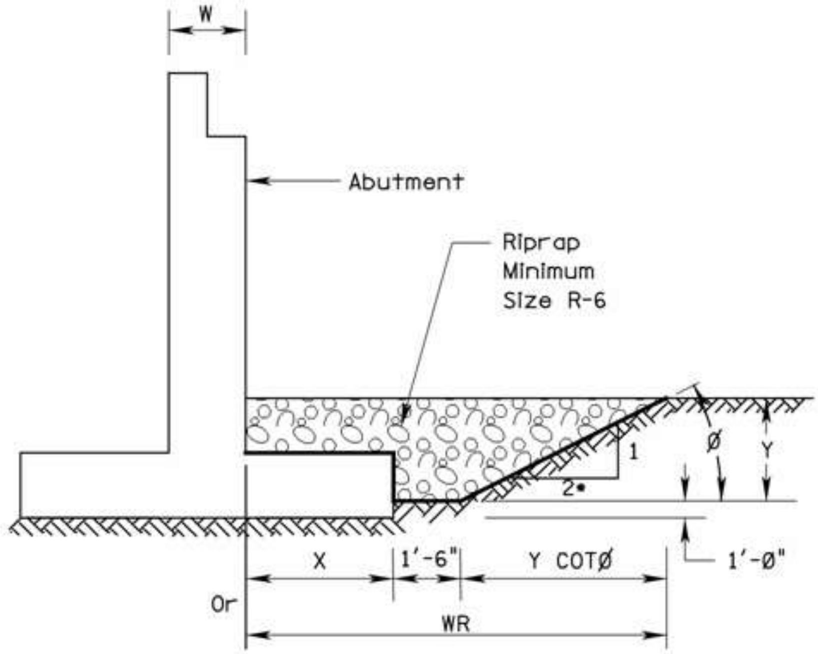
39.7 Scour Protection At Culverts

1. Hydraulic design: Chapter 4 of *AASHTO Highway Drainage Guidelines Manual* and HEC 23 provide design procedures for the hydraulic design of highway culverts. Included therein are design examples, tables and charts that provide a basis for determining the selection of a culvert opening.
2. Footings for any flared wingwalls, provided at the entry and the exit of culverts will be protected by riprap or alternate armoring countermeasures.
3. For high velocities exceeding 12 ft/sec, riprap at wingwalls will be replaced by a concrete apron, which is to extend between the opposite wingwalls and to the edge of the culvert.
4. Regular monitoring will be required if riprap has been installed at the entry and exit of culverts.

39.8 Scour Protection Detailing

The following illustrations provide details for riprap placement at abutments and piers.





Y = DESIGN DEPTH OF RIPRAP
W = WIDTH OF PIER
WR = WIDTH OF RIPRAP
Ø = ANGLE OF REPOSE OF SOIL (OBTAIN FROM GEOTECHNICAL REPORT)

• USE 2 HORIZONTAL TO 1 VERTICAL SLOPE, IF Ø VALUE IS NOT KNOWN.

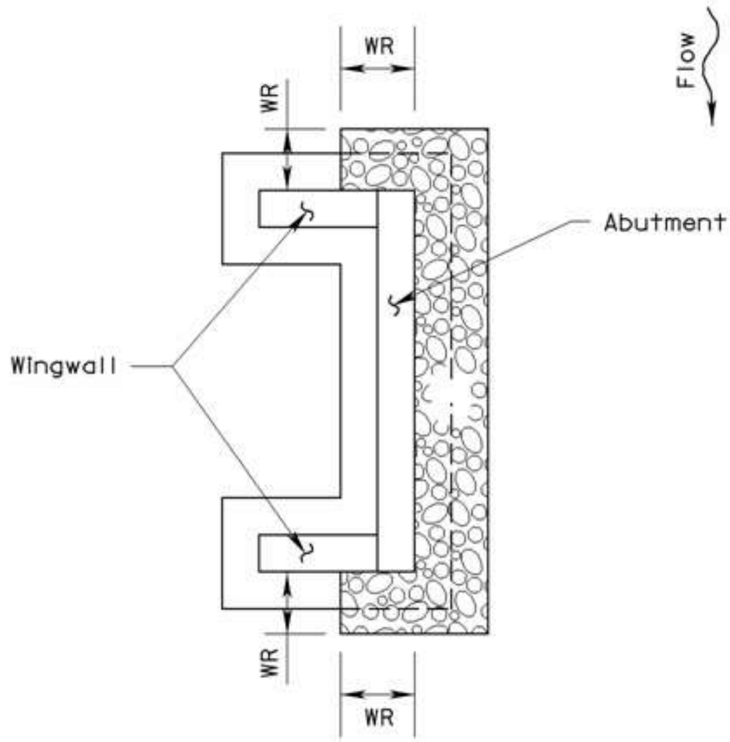
USE GREATER OF:

1. WR = X + 18" + Y COTØ
2. 2W
3. WIDTH OF SCOUR HOLE AT PIER

TYPICAL ABUTMENT SECTION

N.T.S.

SCOUR COUNTERMEASURES

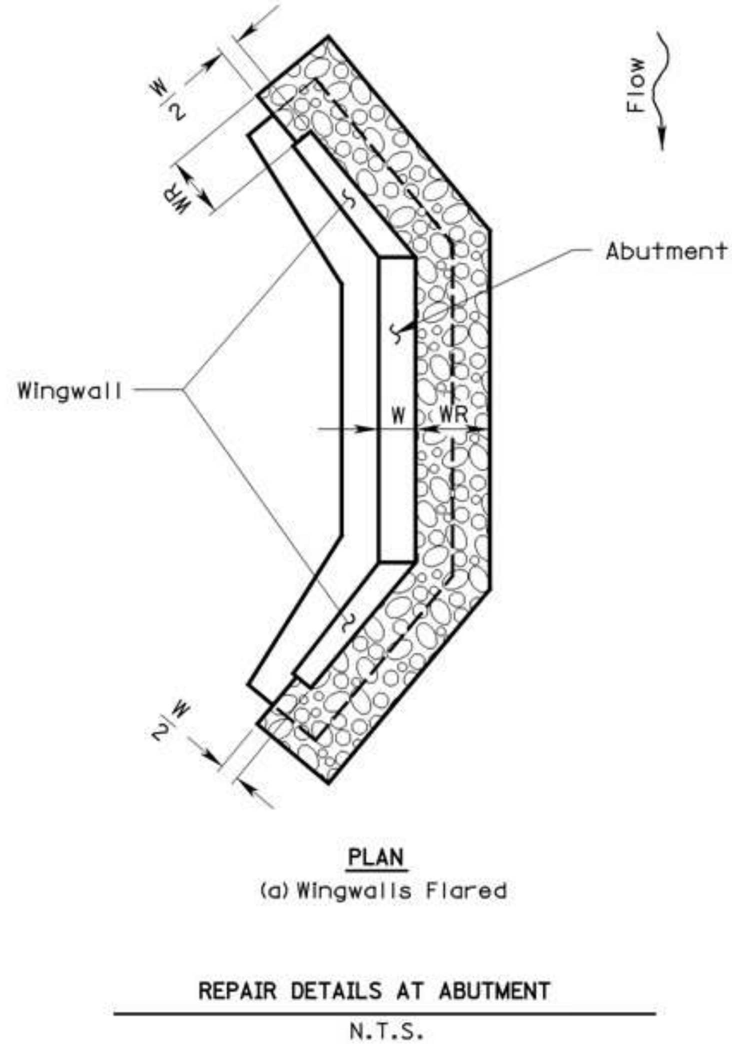


PLAN
(a) Wingwalls Normal to Abutment

REPAIR DETAILS AT ABUTMENT

N.T.S.

SCOUR COUNTERMEASURES



SCOUR COUNTERMEASURES