Appendix 6-D (updated September 2018)

MDOT Guidelines for Evaluation of Scour and Scour Analysis Worksheets
INTRODUCTION

These guidelines are proposed for the evaluation of scour at existing bridge structures for the Michigan Department of Transportation (MDOT) and local agencies. The guidelines supplement the following Federal Highway Administration (FHWA) publications and directives on scour:

2. Technical Advisory T 5140.23

Scour is a dynamic sediment transport process. Research on scour is ongoing, and revisions to the methods of scour and stream stability analyses may occur.

These guidelines are organized to discuss the priority of evaluation, the three levels of analysis, the National Bridge Inventory System (NBIS), the plan of action, and design of scour countermeasures for scour critical bridges. It is important that an interdisciplinary team consisting of hydraulic, geotechnical, and structural engineers be involved in all levels of analysis and the evaluation process.

Chapter 10 of FHWA's HEC-18 outlines a scour evaluation process for existing bridges. HEC-18 recommends documentation of each level of analysis. Documentation for Michigan includes updating Item 113 of the NBIS at each level of analysis and action and retaining the Level One and Level Two Worksheets. The Level Two Worksheet should include, if needed, recommended scour countermeasures and a "Plan of Action." The Plan of Action should include a timetable to implement the design and construction of accepted scour countermeasures.

PRIORITY OF EVALUATION

In 1991, MDOT developed a scour screening procedure for development of an initial priority list. This procedure was approved by FHWA and distributed to local agencies. Each agency should now have a "priority list" based on this procedure to start its scour evaluation program. An agency should use this priority list to schedule the proposed Level One analysis given in these guidelines. The Level One analysis must be completed to determine the need for a Level Two analysis.
Structures with unknown foundations will have Item 113 coded as a "U" in the NBIS. MDOT recommends as a minimum a Level One analysis, and the hydrologic, hydraulic, and scour calculations of a Level Two analysis be done. The findings can be used to evaluate the potential risk to these structures once the type of foundation is determined.

**LEVEL ONE - QUALITATIVE ANALYSIS**

A Level One analysis is an information gathering effort consisting of office and field reviews of the structure. The following information should be obtained, reviewed, and commented on:

- Bridge Inspection Reports
- Underwater Inspection Reports (if available)
- Items 60, 61, 71, 92, 93, and 113 of the NBIS (see HEC-18, Appendix J, for definitions)
- Construction, design, and maintenance files for repair and maintenance work done on the structure
- Hydraulic Data (Flood Insurance Study or original design analysis)

The Level One analysis procedure is outlined in Chapter 3 of HEC-20. It is a six-step process that covers stream characteristics, land use, stream stability, lateral stability, vertical stream stability, and channel response to change. Items used in the initial screening procedure should be verified, corrections made to the screening database, and the priority list updated accordingly.

A field investigation will be required to obtain the above stream characteristics and confirm the minimum hydraulic parameters, i.e., channel slope, channel and overbank roughness coefficients, plan elevations and dimension of structure, foundation conditions, etc.

If a Level Two analysis is recommended, a code of "6" should be entered for Item 113.

**LEVEL TWO - BASIC ENGINEERING ANALYSIS**

The Level Two scour analysis is an eight-step process to define stream stability and scour problems. These steps cover:

1. Hydrology or flood history
2. Hydraulic conditions
3. Geotechnical - bed and bank material evaluation
4. Watershed sediment yield
5. Incipient motion analysis
6. Armoring potential
7. Rating curve shifts
8. Scour conditions
Appendix B of these guidelines provides a worksheet for a Level Two scour analysis. The following is a discussion of each of these eight steps:

**HYDROLOGY**

The discharge estimate used in the scour screening procedure should not be used for scour design. The Michigan Department of Environmental Quality (MDEQ) will not provide flood frequency discharge estimates for scour evaluation studies. Therefore, it is recommended that a range of flood discharges that approximate the 2 percent, 1 percent, and 0.2 percent chance floods be used. If flood estimates are not readily available, the MDEQ recommends the following methods for estimating flood discharges:

- For drainage areas less than 20 square miles use:


- For drainage areas greater than twenty square miles use:


- Drainage area ratio method on gaged streams can be used where USGS gages exist, or recent MDEQ discharge estimates at or near the bridge may be used. The ratio of the drainage areas should be raised to the 0.89 power when estimating the discharge. This method should only be used if the hydrologic characteristics of the two drainage basins are similar.

Estimated discharges are for evaluation purposes only. Design and construction of structure repair, replacement, or scour countermeasures requires a discharge estimate from MDEQ with a permit application for the proposed work. The MDEQ discharge estimate should be compared with the range of discharges used in the scour evaluation. Engineering judgement should be used to determine if the scour evaluation is adequate.

NOTE: The use of a flood hydrograph is beneficial to scour analysis since it can illustrate the time and duration that hydraulic forces are present to transport bed material. However, development of flood hydrographs for the recommended range of flood flows is beyond the scope of a Level Two analysis and is recommended for Level Three.
HYDRAULICS

Chapter 2 of HEC-18 recommends the utilization of existing hydraulic studies. If these studies are not available, a "worst-case analysis" is suggested. It is assumed that a detailed hydraulic survey of the channel cross sections will not be done. Channel cross sections can be developed based on existing bridge plans, topographic maps, and data gathered during the Level One field investigation. These cross sections should have a minimum of eight station points to define the cross section. A sufficient number of cross sections downstream of the structure should be input to achieve a normal water surface. Duplication of existing cross sections is an acceptable technique.

MDOT recommends the use of the U.S. Army Corps of Engineers Hydrologic Engineering Center HEC-RAS computer program for the computation of water surface profiles and the hydraulic parameters needed in the scour calculations.

GEOTECHNICAL

A soil gradation curve of streambed and overbank material is needed to determine the D_{50} and D_{84} particle sizes for use in the respective contraction scour and pier scour equations. Gradation curves or soil boring information used in the original plans of the structure can be used. A geotechnical engineer should be consulted for an estimation of the D_{50} and D_{84}.

If existing plans or soil information are not available, analyze based on the worst-case scenario. It is recommended that Laursen's live bed contraction scour equation be used with a K_1=0.69.

WATERSHED SEDIMENT YIELDS

The availability of watershed yield is imprecise. Information on Michigan streams is limited and, therefore, not used in the overall evaluation of a Level Two Analysis.

INCIPIENT MOTION ANALYSIS

Use of the Shields relation (Chapter 6 of HEC-20) for the range of discharges may provide information on the channel stability and what flood may cause stream channel instability. This relation is recommended for gravel or cobble stream systems only.

ARMORING POTENTIAL

Determination of the potential armoring of a streambed is discussed in Chapter 6 of HEC-20.
RATING CURVE SHIFTS

USGS stream gage data is limited to a few locations on Michigan streams. Analyses of rating curve shifts have not been completed in Michigan. Therefore, this portion of a Level Two analysis cannot be done.

SCOUR CALCULATIONS

Scour has three additive components: local scour at abutments and piers, contraction scour, and aggradation/degradation of the streambed. HEC-18 provides detailed computational procedures. The total scour depth should be reviewed by geotechnical and structural engineers to evaluate the stability of the structure.

LEVEL THREE - MATHEMATICAL AND PHYSICAL MODEL STUDIES

A detailed evaluation and assessment of stream stability can be completed by either mathematical or physical model studies. However, such studies are beyond the scope and monies available for a majority of Michigan projects.

NATIONAL BRIDGE INVENTORY SYSTEM (NBIS)

The scour evaluation program should result in the proper code for Item 113 of the NBIS. For state trunkline structures, the worksheet with the appropriate code should be forwarded to the Hydraulics/Hydrology Unit for review after each level of analysis. A copy of the Structure Inventory and Appraisal (SI&A) form (MDOT form Q1717A) will then be forwarded to the Bridge Operations Unit of MDOT. Local Agencies should send the SI&A form to the Bridge Operations Unit, Construction and Technology Division, Michigan Department of Transportation, P.O. Box 30049, Lansing, Michigan, 48909. Local agencies may also submit the form electronically.

PLAN OF ACTION AND SCOUR COUNTERMEASURES

Scour countermeasures are needed at the bridge to make it less vulnerable to either damage or failure from scour. For existing bridges, recommended countermeasures include:

- Riprap at piers and abutments with monitoring (visual, cross sections, instrumentation, etc.) during and after flood events
- Guide banks
- Channel improvements
- Strengthening bridge foundations
- Relief bridges
A plan of action is needed and can be part of the Level Two documentation. The plan of action should be developed among the hydraulic, geotechnical, and structural engineers. Examples include the following:

- Monitor for scour during regular bridge inspection
- Increase monitoring frequency
- Temporary countermeasures - riprap and monitor
- Selection of scour countermeasures
- Scheduling of scour countermeasure construction
LEVEL ONE WORKSHEET
MICHIGAN DEPARTMENT OF TRANSPORTATION
LEVEL ONE SCOUR ANALYSIS WORKSHEET

Date: _________  By: _____________  Structure No: _____  Control Section: __________

Job No. _________  Route: _____________  Watercourse: ____________________________

All references are to HEC-20, 3rd Edition.

Data Collection

____  Bridge Inspection Reports (Maintenance Division)
____  Underwater Inspection Reports (Maintenance Division)
____  Review existing items 60, 61, 71, 92, 93, and 113 of the NBIS
____  Review available construction, design, and maintenance files for repair and
      maintenance work done on structure

Field Investigation  Date: __________

____  Channel bottom width approximately one bridge span upstream = ________ feet
____  Overbank and channel Manning’s roughness coefficients

       _______  Left  _________  Channel  _________  Right

____  Is there sufficient riprap?  Abutments _________  Piers _________

____  Photographs

____  Cross sections at upstream and downstream faces of bridge

Comments:

Stream Characteristics

____  Complete the attached Figure 2.6 from HEC-20.

Comments:

Land Use: Identify the existing and past land use of the upstream watershed:

Urban Area  Yes__  No__  Comments:
Sand and Gravel Mining  Yes__  No__  Comments:
Undeveloped Land  Yes__  No__  Comments:
**Lateral Stability:** Refer to HEC-20, Section 2.3.9 on Channel Boundaries and Vegetation for channel bank stability. Comment:

**Vertical Stability:**

- streambed elevation change from as-built plans? Yes ____ No ____
- exposed pier footings (degradation)? Yes ____ No ____
- exposed abutment footings (degradation)? Yes ____ No ____
- channel bank caving in (degradation)? Yes ____ No ____
- eroding floodplain (aggradation)? Yes ____ No ____
- crossing at confluence or tributaries? Yes ____ No ____
- bridge sites upstream and downstream? Yes ____ No ____
- grade or hydraulic controls, i.e. dams, weirs, diversions? Yes ____ No ____
- foundation on rock Yes ____ No ____
- channel armoring potential Yes ____ No ____

Comments:

**Stream Stability:** Make a qualitative assessment of the overall stream stability by referring to the above information and Figure 2.6 and Table 3.2 from HEC-20 (attach copies of figures).

Stable______ Unstable______ Degrading_____ Aggrading_____

Comments:

**RECOMMENDED NBIS ITEM 113 CODE:**____

**LEVEL TWO ANALYSIS NEEDED:** YES____ NO____

Worksheet approved by:___________________ P.E. License # ________ Date ________
LEVEL TWO WORKSHEET
MICHIGAN DEPARTMENT OF TRANSPORTATION
LEVEL TWO SCOUR ANALYSIS WORKSHEET

Date: __________ By: _____________________

Structure No: _____ Control Section: __________ Job No. __________

Route: __________ Watercourse: _______________________

Page numbers refer to HEC-20, 3rd Edition and HEC-18, 4th Edition. Attach water surface profile modeling printouts with pertinent variables highlighted. Scour calculations automatically done by HEC-RAS are not acceptable. All calculations must be attached or on the back of their respective pages.

1. **Hydrology:**
   
   Method of Analysis: DEQ estimate, SCS, Regression, DAR to gage, other
   
   Drainage Area: ______ square miles
   
   $Q_{50} = _________$ cfs \hspace{5mm} $Q_{100} = _________$ cfs \hspace{5mm} $Q_{500} = _________$ cfs

2. **Hydraulics:** Water surface profiles by: HEC-2 ___ WSPRO ___ HEC-RAS ___

3. **Geotechnical:** Bed and overbank material values:
   
   $D_{50}$ ___ $D_{84}$ ___ (ft) \hspace{5mm} Left Overbank
   
   $D_{50}$ ___ $D_{84}$ ___ (ft) \hspace{5mm} Right Overbank
   
   $D_{50}$ ___ $D_{84}$ ___ (ft) \hspace{5mm} Main Channel

   Source of information:

4. **Incipient motion analysis:** For gravel and cobble streams only. Refer to Page 6.14 of HEC-20.

5. **Armoring potential:** Refer to Page 6.16 of HEC-20.
LEVEL TWO SCOUR ANALYSIS WORKSHEET

Str. No. _____ C.S. _____________ Job No. _________ By: __________________ Date: ______

6. **Scour calculations**

**LONG-TERM BED ELEVATION CHANGES - AGGRADATION/DEGRADATION**

___ Use information from **Level One** Analysis

___ Use information from bridge inspection reports

___ Estimate change during the next 100 years if enough information exists

Estimated aggradation/degradation = ____ feet

*** Do not adjust fixed bed hydraulics for contraction scour and local scour. If channel has aggraded, do not adjust the estimated scour depth.

**CONTRACTION SCOUR** (Section 5.2, HEC-18)

Bridge Site Condition:

CASE: 1a__ 1b__ 1c__ 2___ 3__ 4__

Compare critical velocity \( V_c \) to the mean velocity \( V \).

\[
V_c = 11.17 y^{1/6} D^{1/3} \quad (p. 5.2, HEC-18)
\]

\[
y =
\]

\[
D_{50} =
\]

\[
V_c =
\]

If \( V_c < V \), use Laursen's Live-Bed contraction scour.

If \( V_c > V \), use Laursen's Clear-Water contraction scour.

If coarse sediments in bed material, see p 5.12, HEC-18.
LEVEL TWO SCOUR ANALYSIS WORKSHEET

Str. No. _____ C.S.___________ Job No. ________ By:_______________ Date:_________

Laursen's live-bed scour equation (p 5.10, HEC-18):

\[
y_2/y_1 = (Q_2/Q_1)^{6/7} (W_1/W_2)^{k_1} \text{ and}
\]

\[y_s = y_2 - y_0 = \text{average contraction scour depth (feet)}\]

\[y_1 = \text{________ ft} \quad V^* = \text{________ ft/s}\]
\[y_2 = \text{________ ft} \quad \omega = \text{________ ft/s}\]
\[y_0 = \text{________ ft} \quad S_1 = \text{________ ft/ft}\]
\[W_1 = \text{________ ft} \quad V^*/\omega = \text{________}\]
\[W_2 = \text{________ ft} \quad k_1 = \text{________}\]
\[Q_1 = \text{________ cfs} \quad y_s = \text{________ ft}\]
\[Q_2 = \text{________ cfs}\]

Laursen's Clear-Water Contraction Scour (p. 5.12, HEC-18)

\[y_2 = (0.0077 \frac{Q_2}{D_h^{2/3} W^2})^{3/7}\]

\[y_s = y_2 - y_0 = \text{average scour depth (feet)}\]

\[y_0 = \text{________ ft} \quad D_m = \text{________ ft}\]
\[y_2 = \text{________ ft} \quad D_{50} = \text{________ ft}\]
\[Q = \text{________ cfs} \quad y_s = \text{________ ft}\]
\[W = \text{________ ft}\]

LOCAL SCOUR

ABUTMENTS

Froehlich's live-bed scour equation. (If L'/y_1 > 25, use HIRE equation, p. 7.8, HEC-18.)

Froehlich's equation: \[y_s/y_a = 2.27 K_1 K_2 (L'/y_a)^43 (Fr)^{0.61} + 1 \] (p. 7.8, HEC-18)
LEVEL TWO SCOUR ANALYSIS WORKSHEET

Str. No. _____ C.S. ___________ Job No. __________ By: ___________ Date: __________

<table>
<thead>
<tr>
<th>Left Abutment</th>
<th>Right Abutment</th>
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<tbody>
<tr>
<td>K₁ = __________</td>
<td>__________</td>
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<tr>
<td>K₂ = __________</td>
<td>__________</td>
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<tr>
<td>L' = __________ ft</td>
<td>__________ ft</td>
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<td>Aₑ = __________ ft²</td>
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<td>Qₑ = __________ cfs</td>
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<td>Vₑ = __________ ft/s</td>
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<td>Fr = __________</td>
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<tr>
<td>$yₐ$ = __________ ft</td>
<td>__________ ft</td>
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<tr>
<td>$yₛ$ = __________ ft</td>
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</tbody>
</table>

PIER(S)

Colorado State University equation (p. 6.2, HEC-18):

$$yₛ/y₁=2.0 \, K₁ \, K₂ \, K₃ \, (a/y₁)^{0.65} \, (Fr₁)^{0.43}$$

Pier #:

<table>
<thead>
<tr>
<th>Pier #</th>
<th>Left</th>
<th>Middle</th>
<th>Right</th>
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</thead>
<tbody>
<tr>
<td>$y₁$ = __________ ft</td>
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<tr>
<td>K₁ = __________</td>
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<td>K₂ = __________</td>
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<td>K₃ = 1.1</td>
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<td>K₄ = __________</td>
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<td>Fr₁ = __________</td>
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<td>$yₛ$ = __________ ft</td>
<td>__________ ft</td>
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Note: If there is a possibility of channel migration, use the worst-case condition for all piers. For complex pier foundations, see Section 6.4, HEC-18.

SUMMARY
# LEVEL TWO SCOUR ANALYSIS WORKSHEET

Str. No. _____ C.S. ____________ Job No. _________ By: ____________ Date: __________

## 100 YEAR

<table>
<thead>
<tr>
<th>Element</th>
<th>Long-term (ft)</th>
<th>Contraction (ft)</th>
<th>Local (ft)</th>
<th>Total (ft)</th>
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<tbody>
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<td>Left Abutment</td>
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Adjust total scour depth as needed if scour holes overlap.

## 500 YEAR

<table>
<thead>
<tr>
<th>Element</th>
<th>Long-term (ft)</th>
<th>Contraction (ft)</th>
<th>Local (ft)</th>
<th>Total (ft)</th>
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<tbody>
<tr>
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Attach sketch or marked copy of existing design plan showing 100-year and 500-year total scour depths in relation to foundation. Foundation elevations must be shown.

Geotechnical Evaluation of scour results by: ______________________

Structural Evaluation of scour results by: ______________________

Is the structure stable under the estimated scour depth presented in this scour evaluation?

Yes _____ No _____

**RECOMMENDED NBIS ITEM 113 CODE:** ____ (p. J.14, HEC-18)
LEVEL TWO SCOUR ANALYSIS WORKSHEET

Str. No. _____ C.S. ___________ Job No. ___________ By: ___________ Date: ___________

ATTACHMENTS:

1. Calculations
2. Water surface profile computer output with pertinent values highlighted
3. Sketch of bridge with scour depths in relation to foundation
4. Scour countermeasure calculations with plans showing limits of countermeasures
5. Recommended plan of action

Worksheet approved by: ________________ Date: ________________

P.E. LICENSE # ______________

Additional comments: