Texas Department of Transportation

TEXAS SECONDARY EVALUATION AND ANALYSIS FOR SCOUR (TSEAS)

for

Texas Bridge Scour Program

Prepared by:

The Division of Bridges and Structures
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TEXAS SECONDARY EVALUATION AND ANALYSIS FOR SCOUR (TSEAS)

A. Introduction

The bridge scour evaluation program is being conducted to conform with the Federal Highway Administration Technical Advisory 5142.23. The goal of the program is to identify bridges over waterways whose foundations may be at risk of failure due to streambed scour or erosion. Having identified problem locations, recommendations for monitoring or physical mitigation can be set forth.

The initial screening process was devised and performed to eliminate sites which are considered low risk for scour-related problems. Fewer than 1% of the on-system bridges remain to be screened and more than 7000 bridges were identified by the screening as requiring further evaluation. To date, "further evaluation" has involved a detailed hydraulic and scour analysis often referred to as a "Level 2" analysis. The following factors have exemplified the need for a secondary evaluation process that is simpler than a detailed "Level 2" evaluation (hereafter referred to as a Detailed Analysis).

- At an estimated cost of $8000 or more per site per Detailed Analysis and a deadline of January 1997, the cost to the department would exceed $15,000,000 per year over the next four years to complete the on-system bridges only.
- The initial screening may have exaggerated the number of bridges subject to scour susceptibility.
- A statewide training program for scour evaluation has increased awareness of stream stability issues and scour potential and increased ability to perform evaluations.
- Detailed bridge scour calculations do not account for any stream stability problems. It is possible that many bridge sites experience stream stability problems yet may not be susceptible to bridge scour problems.

Note: Stream stability problems are those erosion problems that may occur in a stream system even without the presence of a bridge. Examples of such are lateral migration, head cuts, and general vertical and/or horizontal channel degradation. Since the bridge scour calculations involved in a Detailed Analysis do not address stream stability problems, bridge scour calculations are not recommended for those sites having risks due to stream stability factors but low susceptibility to bridge scour; however, such sites may require some form of mitigation to address the stream stability problems.

The Texas Secondary Evaluation and Analysis for Scour (TSEAS) process, has been designed to address the issues of bridge scour and stream stability and still comply with the intent of the technical advisory. The implications of this secondary analysis process are enormous since the results will define the level of effort and subsequent expenditure that will be required to complete the appraisa of all bridges over waterways (ultimately including off-system bridges). **Those bridges that hav not been through the initial screening need not be subjected to the initial screening process, bu they must be processed through the secondary evaluation process.** If a Detailed Analysis has bee performed on a site, then only the Reporting Procedures portion of this evaluation need be addresseo

B. Description of the Secondary Evaluation and Analysis Process

TSEAS comprises two distinct parts. The first, entitled "Secondary Screening", is a question and answer process, somewhat similar to the initial screening, which is intended to identify risk factors and differentiate between stream stability and bridge scour factors. The second part is entitled "Concise Analysis" and is a simplified bridge scour analysis procedure which may be performed dependent on the results of the secondary screening. This secondary evaluation has been designed to minimize the level of effort necessary to evaluate each site for potential scour (see Figure 1). The following summarizes the major features:

- Those structures with foundations embedded in non-erodible rock can be considered stable to bridge scour with no further evaluation necessary. **Note: Some sites emerged from the initial screening process as being susceptible to scour yet were embedded in rock. The first question on the secondary screening addresses this issue.**

- Those bridges which are already considered to be scour critical[1] and do not have foundations embedded in non-erodible rock may bypass the evaluation and be prioritized for monitoring or remedial action.

- Those bridges rated as susceptible to bridge scour rather than just stream stability may bypass portions of the secondary screening and continue to the Concise Analysis.

- Structures identified during the secondary screening as not having significant risks to bridge scour but susceptible to stream stability problems may forego further analysis, but may require recommendations for monitoring or physical mitigation measures.

- Structures identified during the secondary screening as having low risk factors for bridge scour and stream stability can be considered stable with no further scour evaluation necessary.

- Structures identified during the secondary screening process as having any significant bridge scour risks must receive a Concise or Detailed Analysis.

- The results of the Concise Analysis will enable a site to be rated as either stable for bridge scour, scour critical and in need of a mitigation plan, or require a Detailed Analysis.

This evaluation should be performed by experienced personnel, preferably those who have attended hydraulics and scour analysis training. The evaluation addresses 11 questions which are intended to discern whether potential erosion problems relate to stream stability (SS) only, bridge scour (BS) only, both bridge scour and stream stability (SS and BS), or no significant potential stream stability or bridge scour related problems.

The following is a list of suggested items that you may need to reference to answer the questions.

- Previously completed initial screening forms 113.1, 113.2, and 113.3

- As-built bridge layouts

[1] A scour critical bridge is one that may collapse if ultimate scour conditions occur. Some structures identified as having known scour may be in such a condition that any additional scour could cause failure.

- Topographic maps and/or aerial photographs
- Existing hydraulic data
- Recent and previous sections at bridge, if available
- Bridge inspection records

A field visit is recommended, especially if the documentation for the initial screening is insufficient to complete the responses the secondary screening questions as well as making determinations of physical characteristics for the Concise Analysis.

Appendices A and B contain worksheets for performing the Secondary Screening and Concise Analysis, respectively, and should be copied and completed for each site. Copies of these instructions need not be attached to each evaluation. Once a user becomes familiar with these instructions to the extent that only nominal reference is needed, the estimated average time and cost per site evaluation is expected to be as follows:

Secondary Screening w/ field visit	4 hrs	$ 300.00
Concise Analysis w/existing hydraulics	2 hrs,	$ 150.00
Concise Analysis w/ no existing hydraulics	4 hrs,	$ 550.00

Which sites should receive a secondary evaluation?

Since the expected costs are so much smaller than those involved with a Detailed Analysis (est. $8000 per site and up), it is recommended that a secondary evaluation be performed on all bridges currently identified as requiring a Detailed Analysis. i.e. all structures rated during the initial screening and prioritization process as having **known scour, high or medium susceptibility to scour**. Structures which are already considered to be scour critical and are expected to require replacement may bypass the evaluation but must be coded appropriately on the Bridge Inventory, Inspection and Appraisal Program (BRINSAP) item 113*. As mentioned in the introduction, any site which has not yet been screened must receive a secondary evaluation. Also to be included are sites which were temporarily classified as low risk due to Average Daily Traffic (ADT) counts of less than 150. Each district will have received an updated list of structures. The list of structures should be adjusted to identify parallel structures and relief openings. Such structures spanning the same waterway on the same highway should be considered as one site. Those sites on which Detailed Analyses (Level 2) have already been performed need neither a secondary screening nor a Concise Analysis; however, the reporting procedures outlined in Section E must be followed.

By when should the Secondary Evaluation Process be complete?

The following target dates have been established for completion of the Secondary Evaluation process based on:

- response from the districts
- initial screening categories
- National deadline

1. All on-system structures identified as having known scour, high and medium susceptibility - July, 1996.

2. On-system low risk by ADT < 150 - July, 1997.

3. Off-system - date to be established based on experience with on-system evaluations.

4. Unknown foundations - a separate procedure for handling these will be developed.

* Note that some level of scour analysis will probably be necessary for the design of bridge replacements.

C. Secondary Screening

The Secondary Screening should be performed by completing Appendix A which contains 11 questions. The following section provides detailed explanations for each question. The item number adjacent to some questions relates to the initial screening form 113.1 and associated question number which should have been completed during the initial screening process. The response to some of these questions will require a field visit if the documentation established during the initial screening is insufficient.

1. FOUNDATION SET IN NONERODIBLE ROCK

The following are examples of strata that can be considered [illegible]

- Granite
- Basalt
- Limestone
- Chalk
- Sandstone
- Shales (not in all cases - refer to the Geotechnical Section)

A review of the boring log and footing information should help determine whether the structure is founded on rock. It is important to consider the potential erodibility of the rock. The following is based upon recommendations of the Geotechnical Section of the Division with whom you may wish to consult.

- Standard penetration test information indicating 100 or more blows per foot for any material except non-cohesive soils can be considered non-erodible for the evaluation of existing structures.

- Fragmented rock, conglomerates and rock/clay mixtures should be considered erodible.

- Generally, igneous and metamorphic rocks can be considered non-erodible for evaluation of existing structures.

Unless there is reason to believe the rock is erodible and/or erosive forces might threaten the integrity of the bridge foundations and the expected unsupported length of foundations is considered to be stable[2], the structure can be considered not to be scour critical. If this is the case, no further evaluation is deemed necessary and a BRINSAP code of 8 can be applied to item 113. If the foundation is expected to be laterally unstable based on the assumption of scour down to the bedrock, the remaining screening questions may be skipped, but a Concise Analysis should be performed to determine if scour can be expected to reach the bedrock.

2. EXISTING COUNTERMEASURES

The structure may have experienced significant scour problems that have been addressed by providing protection measures such as rock rip rap around the footings, and sheet piling or rock rip rap to protect abutments. If such provisions have been made and, based on inspections, appear to be providing suitable protection, further evaluation will not be necessary. If this is the case, a code

[2]The lateral stability should be checked either by using the approximate method in Section D 2.3 or by requesting Division evaluation.

of 7 may be applied to BRINSAP item 113 (see Section E). If there is any doubt about the effectiveness of any mitigation measures, then respond "NO" and continue with the screening.

If the response is "NO", figure 1 indicates a choice of either continuing with the screening and Concise Analysis or proceeding to the prioritization process for Detailed Analysis. **It is recommended that the screening and, if necessary, the Concise Analysis be completed due to the potential of eliminating the need for a Detailed Analysis.**

3. FOUNDATION IN SAND-BED CHANNEL

Typically, the support length for piles or drilled shafts in an erodible soil has been designed considering a point of fixity of about 10 feet below original natural ground. The possibility of scour occurring below ten feet is much more likely in a non-cohesive small-grained bed material such as sand or alluvium. Therefore, even if there are no other significant risk factors, we recommend that either a Concise or Detailed Analysis be performed if a non-cohesive soil of sand-size grains and smaller is deeper than 10 feet below natural ground. If the bed material consists of cohesive soil such as clay, the response should be "NO", but the remaining questions must be addressed. Boring logs will be most useful for making this determination.

4. GENERAL CHANNEL DEGRADATION, LOCAL BRIDGE SCOUR, OR BOTH (VERTICAL DEGRADATION)

The response to Question 2 on form 113.1 may have been positive; however it is important to distinguish the difference between channel degradation that would occur even without the presence of the bridge. An example of this is the North Sulphur River which is drastically degrading over a long reach not due to the effect of a bridge, but due to significant straightening of the river and changes in the land use. Detailed scour calculations would not address this stream stability problem, yet the degradation still poses a potential threat to bridge crossings. Bridge scour could also combine with the effects of this degradation if there is a contraction at the bridge and/or presence of piers (SS and BS). If there is little or no encroachment of the road on the waterway and there is no sign of scour over and above the general channel degradation levels, the response should be "NO" (SS). The evaluator should be aware of the possibility that scour holes may have developed and subsequently been refilled by natural deposition. Head cut problems that appear to have migrated from a significant distance downstream of a structure yet may threaten the structure should also be considered as a stream stability problem (SS). A high potential for head cuts migrating upstream can result from mining or dredging operations downstream of the structure. Aggradation/degradation problems can also result from the impact of confluencing streams. Question 9 on the initial screening form 113.1 addressed this; however, it is considered that the effects of such a confluence can be addressed with this question. That is, if there is evidence to indicate increased erosion or degradation at the structure, respond "YES" (BS and SS).

5. IMPACT OF STREAM MIGRATION OR BEND (HORIZONTAL STABILITY)

This question attempts to address horizontal migration of the streambed or banks. The response to Question 8 of form 113.1 may have been positive; however, there may be potential for erosion due to streambed or bank migration. If there is any potential for bridge scour, it will be significantly higher when the bridge is located on a sharp channel bend due to higher local velocities and shear stresses. Such a situation should be deemed a risk in terms of both stream stability and bridge scour if the header banks or any bents could be threatened (SS and BS). Meanders upstream of a bridge

which appear to be migrating could also pose this threat. If the channel is gently winding in plan form, but appears to be stable with no significant signs of horizontal migration then the response may be "NO". Consideration should also be given to stream bank erosion that may be the result of the tendency of the channel system to widen. Usually, general vertical degradation is accompanied by horizontal degradation. If this is deemed to be the case and there is no significant meander, and if there are foundations that may be threatened by this widening, the response should be "YES" (SS, but not BS). If erosion on the banks only seems to be occurring in the vicinity of the bridge site rather than a long distance upstream and downstream, the response should be "YES" (SS and BS) indicating the higher risk for bridge scour.

6. HISTORICAL SCOUR DAMAGE:

Question 6 on form 113.1 may have had a positive response; however, the structure may have experienced significant flooding yet the scour that has occurred has in no way threatened the integrity of the foundations. The question is intended to address damage that is specifically attributed to scour such as the washing out of header slopes and the subsidence of bents. Damage incurred due to roadway overtopping such as guardrail damage and embankment sloughing should not be included. Also, it is important in this process to separate what is considered to be general channel degradation from bridge scour. If some general degradation has occurred, but the structure seems not to have suffered significant contraction, abutment, or pier scour the response to this question may be "NO". (General degradation was addressed in Question 4 of this screening). If scour has occurred but mitigation measures (such as the placement of rock riprap) have been performed and deemed successful, then respond "NO" (Note: Question 2 of this screening should have already addressed this but there may be instances in which the evaluator still wishes to address all questions).

7. EFFECTS OF MINING OR RELATED OPERATIONS:

Question 10 on form 113.1 addresses upstream and downstream mining or related operations. A mining or related operation within 1 mile upstream of the bridge site should be considered as an additional risk to scour (BS) due to the potential for channel degradation and possible clear water scour. Mining operations downstream may cause head cut problems that migrate upstream and are considered to be stream stability problems (SS) and should be addressed in Question 4.

8. IMPACT OF SKEWED BENTS:

Consideration should be given to the shape of the bridge foundations (piles, piers and or pile caps) that are likely to be exposed to flood waters and the angle at which the floodwaters might attack the foundations. If the bridge has only circular shaft or rectangular pile foundations at a zero to 15° angle of attack, the additional risk of pier scour can be considered to be small. At greater angles this risk can become significant (BS). If rectangular spread type footings (with or without pile supports) may be exposed, the potential for scour is much higher than for circular columns and should be considered as a bridge scour risk (BS).

9. IMPACT OF DAMS OR OTHER CONTROL STRUCTURES:

Question 12 on form 113.1 applied a significant risk to any site that was within one mile upstream or downstream of a dam. Higher depths of flow can create higher depths of scour. However, the increase in backwater upstream from a dam is accompanied by a decrease in velocity. The decrease in velocity may not completely offset the increase in depth in terms of pier scour, but a sensitivity analysis on pier scour indicates that a substantial increase in depth of flow translates to only a small

increase in pier scour depth. Additionally, since velocities are reduced in the backwater region upstream of dam, the potential for contraction scour and general degradation is decreased. Therefore, unless there is indication otherwise, bridges upstream of a dam need not be considered to be a significant additional risk and the response can be "NO". On the other hand, water released from a dam is usually clear (sediment deficient) and velocities tend to be higher resulting in clear water scour. Therefore, structures immediately downstream of a dam have a significantly higher potential for scour. Additionally, if the structure is on a tributary within one mile of a confluence with a main stream and the main stream has a dam within one mile upstream of the confluence, the response should be "YES" (BS and SS). The term "dam" is intended to apply to any major control structure such as at a water supply reservoir. Small check dams with no significant retention or detention capacity need not be considered.

10. SPREAD FOOTINGS

Question 4 on form 113.1 applied additional scour risk to any bridge that has any spread footing foundations which are not supported by piles or not embedded in solid rock. This risk factor is still applicable, so if the response to the original screening was "Yes" respond similarly. If the original screening has not been performed the appropriate response must be determined for the secondary screening.

11. DEBRIS

An additional risk for bridge scour results from structures that are prone to trap significant quantities of debris. Significant problems have been identified where large tree trunks and branches accumulate at the structure, reducing flow area and increasing velocities and turbulence. A blockage of flow area of ten percent or more should be considered significant, in which case the response should be "YES". It may be necessary to check maintenance logs to determine whether large amounts of debris have been removed from the structure.

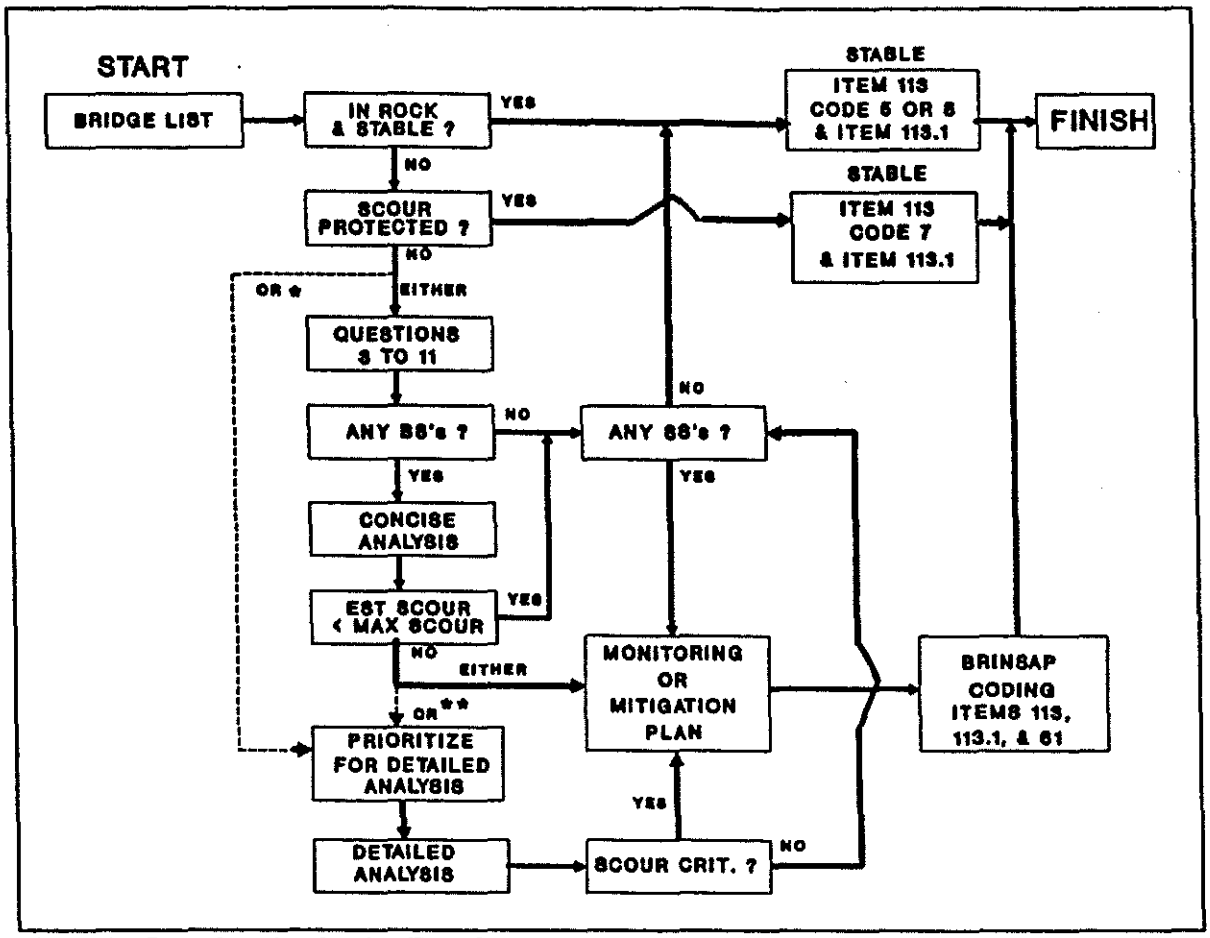


Figure 1 - Secondary Evaluation Flowchart

1 It is recommended that the Concise Analysis be performed on all but the most hydraulically complex sites or sites at which the structure severely constricts the waterway. (See Appendix D for assumptions.)

2 A Detailed Analysis should be contemplated if the results of the Concise show borderline instability if there is concern over the accuracy of the hydraulic information.

3 For stable by secondary screening, use a code of 8 for BRINSAP item 113.

D. Concise Analysis

i. Concise versus Detailed Analysis

The bridge scour calculations are reasonably straight forward; however, they are dependent on suitable hydraulic parameters. A typical Detailed Analysis involves the acquisition of several stream cross sections and field data, a determination of hydrologic parameters, a standard step backwater analysis with substantial manipulation of the data to retrieve the necessary variables for application in the appropriate scour equations. The significant abbreviation in the concise version is that the retrieval of the hydraulic data has been simplified to variables that will either have been determined during the design of the structure (and available in the construction plans) or can be estimated based on historic information and nominal additional field data. (If neither of these means of determining hydraulic parameters are reasonable, then a Detailed Analysis is recommended). Additionally, several nomographs (Appendix C) have been developed to solve the relevant scour equations. These nomographs are applicable to both the Concise Analysis and Detailed Analysis.

The following is an outline of the steps involved.

- Determination of hydraulic variables such as natural channel and through-bridge velocities, highwater elevations, and cross-section wetted perimeter and "n" values.
- Determination of maximum allowable scour based on estimated foundation bearing capacity and lateral stability.
- Estimation of maximum pier scour.
- Determination of the potential for contraction scour.
- Determination of maximum allowable flow contraction ratio.
- Determination of channel geometry contraction ratio.
- Estimation of actual flow contraction ratio
- Comparison of allowable scour depths with estimated scour depths
- Recommendations for BRINSAP coding and/or further handling.

The Concise Analysis Worksheets (Appendix B) should be completed for all structures needing such an evaluation. The worksheets will serve as the documentation. A detailed description of the Concise Analysis follows.

Note: Once the user becomes familiar with these instructions, the worksheet will be the only paperwork necessary. These instructions need not be attached to each site evaluation.

1.0 DETERMINATION OF HYDRAULIC VARIABLES

The following information is required for a Concise Analysis.

- Unconstricted section at bridge (natural channel)
- Location of bridge headers and piers and lowchord elevation
- Discharge (Q)
- Section roughness coefficients (Manning's "n")
- Highwater elevations
- Unconstricted channel average velocity (V_c)
- Constricted average velocity (through-bridge) (V_b)

This information, at least for newer structures, should be available in the construction plans or in the design files. If this information is not available, refer to 1.1 for recommendations on how to acquire suitable information without resorting to a Detailed Analysis.

The discharge, average velocities (unconstricted and constricted), and water surface elevation to be applied in the Concise Analysis should be the lower of the following:

- The highest frequency that the bridge will convey without overtopping the roadway or bridge
- The 100 year flood

For example, if a structure has been designed to clear the 100 year flood without causing any overtopping, then the Concise Analysis should be based on the velocities and highwater resulting from the 100 year flood. If overtopping is expected during the 100 year flood, then the highest design flood that will not incur overtopping should be used.

If the design or historic maximum highwater elevation and discharge are available with no documentation of velocities, the average unconstricted velocity may be determined by dividing the discharge by the area subtended by the highwater in the unconstricted section, and the average through-bridge velocity by dividing the discharge by the area subtended by the highwater at the bridge opening. Alternatively, the method outlined in 1.1 may be used.

1.1 Simplified Derivation of Hydraulic Variables for Concise Analysis

In some instances, especially for older structures and off-system structures, the required hydraulic variables are not readily available. This section outlines a means by which the following variables can be estimated for use in the Concise Analysis.

- Highwater elevation for maximum potential scour
- Discharge for maximum potential scour
- Unconstricted average velocity
- Through-bridge average velocity

Once these variables have been determined, the Concise Analysis can proceed as outlined in Section D. The variables determined here are based on the assumption that the worst scour condition is likely to occur just as the roadway or structure is about to be overtopped (incipient overtopping). For many structures this will occur at flood frequencies of less than 100 years. This method will only be too conservative if a structure is likely to pass a flood in excess of the 100 year flood without overtopping. If a structure is likely not to overtop during a 500 year flood, it may be preferable to use usual hydrologic and hydraulic methods (Detailed Analysis) to determine scour depths. On the other hand, this process is relatively straight forward to such an extent that it may be worthwhile to apply it even on such high flow capacity structures, then only perform a Detailed Analysis if the resulting scour depths appear excessive (i.e. the structure is unstable for such an extreme condition but may not be for the expected 100 year conditions). This method should only be applied for single opening structures. If no existing hydraulic information is available for a multiple opening site, a Detailed Analysis using WSPRO is suggested.

The approach is as follows.

1. Retrieve one field cross section in the vicinity of the bridge but away from the influence of the highway embankment. e.g. along right-of-way line. Ensure that the section is taken approximately perpendicular to the direction of flood flow or adjusted appropriately.

2. Make a field visit to estimate section roughness coefficients (Mannings "n").

3. If no bridge section data is available, determine the location of the bridge headers and piers, the elevation at which either the road or the bridge will overtop, and the lowchord elevation.

4. Use a topographical map, such as the 7.5' USGS quadrangles, to estimate an average channel bed slope.

5. Use the HYDRA subsystem of THYSYS (or any suitable program) to develop a stage discharge curve using the surveyed section, assigned "n" values, estimated slope and any random discharge (for THYSYS).

6. Abstract the discharge (Q) and average velocity (V_c) at the incipient overtopping elevation.

7. Using the CULBRG subsystem of THYSYS (or other program) append the bridge information to the previous HYDRA information and determine the through-bridge velocity (V_b) using the discharge (Q) derived in step 6 and the incipient overtopping elevation.

8. Proceed to the Concise Analysis worksheets using the incipient overtopping elevation and the surveyed section to determine appropriate depths of flow, and using Q, V_b, and V_c as determined above.

Section B indicated an estimated time and expense for sites with no hydraulic data. This is to account for the extra effort outlined above. Note that considerable time has been saved by avoiding a detailed hydrologic investigation, but as previously mentioned, the additional expense of a Detailed Analysis may be warranted if the results of this approach seem too conservative.

2.0 DETERMINATION OF ALLOWABLE SCOUR DEPTH

Determine maximum allowable scour depth (y_a) based on the lateral stability and bearing load stability of the foundation. The embedment depth at every pier need not be computed but the critical pier (ie. minimum embedment) should be considered for this application. The scour depths are typically larger within the main channel through the bridge because of the higher velocities and depths of flow; therefore, careful consideration should be given to the selection of the pier embedment depth utilized (see Figure 2). If the channel has the propensity to meander, and piers that are not within the main channel at the present time may inevitably be located as such, the minimum embedment of piers located in the overbank areas under the bridge may need to be considered. Otherwise, typical main channel and overbank pier embedment depths may be utilized in the estimation of allowable scour depths (Figure 2). The lateral stability of the pier/column must be checked to ensure the stability of the foundation based on an increased unsupported column length caused by a scour hole.

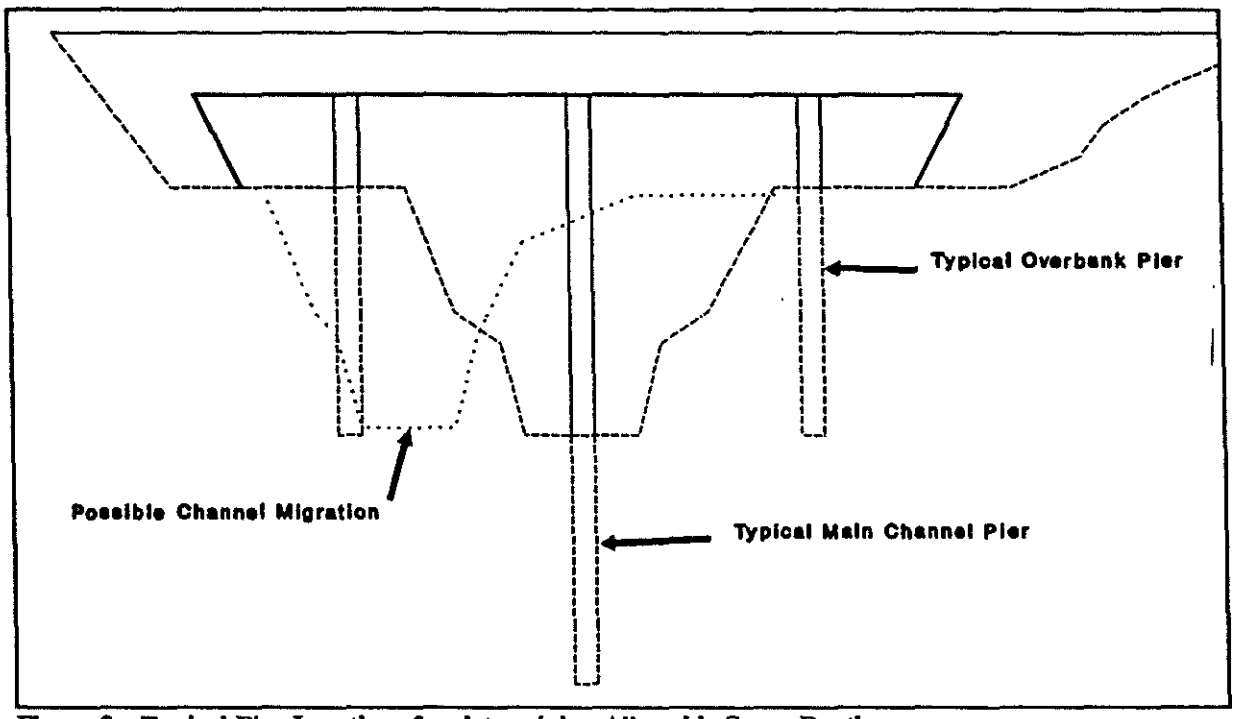


Figure 2 - Typical Pier Locations for determining Allowable Scour Depths

The following steps outline the procedure:

2.1 Allowable scour depth at a pier/column based on bearing load stability (see Figure 3):

y_{ab} = 50 % of original foundation embedment

2.2 Allowable unsupported column length for lateral stability:

Column/Drill Shaft:

y_u (feet) = 1.5 x diameter of column/drill shaft (inches)

Trestle Pile:

y_u (feet) = 2.0 x diameter of pile (inches)

H or Square Pile:

y_u (feet) = 2.0 x nominal section depth of pile (inches)

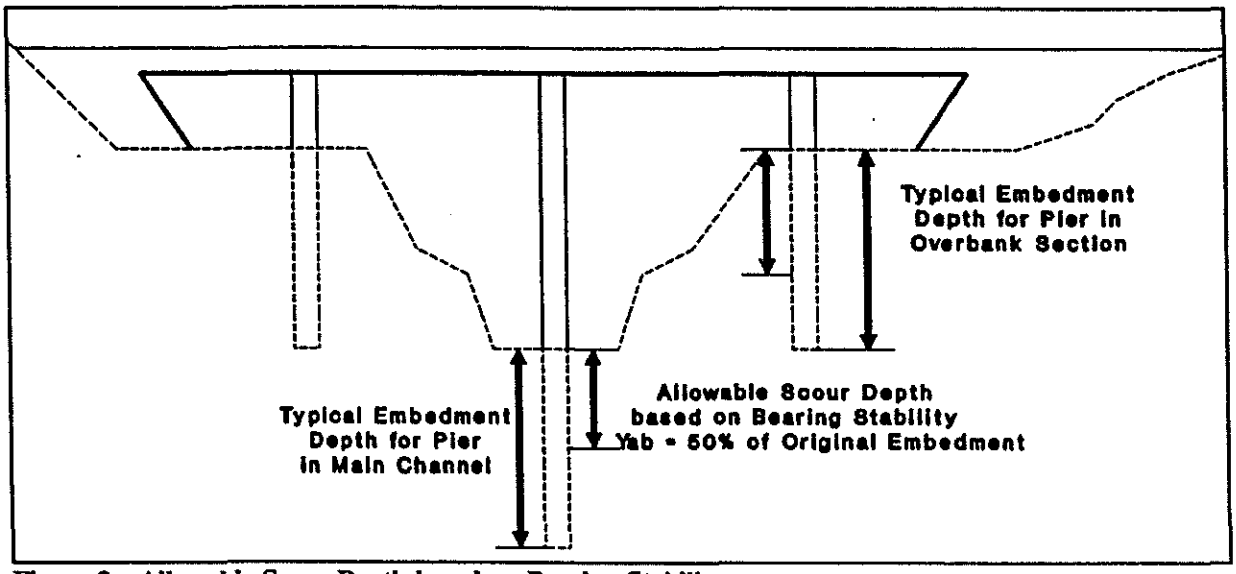


Figure 3 - Allowable Scour Depth based on Bearing Stability

2.3 The Maximum allowable scour depth based on lateral stability (see Figure 4):

y_{al} = The allowable unsupported length (y_u) - existing exposed length (y).

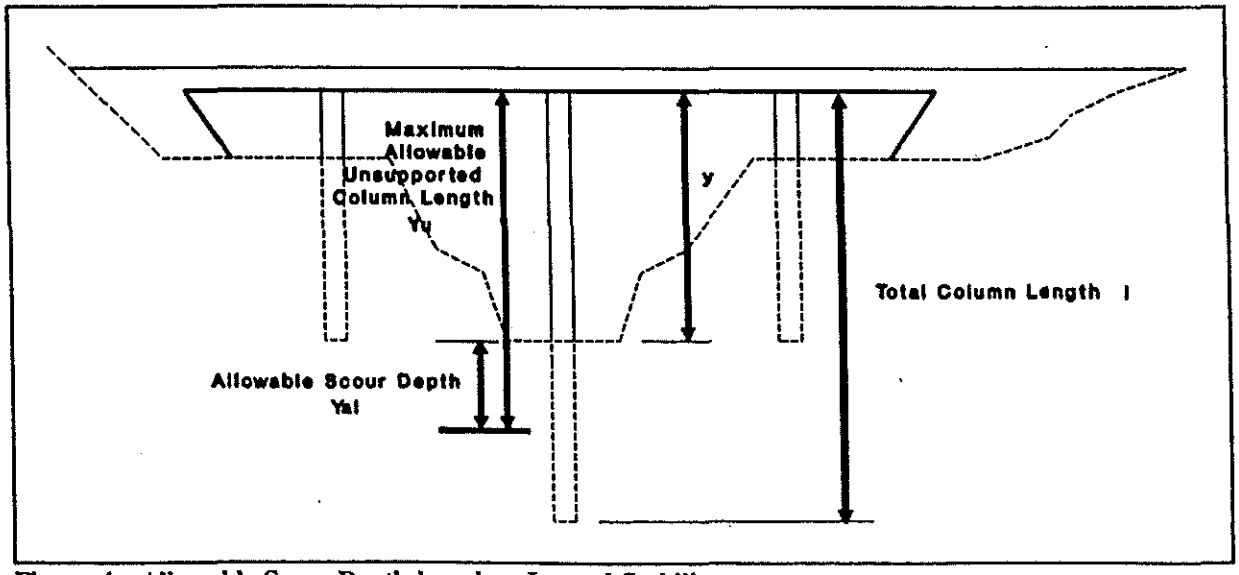


Figure 4 - Allowable Scour Depth based on Lateral Stability

2.4 The maximum allowable scour depth at a particular column or representative group of columns is the minimum value based on the bearing or the lateral stability:

$y_a = y_{al}$ if $y_{al} < y_{ab}$

$y_a = y_{ab}$ if $y_{ab} < y_{al}$

What if the above procedure is not applicable for some foundations?

The Concise Analysis can still be performed for situations in which an allowable scour depth is not readily determinable. Subsection 5 of Section D outlines the relevant approach.

3.0 DETERMINATION OF MAXIMUM PIER SCOUR DEPTH

The maximum potential pier scour should be determined for representative pier locations. Consideration should be given to piers within the main channel and/or to piers in the channel overbank portions where velocities and depths differ. If the channel has the potential to laterally migrate and piers which are not presently within the main channel could be within the expected life of the structure, consider those piers to be located within the main channel for pier scour estimates.

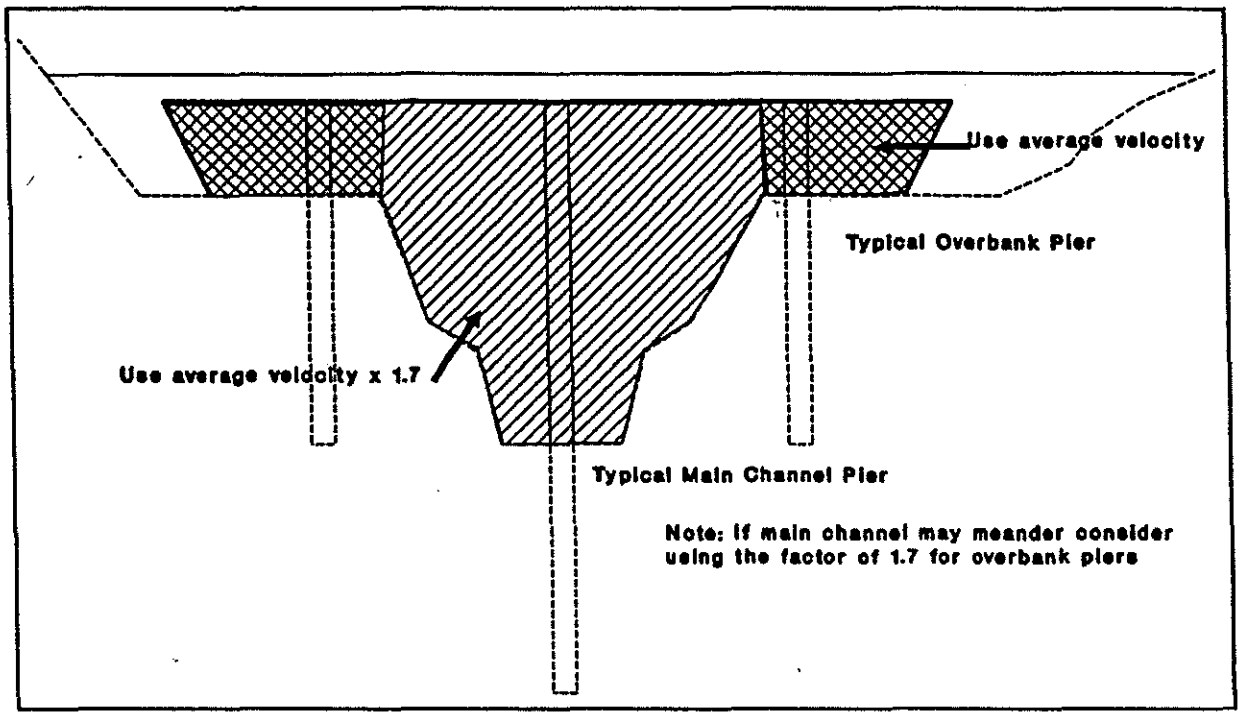


Figure 5 - Locations, Velocity and Depths for Pier Scour Calculations

The following steps outline the procedure:

3.1 The average through bridge velocity (V_b) and the maximum depth of flow in the main channel and/or overbank portions under the bridge (y_1) for the highwater condition established in accordance with 1.0 or 1.1., should be used. For irregular channel cross sections and piers located within the main channel, the velocity used in the pier scour calculation should be $V = 1.7 \times V_b$. If the section under the bridge approximates a trapezoid, use $V = V_b$ since there tends to be much less of a variation between local velocities and the average velocity. $V = V_b$ can also be used as a conservative estimate for pier scour in overbank areas since local velocities in overbank areas tend to be lower than the average velocity.

Adjustment for debris:

In an attempt to account for the increased scour potential resulting from debris, the Hydraulics Section recommends the following adjustment to the estimate of velocity for pier scour computation:

1. **Estimate the percentage of bridge area that is blocked or typically gets blocked by debris - P %**

2. **Multiply the appropriate velocity described above by the factor (1+P/100)**

3. **Use the adjusted velocity to compute pier scour.**

3.2 Using the pier scour nomograph C-1 (Appendix C), enter with the pier width (a), velocity (V), depth of flow (y_1), determine the maximum estimated pier scour (y_s). The pier scour nomograph is based on the following equation:

$$y_s = 2.0 y_1 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} \qquad \textbf{Equation (1)}$$

where:

y_s = depth of scour (feet)
y_1 = flow depth upstream of the pier (feet)
a = pier width (feet)
g = gravitational constant = 32.2 ft/s^2

Fr_1 = Froude number = $\dfrac{V_1}{\sqrt{g y_1}}$

3.3 Using the scour depth obtained from the nomograph, make adjustments to y_s for pier nose shape, angle of attack, the spacing of columns or piers, and compute the maximum potential pier scour as follows:

Using a modified pier scour equation:

$$y_{ps} = K_1 K_2 y_S \qquad \textbf{Equation (2)}$$

where:

y_s = pier scour value obtained from the nomograph (feet)
K_1 = Correction factor for pier nose shape (see Appendix E)
K_2 = Correction factor for angle of attack (see Appendix E)
y_{ps} = maximum pier scour (feet)

Determination of K_2 requires the pier length (L). The following recommendations are made for determining L.

- For single-column bent use L = pier diameter in feet.

- For multiple-column bent:
  If clear distance between columns > 5 column diameters and no significant debris, use L = pier diameter in feet.
  If clear distance between columns > 5 column diameters but large size debris expected, use L = distance from upstream face of upstream pier to downstream face of downstream pier in feet.
  If clear distance between columns ≤ 5 column diameters, use L = distance from upstream face of upstream pier to downstream face of downstream pier in feet.

- For webwalls or rectangular footings, use actual length of bent or footing in feet.

- If piers are supported on spread-type footings that are likely to be exposed during flooding, use spread footing length.

The pier width (a) should be based on the widest obstruction of the bent that is likely to be exposed during flooding.

3.4 If the allowable scour depth (y_a) is greater than the estimated pier scour (y_{ps}), i.e. $y_a > y_{ps}$, then continue to 4.0. Otherwise, if the estimated pier scour is greater than the allowable, i.e. $y_{ps} > y_a$, the bridge may be considered unstable and may require a Detailed Analysis, monitoring and/or physical mitigation measures and should be coded as a 3 for BRINSAP item 113, and go to Section E - Reporting Procedures.

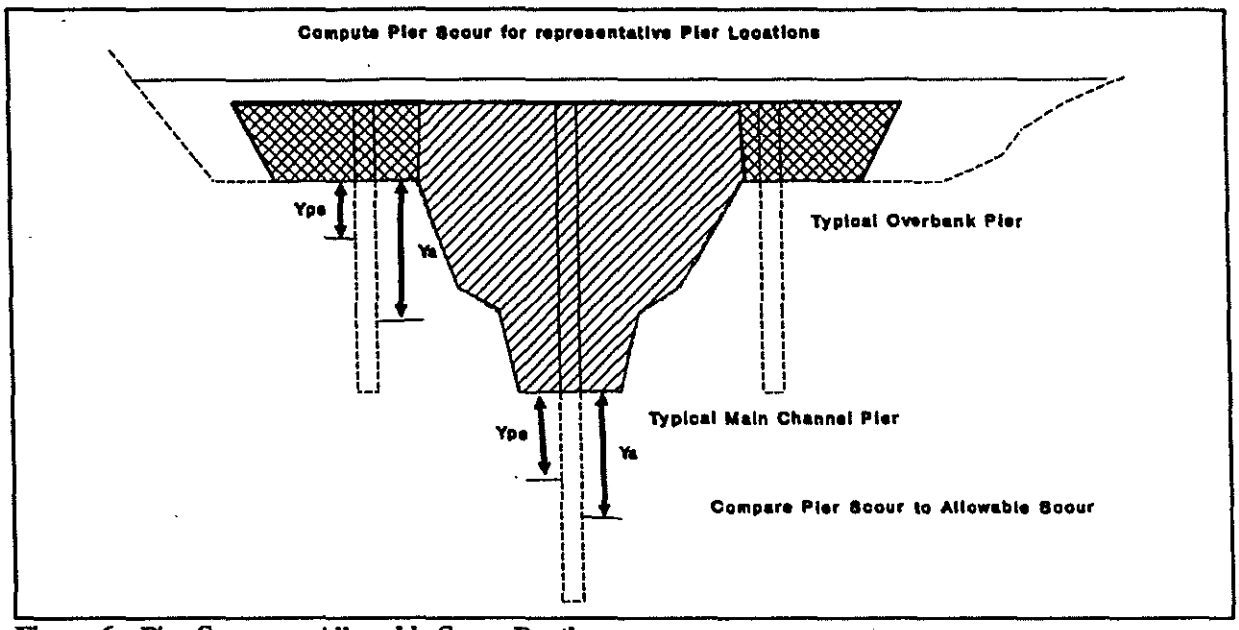


Figure 6 - Pier Scour vs. Allowable Scour Depth

4.0 DETERMINATION OF CONTRACTION SCOUR DEPTH

The two types of contraction scour which may occur are Live-bed and Clear-water scour. The live-bed scour will typically occur within the limits of the main channel where approaching velocities are higher. Clear-water scour may typically occur within the overbank areas under a bridge structure or through the entire limits of a relief structure where, in both instances, approaching velocities to these areas are typically less than those found in the main channel. The determination of which type of contraction scour and the limits over which it will occur must be investigated (see Figure 7 for typical locations).

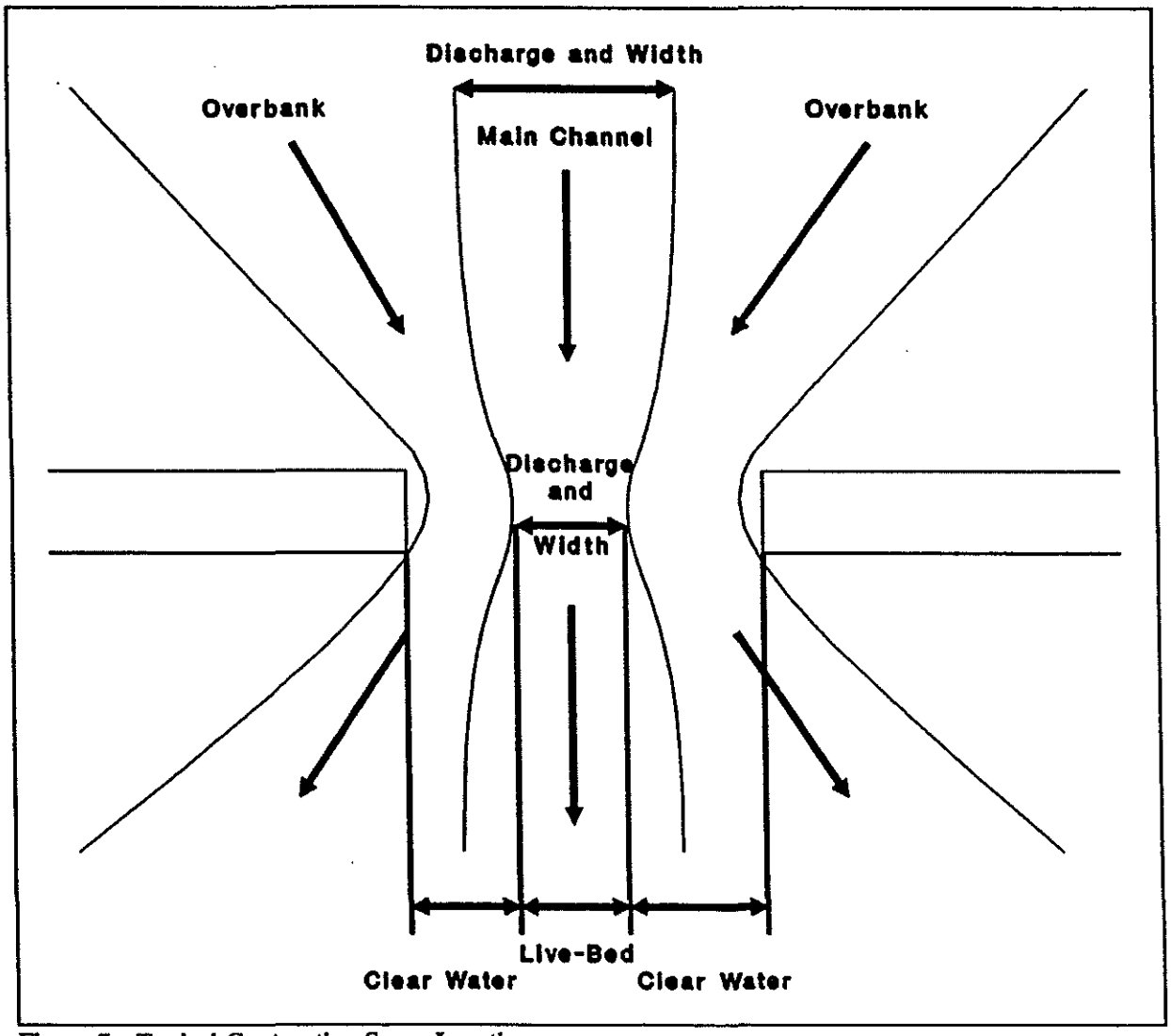


Figure 7 - Typical Contraction Scour Locations

The following outlines the appropriate steps:

4.1 If the highway embankment does not encroach on the flow, jump to 4.9 because no contraction scour needs to be computed. Otherwise, proceed to 4.2. The absence of a contraction may be determined because the through bridge velocity is not higher than the average unconstricted velocity. The total scour is merely the pier scour which was already

evaluated in step 3.4 as being less than the allowable scour depth so the bridge can be considered stable.

4.2 If a contraction exists, determine the maximum non-scour velocity allowed based on the soil type and depth of flow from Appendix F. Use the average through bridge velocity $V = V_b$ when considering contraction scour in a trapezoidal channel section or overbank areas under the bridge, otherwise, use $V = 1.7 \times V_b$ for contraction scour in the main channel. If the velocity through the bridge (V) is less than the value obtained from Appendix F the velocity is not high enough to cause contraction scour. The total scour is merely the pier scour which, to have reached this step, already should have been evaluated in step 3.4 as being less than the allowable scour depth so the bridge can be considered stable. If this is the case, jump to 4.9, otherwise proceed to step 4.3.

4.3 Compute the maximum allowable contraction scour depth (y_c) for each applicable region under the bridge (Figure 8). In many instances, the bridge section can be split up into three regions: left overbank, main channel, and right overbank. Some bridges may only span the main channel, in which case no overbank regions will be applicable.

y_c = maximum allowable scour depth - maximum potential pier scour depth (feet)

ie:

$y_c = y_a - y_{ps}$

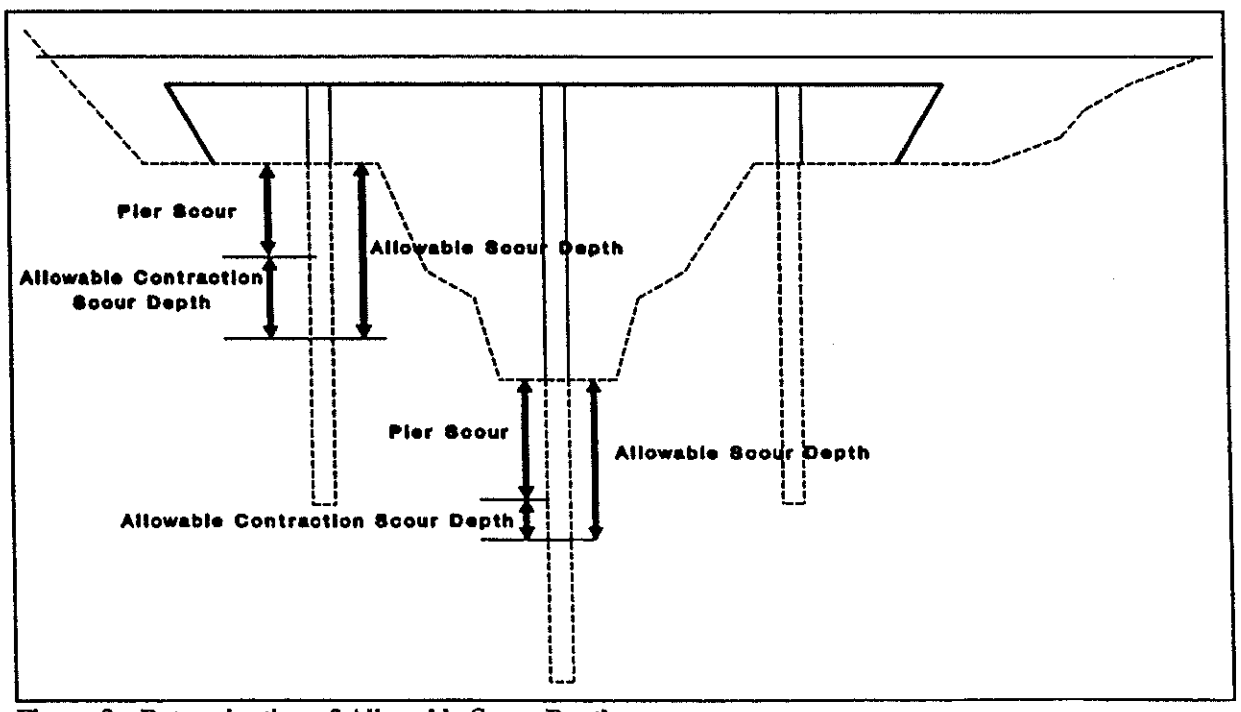


Figure 8 - Determination of Allowable Scour Depths

4.4 Determine maximum unconstricted velocities for each applicable region. i.e. the same regions as used in step 4.3. (left overbank, main channel, and/or right overbank). The maximum velocity in the unconstricted main channel may be taken as $V = 1.7 \times V_c$ or, for rectangular

or trapezoidal channels use $V = V_c$. V_c is the average unconstricted channel velocity determined in 1.0 or 1.1. Generally, for the left and right overbank subsections velocities are significantly less than the average section velocity. If V_c is used in such instances, it is more than likely that the process would identify live bed scour when clear water scour should be occurring. A value of $V = 0.7 \times V_c$ is considered to be reasonable for the overbanks. However, if the depth of flow in the overbank is greater than half the depth of flow in the main channel, use $V = V_c$.

4.5 If contraction scour can occur, determine which type of contraction scour to estimate (live-bed, clear water, or both) and the location of each type under the bridge opening. This step is necessary if the through bridge velocity is higher than the non-scour velocity from Appendix F as determined in step 4.2.

Compute the critical velocity for incipient motion using Equation 3.

$$V_{cr}=11.52y^{\frac{1}{6}}d_{50}^{\frac{1}{3}} \qquad \textbf{Equation (3)}$$

where:

V_{cr} = Critical velocity for incipient motion (fps)(based on a bed material with a specific gravity of 2.65).
y = depth of flow (ft).
d_{50} = median particle size diameter (ft) (a suggested minimum for cohesive soils is 0.1 mm = .000328 ft).

For each applicable region, if $V > V_{cr}$, consider live-bed contraction scour to occur, within the applicable portion of the cross section and proceed to step 4.6. Otherwise, consider clear water contraction to occur within the applicable section and proceed to step 4.7.

4.6 **Live-bed contraction scour**

Using the live-bed contraction scour nomograph C-2 (Appendix C) estimate the discharge ratio (q_a), $q_a = Q_t/Q_c$, that would be required to create the allowable contraction scour (y_{ca}) The nomograph is based on the contraction scour equation:

$$\frac{y_2}{y_1}=\left[\frac{Q_t}{Q_c}\right]^{\frac{6}{7}}*\left[\frac{W_1}{W_2}\right]^{.69} \qquad \textbf{Equation (4)}$$

where:

y_{ca} = contraction scour depth = $y_2 - y_1$ (feet)
y_1 = average depth in main channel upstream of contracted section (feet)
y_2 = average depth in contracted section including contraction scour (feet)
W_1 = bottom width of main channel upstream of contracted section (feet)
W_2 = bottom width of contracted section less the cumulative width of piers in the main channel (feet)
Q_c = main channel flow upstream of contracted section (cfs)

Q_t = main channel flow in contracted section (cfs)

The process can be determined as follows:

a. Compute the width ratio (w) = W_1/W_2. If there is no width contraction in the main channel through the bridge where w < 1.0, use w = 1.0.

b. Enter the live-bed contraction scour nomograph with the width ratio (w), y_1 (average depth of flow in unconstricted channel), $y_2 = y_c$ (allowable contraction scour) + y_1, and determine the maximum allowable q_a, discharge ratio (Q_t/Q_c). The depth of flow in the unconstricted section (y_1) should be based on the computed highwater (HW) for the bridge less the flowline (thalweg) of the main channel.

4.6.1 Estimate the actual discharge ratio. Given $q = Q_t/Q_c$, assuming the discharge through the main channel of the bridge is equal to the total discharge (i.e. no overtopping). Estimate the discharge ratio using the following equation[3]:

$$q=\left(\frac{n_b}{n_u}\right)\times\left(\frac{V_b}{V_u}\right)^{\frac{5}{3}}\times\left(\frac{P_b}{P_u}\right)^{\frac{2}{3}} \qquad \text{Equation (5)}$$

where:

q = estimated actual discharge ratio
n_b = weighted "n" value through the bridge opening
n_u = weighted "n" value in the unconstricted natural section
V_b = average through bridge velocity (fps)
V_u = average unconstricted (natural section) velocity (fps)
P_b = estimated total wetted perimeter through the bridge opening (feet)
P_u = estimated total wetted perimeter in the unconstricted (natural) section (feet)

4.6.2 Compare the actual discharge ratio (q) with the maximum allowable discharge ratio (q_a). If the discharge ratio computed in 4.6.1 is less than the maximum allowable obtained from nomograph C-2 then the bridge is not at risk to scour failure based on this abbreviated analysis, and the bridge may be considered stable for the scour conditions utilized. (A code of 8 may be entered for BRINSAP Item 113). If the actual discharge ratio (q) is greater than the maximum allowable ratio (q_a) then there is a potential for unstable conditions. An appraisal of the boring logs should be made to consider the erodible nature of subsurface material and whether a Detailed Analysis, monitoring, and/or physical mitigation is required. If no other contraction scour components are expected then jump to 4.9, otherwise proceed to 4.7.

[3]See Appendix D for explanation and limitations.

4.7 **Clear-water contraction scour**

Estimate clear-water contraction scour for all applicable areas under the bridge structure. The clear water scour nomograph (Appendix C) is based on the following equation:

$$y_2 = \left[\frac{Q^2}{120 d_{50}^{\frac{2}{3}} W^2} \right]^{\frac{3}{7}} \qquad \textbf{Equation (6)}$$

where:

y_2 = Average depth in contracted section including contraction scour (feet)
Q = Total discharge in the section experiencing clear water scour (cfs)
d_{50} = Median particle size diameter (feet) (a suggested minimum for cohesive soils is 0.1 mm = 0.000328 feet)
W = Total width in the sub-section experiencing clear water scour less the width of any piers in the sub-section (feet).

The process can be determined as follows:

a. For overbank areas under the bridge, compute the discharge by estimating the area of flow in the applicable overbank (A) and use the relationship $Q = A \times 0.7 \times V_{ave}$*. For a relief structure use the entire discharge through the bridge.
* The application of 0.7 times the average channel velocity to the overbank area generally is reasonable since lower than average velocities typically exist in the overbanks (often less than half of V_{ave}). Use of V_{ave} was determined to be too conservative for most situations; however, if the flow depths in the overbanks are more than half the depth in the main channel, use V_{ave} as a conservative estimate.

b. Enter the clear water scour nomograph (C-3) with the ratio Q/W and the d_{50} particle size to obtain the value for y_2.

c. Compute the clear water contraction scour depth (y_{cs}) from the value y_2 and the depth of flow through the applicable sub-section (y_1) using:
$y_{cs} = y_2 - y_1$ (feet)

4.8 Compare the clear water scour depth (y_{cs}) with the maximum allowable contraction scour depth (y_c) through the applicable portions of the bridge opening. If the scour depth computed (y_{cs}) in 4.7 is less than the maximum allowable contraction scour (y_c) from 4.3 then this portion of the bridge or the entire bridge, if applicable, is not at risk to scour failure based on this abbreviated analysis. The bridge may be considered stable for the scour conditions utilized and a code of 5 or 8 may be entered for BRINSAP Item 113. If the computed clear water scour depth is greater than the maximum allowable contraction scour then there is a potential for unstable conditions. An appraisal of the boring logs should be made to determine if erodible material exists and whether a Detailed Analysis, monitoring, and/or physical mitigation is required.

4.9 Go to Section E - Reporting Procedures.

5.0 Alternate Concise Analysis

There may be situations in which the guidance for estimation of maximum allowable total scour is not applicable to specific foundation types. In such instances, the Concise Analysis may be performed using the same required information and nomographs, but instead of comparing a maximum allowable contraction ratio to estimated contracted ratio, total scour depths can be estimated as follows.

1. Follow items 4.1 through 4.5 to determine whether or not contraction scour is expected and if so, whether to compute live bed scour or clear-water scour.

2. For live-bed scour:
   a. estimate the actual contraction ratio (q) as outlined in 4.6.1.
   b. Using the variables defined in 4.6 and nomograph C-2, determine the contraction scour (y_{cs}).
      Note: This is done by reversing through the nomograph example to determine y_2, then $y_{cs} = y_2 - y_1$.

3. For clear-water scour, compute y_{cs} as outlined in 4.7 using nomograph C-3.

4. Compute pier scour (y_{ps}) as outlined in 3.1 to 3.3

5. Summate appropriate pier scour and contraction scour ($y_{ps} + y_{cs}$) and indicate depths on bridge layouts.

6. Request the Division appraisal of analysis and foundation conditions to determine stability (see Section E).

7. Based on recommendations from the Division, complete BRINSAP items 113, 113.1 and, if necessary, item 61.

E. Reporting Procedures

The goal of the scour evaluation program is to identify structures that are at risk to scour-related failure. The results of the Secondary Evaluation process should be to place each structure in one of the following categories:

- Stable for bridge scour by screening
- Possible instability due to stream stability problems but stable for bridge scour
- Possible instability due to stream stability problems and unstable for bridge scour
- Stable for bridge scour by Concise Analysis
- Unstable by Concise Analysis
- Report results of Detailed Analysis.

The formal recording of the results of each evaluation must be on the BRINSAP coding program. Table 1 should be used to determine which item and code should be used. This reporting process should be performed by, or in consultation with, your district BRINSAP coordinator. Item 113.1 must be coded to reflect the completion of the Secondary Evaluation. Those structures not coded "Q", "R", "S", "T", or "U" will be assumed to have had no secondary evaluation. Structures having received a Detailed Analysis (Level 2) must also show "S" or "U" on item 113.1. Structures identified as stable by virtue of the secondary screening should receive a BRINSAP item 113 coding of 8. Those structures determined to be stable by Concise Analysis or Detailed Analysis should receive a BRINSAP item 113 code of 5 or 8 (see coding guide). The BRINSAP Manual of Procedures Coding Guide should be referenced for item 113 coding of structures rated as unstable. In some instances, it may be preferable to await results of further evaluation before coding item 113 for unstable structures, especially if the results were borderline unstable using the Concise Analysis. Most often, the Concise Analysis should yield conservative results.

What about the sites determined to be low risk during the initial screening?

With the exception of those structures rated as low risk by ADT < 150, those sites identified as low risk during the initial screening process may be considered stable. The BRINSAP or Scour coordinator should begin updating BRINSAP item 113 with a code of 8 for all such structures. These structures can be identified as those having BRINSAP item 113.1 codes of A or E. The item 113.1 code must not be adjusted.

For structures determined to be unstable for the estimated scour conditions, there are several options:

1. Prioritize for a Detailed Analysis (Level 2).
2. Recommend for prioritization for monitoring.
3. Recommend prioritization for remedial action.
4. Request Division appraisal of site evaluation and recommendations for further action.

In many cases, it is likely that a Detailed Analysis will show similar results to the Concise Analysis. Only the borderline cases may show to be unstable on the Concise but stable on the Detailed Analysis (and vice versa). It is recommended that Detailed Analyses be performed only on those sites for which the assumptions made for the Concise Analysis (see Appendix D) are not reasonable. See Appendix D for guidance on what may not be considered reasonable. Sites with known severe scour problems should be reported and recommended for remedial action or recommended for Division review. (A severe scour problem can be considered one in which scour depths have already exposed 50% or more of the original foundation embedment). Sites with known scour problems but which

do not pose an urgent threat should be recommended for monitoring or Division review.

Some sites may emerge from the secondary screening process as having risks related to stream stability problems. In such cases, whether or not the structure was rated as stable to bridge scour, BRINSAP item 61 should be reviewed and modified, if necessary, to reflect the existence of the problem. Additionally, the site should receive recommendations for prioritization for monitoring or remedial action.

The Secondary Evaluation Process is complete when BRINSAP items 113.1, 113 and 61 have been addressed as described above. Those structures identified as stable with no significant stream stability threats will require no further attention over and above the usual bridge inspection process. For the remaining sites, those that have been identified as requiring a Detailed Analysis will be re-prioritized by the Division in accordance with the procedures adopted during the Initial Screening and Prioritization process. Also, a prioritized list of sites requiring monitoring or remedial action will be developed.

Under what circumstances should I request Division review?

At your discretion, you may request Division review of any scour analysis; however, to promote efficiency, it is recommended that review by the Division be requested for the following situations.

- Either Concise or Detailed results indicate potential unstable conditions, yet experience with the site and soil conditions indicates otherwise.
- Either Concise or Detailed results indicate stable conditions, but a more detailed foundation appraisal and/or detailed review of calculations is desired.
- The structure is in urgent need of mitigation and recommendations from the Division are desired.
- Maximum allowable scour depths based on the foundation type are not readily determinable and the alternate Concise Analysis or Detailed Analysis has been performed.

Any requests for Division review should be made in writing to the Director, to the attention of the planning engineer for your district.

Table 1 - Reporting Options

SECONDARY EVALUATION RESULTS	BRINSAP ITEM 113 (Scour)	BRINSAP ITEM 113.1 (scour vulnerability)	BRINSAP ITEM 61 (Channel conditions)
Low risk by Initial Screening ADT > 150	8	No adjustment	No adjustment
Stable by Secondary Screening	8	Q	No adjustment
Stable by Concise Analysis	5 or 8	R	No adjustment
Stable by Detailed Analysis	5 or 8	S	No adjustment
Unstable by Concise Analysis	*	T	*
Unstable by Detailed Analysis	*	U	*
Stable but Stream Stability risks	5 or 8	Q,R, or S	*
Unstable and Stream Stability risks	*	T or U	*
Remedial measures in place and effective	7	Q	No adjustment

* Refer to BRINSAP Coding Guide and adjust as necessary and/or request Division review

Note: The Initial Screening and Detailed Analyses are not specifically part of the Secondary Evaluation process; however, the reporting procedures are applicable.

F. Summary

The Texas Evaluation and Analysis for Scour (TSEAS) process has been established to conform with the intent of the Federal Highway Technical Advisory 5140.23 and has been modeled around the procedures contained in the Federal Highway Administration Hydraulic Engineering Circular 18 (HEC-18) entitled "Evaluating Scour at Bridges". The goal of TSEAS is to help identify structures that may fail due to the effects of scour. The high number of bridges over waterways in Texas necessitated a relatively short, yet effective means of determining which structures should receive further attention regarding possible scour failure. TSEAS addresses this by providing a Secondary Screening Process and Concise Analysis which, for many sites, will help identify the level of risk to scour at a fraction of the cost associated with conventional extensive analyses (Detailed Analyses). The major differences between a Concise Analysis and a Detailed Analysis are that several simplifying assumptions for the derivation of hydraulic parameters have been incorporated into the Concise Analysis. The scour equations set forth in HEC-18 have not been modified other than the use of several conservative default parameters. Several nomographs have been developed to help reduce calculation time. Some sites will emerge from this process still requiring further analysis; however, it is anticipated that this process will suffice for the majority of sites.

Any questions regarding the procedures outlined in this document should be addressed to the Division, Hydraulics Section.

APPENDIX A
WORKSHEET FOR
SECONDARY SCREENING

Secondary Scour Evaluation

District		County	
Bridge No.		Highway	
Crossing		SVEAR	

1. FOUNDATION SET IN NONERODIBLE ROCK:

Is the foundation embedded in at least one shaft diameter into nonerodible rock (if spread footing at least 3 inches embedment)?

_____ No. The foundation is not embedded in nonerodible rock. Continue with question 2.

_____ Yes. The foundation is embedded in sound, nonerodible rock. Complete the following table to determine if the unsupported length of the critical support is stable.

Pile Type	Steel H Pile	Concrete Pile/Pier	Concrete Column	Other
A. Diameter or width (inches)				
B. Approximate stability limit factor (ft/inch)	2.0	2.0	1.5	
C. Allowable unsupported length = AxB (ft)				
D. Unsupported length (to nonerodible layer)				

√	Recommended Action		Item 113 (1)	Item 113.1
	No further action required	unsupported length, D ≤ C		E
	Analyze unsupported length of supports	unsupported length, D > C		(2)

(1) Code item 113 a 4, 5, or 8 according to the BRINSAP coding guide.
(2) Leave item 113.1 unchanged pending results of structural analysis.

- If yes and unsupported length stable, stop here after checking recommended action above.

2. EXISTING COUNTERMEASURES

Have scour countermeasures been installed which appear to be functioning properly so that no foundations are threatened?

_____ No. Scour countermeasures have not been installed. Continue with questions 3 through 11.

_____ Yes. Scour countermeasures have been installed and appear to be functioning properly. No further investigation of the scour potential is necessary.

√	Recommended Action	Item 113	Item 113.1
	No further action required	7	Q
	Monitor effectiveness of countermeasures	7	Q

- If yes, stop here after checking recommended action above.

3. FOUNDATION IN SAND-BED CHANNEL:

Is the foundation embedded in sand bed (or finer non-cohesive material) channel with more than a 10 foot depth of sand bed below natural ground?

_____No. The foundation is not embedded in a sand bed channel with more than a 10 foot depth of sand below natural ground.

_____Yes (BS). The foundation is embedded in more than 10 feet of sand bed.

4. GENERAL CHANNEL DEGRADATION, LOCAL BRIDGE SCOUR, OR BOTH (VERTICAL STABILITY):

Is there any evidence of scour or erosion at the abutments or piers below the original natural ground line which is localized within the bridge area rather than throughout the channel reach?

_____No. No scour or erosion is evident at the abutments or piers.

_____No (SS). Erosion is evident throughout the channel reach indicating a condition more applicable to long term or channel degradation rather than localized contraction scour problem isolated at the bridge site.

_____Yes (BS). There is evidence of erosion or scour localized at the bridge site which indicates contraction and/or local scour occurring at the bridge instead of channel degradation throughout the channel reach.

_____Both (SS and BS) . Erosion is evident throughout the channel reach with more significant erosion or scour appearing at the bridge site.

5. IMPACT OF STREAM MIGRATION OR BEND (HORIZONTAL STABILITY):

Is the bridge crossing located in a meandering section of the stream or are there indications of lateral migration of the channel bed or banks?

_____Yes (SS). Lateral migration of the channel bed and/or banks could pose a threat to abutment or pier foundations.

_____Yes (SS and BS). The stability of the stream and structure appear to be threatened due to potential or actual meandering and migration of the stream.

_____No. Not applicable or the stream bed is meandering near the bridge section but does not have any foreseeable impact on the structure or stream stability.

6. HISTORICAL SCOUR DAMAGE:

Do the bridge, piers, abutments or highway embankments in the vicinity of the bridge have any history of flood damage that may be associated with scour?

_____No. The bridge, piers, abutments or embankments have not suffered damage from erosion or scour during flood events.
_____Yes (BS). Erosion or scour has damaged the bridge, piers, abutments or embankments during historical floods.
_____No Historical Data Available

_____
_____

7. EFFECTS OF MINING OR RELATED OPERATIONS:

Are there any commercial material mining operations, in-stream borrow areas, or dredging operations located within 1 mile upstream of the bridge?

_____Yes (BS or SS).
_____No.

_____
_____

8. IMPACT OF SKEWED BENTS:

Are the bents skewed to the direction of flow at flood stage?

_____No.
_____Yes. But, the angle of attack at flood stage is less than 15° and the bents consist of a group of cylindrical or square columns.
_____Yes. But, the supports are single column bents.
_____Yes (BS). The angle of attack is greater than 15°
_____Yes (BS). The bents are skewed 5° to 15° and do not consist of a group of cylindrical or square columns.

_____
_____

9. IMPACT OF DAMS OR OTHER CONTROL STRUCTURES:

Is any dam or other control structure located within one mile upstream of the bridge?

_____Yes (BS or SS). There is a dam located within one mile upstream of the bridge.
_____No.

_____
_____

10. SPREAD FOOTINGS

Does the bridge have any spread footing foundations that are not supported by piles or are not embedded at least 3 inches in solid rock?

_____Yes (BS).

_____No.

11. DEBRIS

Does the structure tend to collect large amounts of debris such as to block 10% or more of the opening?

_____Yes (BS).

_____No.

Check appropriate box (boxes) based on the response to questions 3 through 11.

√	Recommended Action	Notes	Item 113	Item 113.1
	No further action required	(1) (6)		Q
	Do Concise	(2)		
	Monitor stream stability problem	(3)(4)(6)		Q
	Investigate countermeasures for stream stability problems	(3) (5) (7)		

(1) If neither bridge scour (BS) nor stream stability problem (SS) are indicated.
(2) If any responses indicating possible bridge scour (BS), leave items 113 and 113.1 unchanged until completion of concise analysis.
(3) If stream stability problem is indicated (SS).
(4) Stream stability problem does not appear to pose an immediate threat.
(5) Stream stability problem deserves immediate attention since it appears to pose an immediate threat to the bridge.
(6) Code Item 113 8, 5 or 4 according to the BRINSAP coding guide.
(7) Code Item 113 a 0, 1, 2, 3, or 4 according to BRINSAP coding guide. Code Item 113.1 according to BRINSAP coding guide.

Name Date

Secondary Scour Evaluation

District		County	
Structure No.		Highway	
Crossing		SVEAR	

Part I Secondary Screening:

Instructions for use:

The following questions were developed to further determine the potential risk of bridges to scour and actions required to evaluate the bridges. The intent of each question is to determine whether certain field conditions indicate a potential bridge scour problem or a stream stability problem. The response to applicable questions may include the designations BS or SS indicating a possible bridge scour or stream stability problem, respectively. Detailed instructions for each question are provided in the directions for "Secondary Scour Evaluation" Section C.

1. FOUNDATION SET IN NONERODIBLE ROCK:

Is the foundation embedded at least one shaft diameter into nonerodible rock (if spread footing at least 3 inches embedment)?

____No. The foundation is not embedded in nonerodible rock, continue with the remaining questions to determine if there is a potential bridge scour problem.

____ Yes. The foundation is embedded in sound, nonerodible rock. No further investigation of the scour potential is necessary. The lateral stability of the potential unsupported length may need to be checked, otherwise no further action is required and a BRINSAP code of 8 may be coded for item 113 and further completion of this form is not necessary. Go to Reporting Procedures.

Note: See instructions for considerations for nonerodible rock.

- <u>IF YES THEN STOP HERE</u>

2. EXISTING COUNTERMEASURES

Have scour countermeasures been installed which appear to be functioning properly so that no foundations are threatened.

____ No. Scour countermeasures have not been installed.

____ Yes. Scour countermeasures have been installed and appear to be functioning properly. No further investigation of the scour potential is necessary. No further action is required and a BRINSAP code of 7 may be coded for item 113 and further completion of this form is not necessary. Go to Reporting Procedures.

- <u>IF YES THEN STOP HERE</u>

3. FOUNDATION IN SAND-BED CHANNEL:

Is the foundation embedded in a sand bed (or finer non-cohesive material) channel with more than a 10 foot depth of sand bed below natural ground?

____ No. The foundation is not embedded in a sand bed channel with more than a 10 foot depth of sand below natural ground.

____ Yes (BS)The foundation is embedded in more than 10 feet of sand bed.

4. GENERAL CHANNEL DEGRADATION, LOCAL BRIDGE SCOUR, OR BOTH (VERTICAL STABILITY):

Item 113.1-2 Is there any evidence of scour or erosion at the abutments or piers below the natural ground line which is localized within the bridge area rather than throughout the channel reach?

____ Not applicable. No scour or erosion is evident at the abutment or piers.

____ No (SS). Erosion is evident throughout the channel reach indicating a condition more applicable to long term or channel degradation rather than a localized contraction scour problem isolated at the bridge site.

____ Yes (BS). There is evidence of erosion or scour localized at the bridge site which indicates contraction and/or local scour occurring at the bridge instead of channel degradation throughout the channel reach.

____ Both (SS and BS). Erosion is evident through the channel reach with more significant erosion or scour appearing at the bridge site.

5. IMPACT OF STREAM MIGRATION OR BEND (HORIZONTAL STABILITY):

Item 113.1-8 Is the bridge crossing located in a meandering section of the stream or are there indications of lateral migration of the channel bed or banks ?

____ Yes (SS). Lateral migration of the channel bed and/or banks could pose a threat to the abutment or pier foundations.

____ Yes (SS and BS). The stability of the stream and structure appear to be threatened due to the potential or actual meandering and migration of the stream.

____ No. Not applicable or the stream bed is meandering near the bridge section but does not have any foreseeable impact on the structure or stream stability.

6. HISTORICAL SCOUR DAMAGE:

Item 113.1-6 Do the bridge, piers, abutments or highway embankments in the vicinity of the bridge have any history of flood damage that may be associated with scour ?

____ No. The bridge, piers, abutments or embankments have not suffered damage from erosion or scour during flood events.

____ Yes (BS). Erosion or scour has damaged the bridge, piers, abutments or embankments during historical floods.

____ Not applicable.

7. EFFECTS OF MINING OR RELATED OPERATIONS:

Item 113.1-10 Are there any commercial material mining operations, in-stream borrow areas, or dredging operations located within 1 mile upstream of the bridge structure ?

____ Yes (BS or SS).

____ No.

Note: Such operations downstream of the site should be addressed in Question 4.

8. IMPACT OF SKEWED BENTS:

Item 113.1-11 Are the bents ~~skewed~~ ORIENTED to the direction of flow at flood stage ?

____ No.

____ Yes. The angle of attack during flood stage is less then 15 degrees and the bents consist of a group of cylindrical piers or a single column bent.

____ Yes (BS). The angle of attack is greater than 15 degrees or the bents are skewed and do not consist of cylindrical piers.

9. IMPACT OF DAMS OR OTHER CONTROL STRUCTURES:

Item 113.1-12 Is any dam or other control structure located within one mile upstream of the bridge ?

____ Yes (BS or SS). There is a dam located within one mile upstream of the bridge.

____ No.

10. SPREAD FOOTINGS:

Item 113.1-4 Does the bridge have any spread footing foundations that are not supported by piles or are not embedded at least 3 inches in solid rock ?

____ Yes (BS).

____ No.

11. DEBRIS

Does the structure tend to collect large amounts of debris such as to block 10% or more of the opening?

____ Yes (BS).

____ No.

Summary of Results

Check appropriate boxes based on the responses to questions 3 through 11.

Any BS	Any SS	Neither

Actions Recommended (see Figure 1):

1. If "neither" bridge scour (BS) nor stream stability problems (SS) are indicated:

   - No further action required and a code of 8 may be coded for BRINSAP Item 113.

2. Any responses indicating possible bridge scour (BS):

   - Perform a Concise Analysis or prioritize for a Detailed Analysis to quantify the risk to scour. Based on the results of the further analysis a code may be obtained for BRINSAP Item 113.

3. Any responses indicating possible stream stability problems (SS):

   - If no responses indicating bridge scour (BS) the structure may be considered stable for scour and coded 8 for BRINSAP Item 113. The condition(s) which present a stream stability problem should be monitored or, depending on the severity, countermeasures may be investigated.

   - If there are any responses indicating both bridge scour and stream stability (BS and SS) , the BRINSAP code should be determined as under item 2 above and the condition(s) which present a stream stability problem should be monitored or, depending on the severity, countermeasures may be investigated.

4. Refer to Section E for Reporting Procedures.

APPENDIX B
WORKSHEETS FOR
CONCISE ANALYSIS

Secondary Scour Evaluation
WORKSHEET 1
ALLOWABLE SCOUR DEPTH

Bent No. _____ located in Main Channel/Left Overbank/Right Overbank/Relief Bridge (circle one):

(1) Elevation of natural ground at base of pier (feet)	
(2) Elevation of bottom of pier/drill shaft (feet)	
(3) Depth of Embedment (feet) (1) - (2) (feet)	
(4) Top of Column Elevation (at Bent Cap) (feet)	
(5) Total Length of column (4) - (2) (feet)	
(6) Diameter of column/drill shaft or nominal section depth of pile (inches)	
(7) Allowable scour depth based on Bearing Stability = 50% of embedment = 0.5 x (3) (feet)	
(8a) Column or Drill Shaft Only: Allowable unsupported column length = 1.5 x diameter of shaft (inches) = 1.5 x (6) (feet)	
(8b) Trestle Pile Only: Allowable unsupported column length = 2.0 x diameter of pile (inches) = 2.0 x (6) (feet)	
(8c) H or Square Pile: Allowable unsupported column length = 2.0 x nominal section depth of pile (inches) = 2.0 x (6) (feet)	
(9) Allowable scour depth based on Lateral Stability = {(8a) or (8b) or (8c)} - {(5) - (3)} (feet)	
(10) Maximum allowable scour depth = minimum value from item (7) or (9) (feet)	y_s =

Secondary Scour Evaluation
WORKSHEET 2
MAXIMUM PIER SCOUR

Bent No. _____ located in Main Channel/Left Overbank/Right Overbank/Relief Bridge (circle one):

(1) Average through bridge velocity (fps)	V_b =
(2) Velocity correction factor, = 1.7 if pier is within main channel (and the section is not trapezoidal), or = 1.0 if pier is located within a trapezoidal channel section or in the overbank areas	
(3) Velocity for pier scour computation = V_b x factor = (1) x (2) (fps)	V_1 =
(4) Water Surface Elevation at Bridge (computed headwater) (feet)	
(5) Natural ground elevation at the base of the bent (feet)	
(6) Depth of flow at the pier = (4) - (5) (feet)	y_1 =
(7) Pier width (feet)	a =
(8) Enter pier scour nomograph C-1 with items (3), (6), and (7) and determine the maximum estimated unadjusted pier scour depth (feet)	y_s =
(9) Pier Length (feet) (See 3.3)	L =
(10) Angle of Attack on the piers (degrees)	
(11) See Appendix E for K_1 based on the pier shape	K_1 =
(12) See Appendix E for K_2 based on the angle of attack if (10) is greater than 0.0, otherwise = 1.0	K_2 =
(13) Estimate maximum adjusted pier scour = (8) x (11) x (12) (feet)	y_{ps} =
(14) Maximum allowable scour from Worksheet 1 item (10) (feet)	y_a =
(15) Maximum allowable contraction scour (14) - (13) (feet), if (13)≥(14) use y_c=0 and see instructions in step 3.4	y_c =

Secondary Scour Evaluation
WORKSHEET 3
MAXIMUM CONTRACTION SCOUR

(1) Average through bridge velocity (fps) (item (1) on worksheet 2)	V_b =
(2) Average unconstricted velocity (fps)	V_c =
(3) Is $V_b > V_c$? ("Yes" or "No") If "No", contraction scour does not need to be computed and proceed to reporting procedures, otherwise continue.	
(4) See Appendix F and determine the maximum non-scour velocity (fps)	V_s =
(5) Is $V_b > V_s$? ("Yes" or "No") If "No", contraction scour does not need to be computed and proceed to reporting procedures, otherwise continue.	
(6) Depth of flow in left overbank (in feet if applicable)	y_l =
(7) Depth of flow in main channel (in feet if applicable)	y_m =
(8) Depth of flow in right overbank (in feet if applicable)	y_r =
(9) See Appendix F for typical d_{50} size based on bed material (feet)	d_{50} =
(10) Compute critical shear velocity for left overbank (if applicable) refer to equation 3 in step 4.5 (which is repeated below) using items (6) and (9)	V_{crL} =
(11) Compute critical shear velocity for main channel (if applicable) refer to equation in 3 in step 4.5 (which is repeated below) using item (7) and (9)	V_{crM} =
(12) Compute critical shear velocity for right overbank (if applicable) refer to equation 3 in step 4.5 (which is repeated below) using item (8) and (9)	V_{crR} =
Determine type and locations of contraction scour:	
(13) If (10) < 0.7 x (2) consider scour in the left overbank as live-bed (LB), otherwise clear water (CW)* - respond "LB" or "CW"	
(14) If (11) < (2) for rectangular or trapezoidal section, or (11) < 1.7 x (2) for other sections, consider scour in the main channel as live-bed (LB), otherwise clear-water (CW) - respond "LB" or "CW"	
(15) If (12) < 0.7 x (2) consider scour in the right overbank as live-bed (LB), otherwise clear water (CW)* - respond "LB" or "CW"	

* See 4.4 for application of factor of 0.7.

Note: For live-bed scour use worksheet 4
For clear water scour use worksheet 5

$$V_{cr} = 11.52 y^{\frac{1}{6}} d_{50}^{\frac{1}{3}} \qquad \text{Equation (3)}$$

Secondary Scour Evaluation
WORKSHEET 4
MAXIMUM LIVE-BED CONTRACTION SCOUR

See Appendix D for assumptions for application

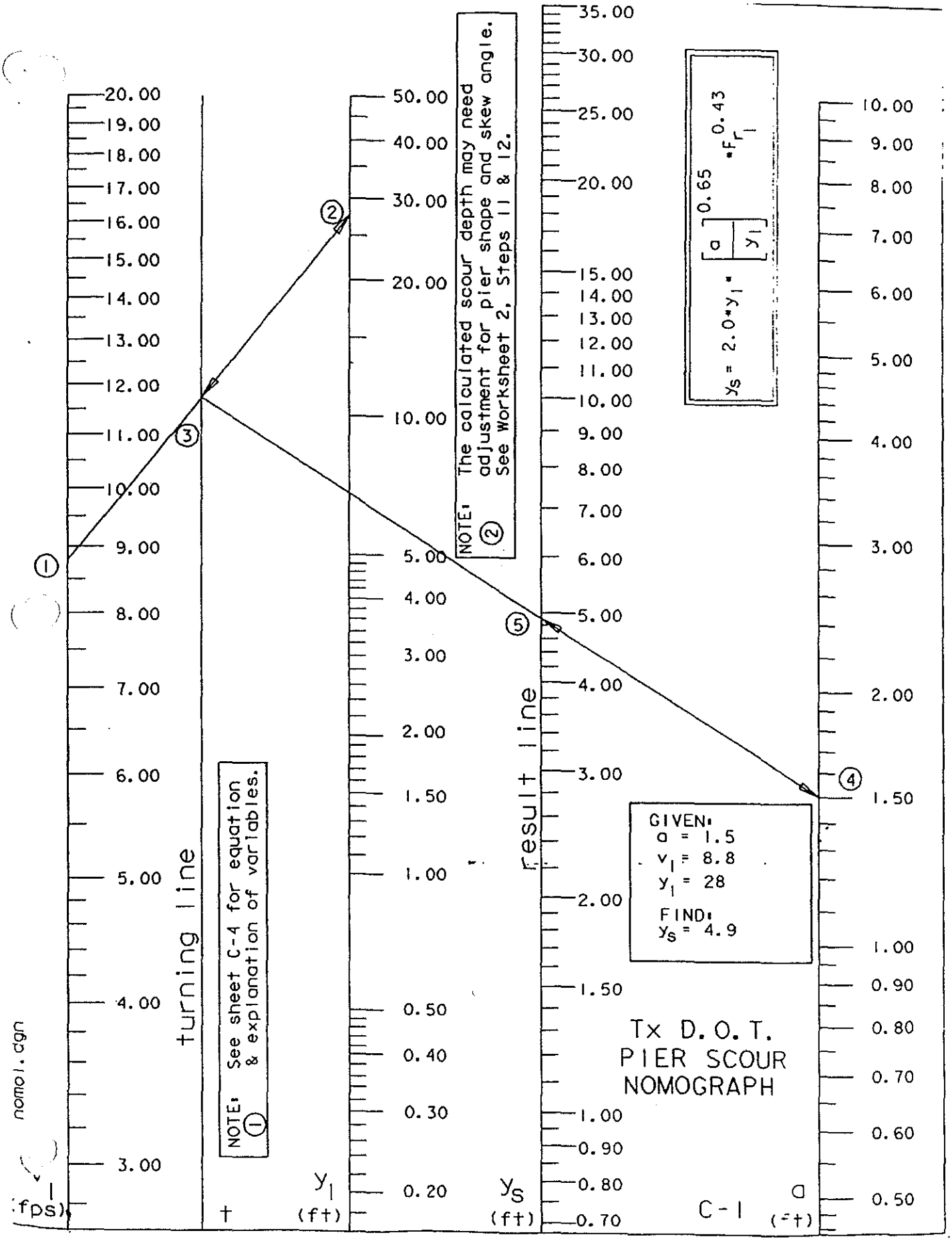
(1) Allowable Contraction Scour Depth from worksheet 2 item (15)	y_c =
(2) Width of main channel approximately one bridge length upstream of the bridge (feet)	W_1 =
(3) Width of main channel at the bridge - width of piers in main channel (feet)	W_2 =
(4) Width ratio = (2) / (3). If less than 1.0 use 1.0	w =
(5) Depth of flow (feet) (computed highwater - flowline)	y_1 =
(6) Depth of flow + contraction scour (feet) (1) + (5)	y_2 =
(7) Use the Live-bed contraction scour nomograph C-2 with items (4), (5) and (6) to determine the maximum allowable discharge ratio that would yield the scour depth in item (1)	q_s =
(8) Weighted "n" value through the bridge opening	n_b =
(9) Weighted "n" value through the unconstricted (natural) section	n_c =
(10) Average through bridge velocity from worksheet 3 item 1	V_b =
(11) Average unconstricted channel velocity from worksheet 3 item 2	V_c =
(12) Estimated wetted perimeter through the bridge opening	P_b =
(13) Estimated wetted perimeter in the unconstricted (natural) section	P_c =
(14) Estimate the actual discharge ratio = $q=(\frac{(8)}{(9)})\times(\frac{(10)}{(11)})^{\frac{5}{3}}\times(\frac{(12)}{(13)})^{\frac{2}{3}}$ Equation (5)	q =
(15) Is $q < q_s$ ("Yes" or "No") If "No" then there is a potential for unstable conditions, otherwise the section of the bridge can be considered stable. Proceed to worksheet 5 (if necessary) or go to Reporting Procedures.	

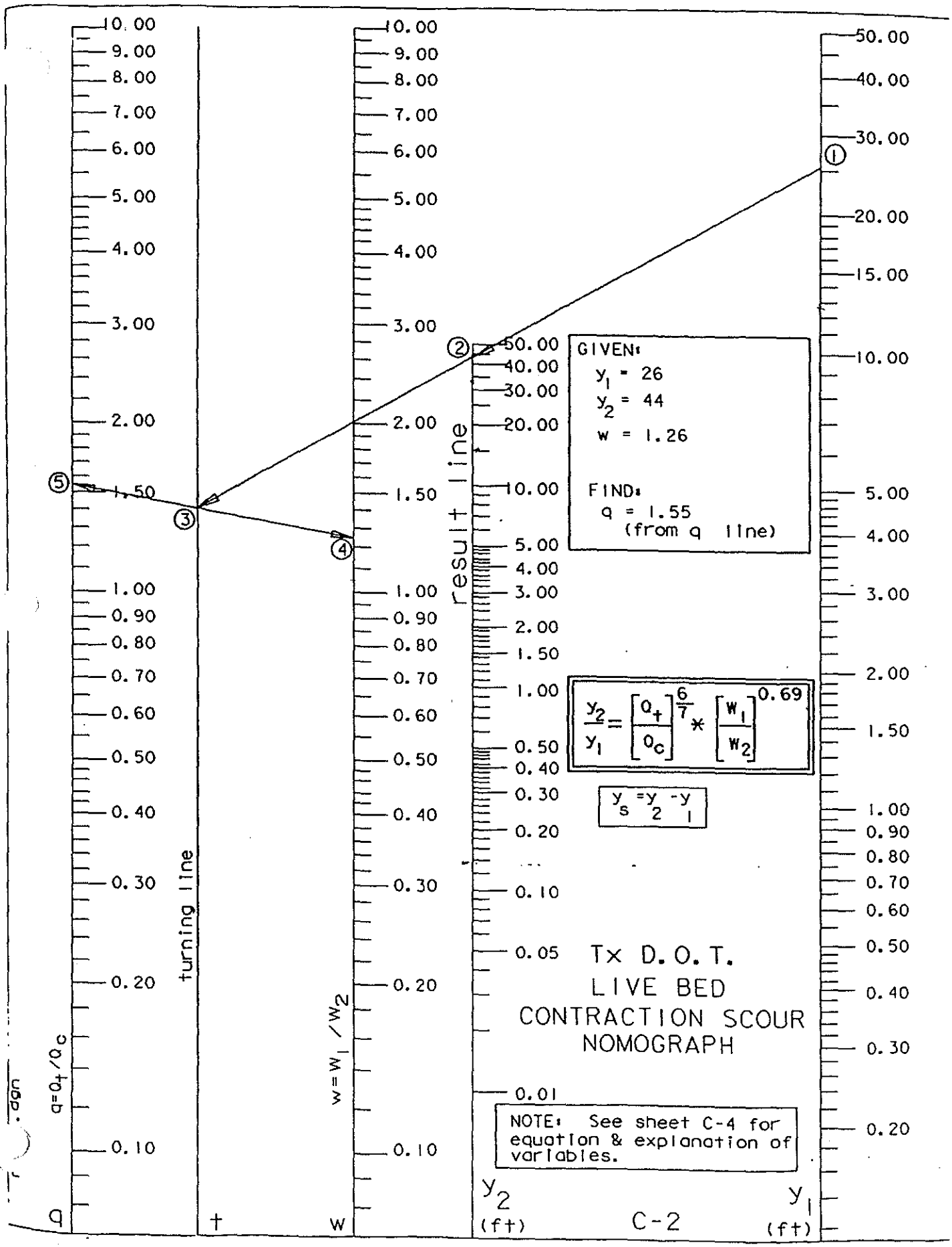
Secondary Scour Evaluation
WORKSHEET 5
MAXIMUM CLEAR WATER CONTRACTION SCOUR

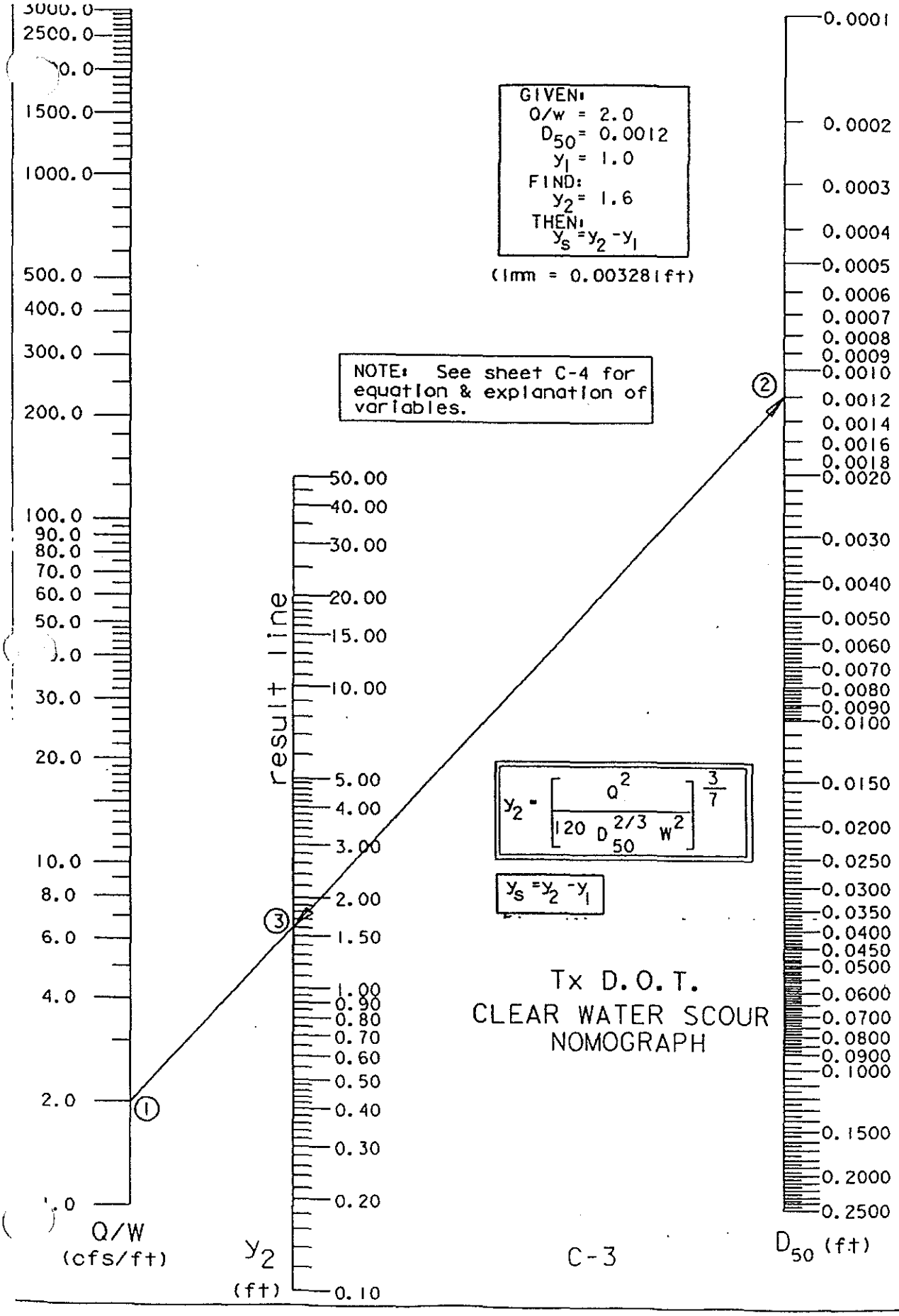
(1) Allowable Contraction Scour Depth from worksheet 2 item (15)	y_c =
(2) Width of channel or overbank area (feet), whichever may be experiencing clear water scour	W =
(3) Depth of flow (feet)	y_1 =
(4) See Appendix F for typical d_{50} size based on bed material (feet)	d_{50} =
(5) Area of flow in the applicable section under the bridge (sf)	A =
(6) Average through bridge velocity (item 1 from worksheet 3) (fps)	V_b =
(7) Discharge through clear water section = (5) x 0.7 x (6) (cfs)*. For a relief bridge use entire discharge through the bridge.	Q =
(8) Discharge-width ratio = (7) / (2)	Q/W =
(9) Use the clear water scour nomograph C-3 with items (4) and (8) to determine a value for y_2 (feet)	y_2 =
(10) Determine the estimated scour due to clear water = (9) - (3) (feet)	y_{cs} =
(11) Is $y_{cs} > y_c$ ("Yes" or "No") If "No" the section of the bridge can be considered stable, otherwise the bridge may be unstable. Complete worksheet 5 for any other relevant clear-water scour portions, otherwise go to Reporting Procedures.	

* See 4.7a for when to drop factor of 0.7.

APPENDIX C
NOMOGRAPHS FOR CONCISE ANALYSIS


Tx D.O.T.
PIER SCOUR
NOMOGRAPH
C-1
GIVEN:
a = 1.5
v_1 = 8.8
y_1 = 28
FIND:
y_s = 4.9
$y_s = 2.0 * y_1 * \left[\frac{a}{y_1}\right]^{0.65} * F_{r_1}^{0.43}$
NOTE: ② The calculated scour depth may need adjustment for pier shape and skew angle. See Worksheet 2, Steps 11 & 12.
NOTE: ① See sheet C-4 for equation & explanation of variables.
turning line
result line
v_1 (fps)
t
y_1 (ft)
y_s (ft)
a (ft)
nomo1.dgn


q = Q_t / Q_c
q
turning line
t
w = W_1 / W_2
w
result line
y_2 (ft)
y_1 (ft)
GIVEN:
y_1 = 26
y_2 = 44
w = 1.26
FIND:
q = 1.55
(from q line)
y_2 / y_1 = [Q_t / Q_c]^(6/7) * [W_1 / W_2]^0.69
y_s = y_2 - y_1
Tx D.O.T.
LIVE BED
CONTRACTION SCOUR
NOMOGRAPH
NOTE: See sheet C-4 for equation & explanation of variables.
C-2


GIVEN:
Q/w = 2.0
D50 = 0.0012
y1 = 1.0
FIND:
y2 = 1.6
THEN:
ys = y2 - y1
(1mm = 0.00328 ft)
NOTE: See sheet C-4 for equation & explanation of variables.
result line
Q/W (cfs/ft)
y2 (ft)
D50 (ft)
Tx D.O.T.
CLEAR WATER SCOUR
NOMOGRAPH

APPENDIX D
DERIVATION OF EQUATION 5

The live-bed contraction scour equation is as follows:

$$\frac{y_2}{y_1} = \left[\frac{Q_t}{Q_c}\right]^{\frac{6}{7}} * \left[\frac{W_1}{W_2}\right]^{K_1} \qquad \textbf{Equation (1)}$$

where:

y_{cs}	=	contraction scour depth (feet)
y_1	=	average depth of flow in the main channel of the unconstricted (natural) main channel section (feet)
y_2	=	average depth in contracted section including contraction scour (feet)
W_1	=	bottom width of the main channel in the contracted (natural) section (feet)
W_2	=	bottom width of the main channel in the contracted section less the cumulative width of piers in the main channel (feet)
Q_c	=	flow in the main channel of the unconstricted (natural) section (cfs)
Q_t	=	flow in the main channel flow of the contracted section (cfs)
K_1	=	0.69 (this is considered to be reasonable (conservative) for the Concise Analysis)

Determination of the hydraulic parameters for this equation can be cumbersome, often requiring a multiple section backwater analysis and some data manipulation to derive the flow ratio q ($q=Q_t/Q_c$). The Concise Analysis incorporates the following simplifying assumptions to determine q:

1. The depth of flow at the approach section is similar to the depth at the upstream face of the structure.

2. The approach section is similar in hydraulic properties to the unconstricted section at the face of the structure.

3. All of the discharge in the unconstricted section is passed through the bridge. The approach can be adjusted to accommodate multiple openings by splitting up the floodplain into appropriate subsections for each bridge opening based on the estimated locations of the flow divides.

4. The drawdown at the downstream face of the structure is small.

Note: Assumptions 1 and 2 and 4 have often been used in the original hydraulic design of TxDOT bridge crossings.

The approach relies on information that has typically been derived for bridge hydraulics within the department as follows:

- Unconstricted section at bridge (natural channel)

- Constricted section (bridge)

- Design and 100 year frequency discharges
- Section roughness coefficients
- Highwater elevations
- Unconstricted channel average velocity
- Constricted average velocity

If this information is not available, refer to 1.1 for a simplified means of determining appropriate variables.

The following variable definitions are used in the derivation:

Conveyance variables:

K_b = Total conveyance through the bridge section
K_u = Total conveyance in the unconstricted (natural) floodplain at the bridge
K_{bc} = Conveyance in the main channel portion of the bridge section
K_{uc} = Conveyance in the main channel portion of the unconstricted (natural) floodplain at the bridge

Discharge variables:

Q = Total discharge through the bridge and in the unconstricted (natural section) (cfs)
Q_{bc} = Discharge in the main channel portion of the bridge section (cfs)
Q_{uc} = Discharge in the main channel portion of the unconstricted (natural) floodplain at the bridge (cfs)

Flow area variables:

A_u = Total flow area in the unconstricted floodplain at the bridge (feet^2)
A_b = Total area of flow under the bridge opening (feet^2)

Wetted perimeter variables:

P_b = Total wetted perimeter of flow under the bridge opening (feet)
P_u = Total wetted perimeter in the unconstricted floodplain at the bridge (feet)

The derivation is as follows:

The discharge ratio from the contraction scour equation (Equation (1)) is:

$$q=\left(\frac{Q_t}{Q_c}\right)=\left(\frac{Q_{bc}}{Q_{uc}}\right) \qquad \text{Equation (D-1)}$$

Since discharge is proportional to conveyance and based on assumption 3,

$$Q_{uc}=Q\times(\frac{K_{uc}}{K_u})$$ Equation (D-2)

and

$$Q_{bc}=Q\times(\frac{K_{bc}}{K_b})$$ Equation (D-3)

Substituting for Q_{uc} and Q_{bc} in D-2 gives:

$$q=\frac{Q_{bc}}{Q_{uc}}=\frac{(\frac{K_{bc}}{K_b})}{(\frac{K_{uc}}{K_u})}$$ Equation (D-4)

Based on assumptions 1, 2, and 4

$$K_{bc} = K_{uc}$$

then

$$q=\frac{Q_{bc}}{Q_{uc}}=\frac{K_u}{K_b}$$ Equation (D-5)

From Manning's Equation, the cross-sectional conveyances are:

$$K_u=\frac{1.486}{n_u}\times A_u\times(\frac{A_u}{P_u})^{\frac{2}{3}}$$ Equation (D-6)

and:

$$K_b=\frac{1.486}{n_b}\times A_b\times(\frac{A_b}{P_b})^{\frac{2}{3}}$$ Equation (D-7)

Substituting for K_u and K_b in Equation (D-5) gives:

$$q=\frac{n_b}{n_u}\times(\frac{A_u}{A_b})^{\frac{5}{3}}\times(\frac{P_b}{P_u})^{\frac{2}{3}}$$ Equation (D-8)

Using the continuity equation, (Q=AV) :

$$A_u = \frac{Q}{V_u} \qquad \text{Equation (D-9)}$$

and:

$$A_b = \frac{Q}{V_b} \qquad \text{Equation (D-10)}$$

substituting for A_u and A_b in Equation (D-8),

$$q = \frac{n_b}{n_u} \times \left(\frac{V_b}{V_u}\right)^{\frac{5}{3}} \times \left(\frac{P_b}{P_u}\right)^{\frac{2}{3}} \qquad \text{Equation (5)}$$

For wide, irregular cross sections with considerable variation in roughness characteristics, it is preferable to calculate K_u and K_b by subdividing the appropriate sections and substituting the calculated values in Equation (D-5) to determine the discharge ratio.

If the assumptions employed in Equations (D-5) and/or (5) are considered to be unreasonable for a particular site, then a Detailed Analysis is recommended. The following may provide guidance on what conditions might be considered unreasonable.

- Structures that appear to create 2 feet or more of backwater most likely are severe encroachments which will create significant drawdowns through the structure
- Complex flow distribution problems such as occur in extremely wide floodplains with multiple openings in which common backwater head can not be reasonably assumed for each opening.
- Conditions in which the water surface elevation just exceeds the overbank elevation may result in an extremely small wetted perimeter ratio. This can be such that, although an actual flow contraction exists, the discharge ratio using Equation (5) calculates to be less than 1. If this condition occurs, do not use Equation 5. Instead, it is recommended that the flow contraction ratio be computed using the computer program WSPRO.
- A contraction ratio of less than 1 could also result from situations in which the conveyance capacity of the bridge section appears to be greater than that of the unconstricted section. If this condition is correct, then Equations (D-5) and (5) become invalid because the assumptions become invalid. In such instances, the use of WSPRO is recommended.

Since Equation (5) is sensitive to the wetted perimeter ratio, it is important that reasonable estimates of the unconstricted and constricted wetted perimeters are made. Note that a large difference in wetted perimeter between the unconstricted and bridge sections actually serves to reduce the contraction ratio! Usually, this should be counteracted by a significant increase in the velocity ratio.

Generally, the Concise Analysis should be so straight forward that it may be worthwhile performing it on all but the most obvious hydraulically complex sites. Test cases on several varied situations have yielded scour depths that compare within 2 to 3 feet of Detailed analyses. This difference is not considered significant enough to warrant a Detailed Analysis on most sites.

APPENDIX E
Secondary Scour Evaluation
Correction Factors for Pier Scour

Correction Factor, K_1 for Pier Nose Shape

Shape of Pier Nose	K_1
Square	1.1
Round	1.0
Sharp	0.9
Circular cylinder	1.0
Group of Cylinders	1.0

Correction Factor, K_2 for Angle of Attack of the Flow

Angle of Attack	L/a = 4	L/a = 8	L/a = 12
0	1.0	1.0	1.0
15	1.5	2.0	2.5
30	2.0	2.5	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5.0

Source: HEC-18, Table 4.2 and 4.3 page 52.

APPENDIX F
NON-SCOUR VELOCITIES FOR SOILS

Soil Type	Grain Dimensions		Approximate Non-scour Velocities (FPS) Mean Depth (ft)			
	mm	feet	1.3	3.3	6.6	9.8
For non-cohesive soils						
Boulders	>256	>0.840	15.1	16.7	19.0	20.3
Large cobbles	256-128	0.840-0.420	11.8	13.4	15.4	16.4
Small cobbles	128-64	0.420-0.210	7.5	8.9	10.2	11.2
Very course gravel	64-32	0.210-0.105	5.2	6.2	7.2	8.2
course gravel	32-16	0.105-0.0525	4.1	4.7	5.4	6.1
Medium gravel	16-8.0	0.0525-0.0262	3.3	3.7	4.1	4.6
Fine gravel	8.0-4.0	0.0262-0.0131	2.6	3.0	3.3	3.8
Very fine gravel	4.0-2.0	0.0131-.00656	2.2	2.5	2.8	3.1
Very course sand	2.0-1.0	0.00656-0.00328	1.8	2.1	2.4	2.7
Coarse sand	1.0-0.5	0.00328-0.00164	1.5	1.8	2.1	2.3
Medium sand	0.5-0.25	0.00164-0.000820	1.2	1.5	1.8	2.0
Fine sand	0.25-0.125	0.000820-0.000410	0.98	1.3	1.6	1.8
For compact cohesive soils						
Sandy loam (heavy)			3.3	3.9	4.6	4.9
Sandy loam (light)			3.1	3.9	4.6	4.9
Loess (settled)			2.6	3.3	3.9	4.3

Derived from "Highways in the River Environment" FHWA-HI-90-016 Table 3.5.2

MIN D_{50} FOR CLAY = 0.1 mm (0.000328')

APPENDIX G
SAMPLE CONCISE ANALYSIS

Secondary Scour Evaluation
WORKSHEET 1
ALLOWABLE SCOUR DEPTH

Bent No. 1 located in Main Channel/Left Overbank/Right Overbank/Relief Bridge (circle one):

(1) Elevation of natural ground at base of pier (feet)	435
(2) Elevation of bottom of pier/drill shaft (feet)	418
(3) Depth of Embedment (feet) (1) - (2) (feet)	17
(4) Top of Column Elevation (at Bent Cap) (feet)	440
(5) Total Length of column (4) - (2) (feet)	22
(6) Diameter of column/drill shaft or nominal section depth of pile (inches)	15
(7) Allowable scour depth based on Bearing Stability = 50% of embedment = 0.5 x (3) (feet)	8.5
(8a) Column or Drill Shaft Only: Allowable unsupported column length = 1.5 x diameter of shaft (inches) = 1.5 x (6) (feet)	N/A
(8b) Trestle Pile Only: Allowable unsupported column length = 2.0 x diameter of pile (inches) = 2.0 x (6) (feet)	N/A
(8c) H or Square Pile: Allowable unsupported column length = 2.0 x nominal section depth of pile (inches) = 2.0 x (6) (feet)	30
(9) Allowable scour depth based on Lateral Stability = {(8a) or (8b) or (8c)} - {(5) - (3)} (feet)	25
(10) Maximum allowable scour depth = minimum value from item (7) or (9) (feet)	y_s = 8.5

Secondary Scour Evaluation
WORKSHEET 1
ALLOWABLE SCOUR DEPTH

Bent No. 2 located in Main Channel/Left Overbank/Right Overbank/Relief Bridge (circle one):

(1) Elevation of natural ground at base of pier (feet)	427
(2) Elevation of bottom of pier/drill shaft (feet)	410
(3) Depth of Embedment (feet) (1) - (2) (feet)	17
(4) Top of Column Elevation (at Bent Cap) (feet)	440
(5) Total Length of column (4) - (2) (feet)	30
(6) Diameter of column/drill shaft or nominal section depth of pile (inches)	15
(7) Allowable scour depth based on Bearing Stability = 50% of embedment = 0.5 x (3) (feet)	8.5
(8a) Column or Drill Shaft Only: Allowable unsupported column length = 1.5 x diameter of shaft (inches) = 1.5 x (6) (feet)	N/A
(8b) Trestle Pile Only: Allowable unsupported column length = 2.0 x diameter of pile (inches) = 2.0 x (6) (feet)	N/A
(8c) H or Square Pile: Allowable unsupported column length = 2.0 x nominal section depth of pile (inches) = 2.0 x (6) (feet)	30
(9) Allowable scour depth based on Lateral Stability = {(8a) or (8b) or (8c)} - {(5) - (3)} (feet)	17
(10) Maximum allowable scour depth = minimum value from item (7) or (9) (feet)	y_s = 8.5

Secondary Scour Evaluation
WORKSHEET 2
MAXIMUM PIER SCOUR

Bent No. 1 located in Main Channel/Left Overbank/Right Overbank/Relief Bridge (circle one):

(1) Average through bridge velocity (fps)	V_b = 6.1
(2) Velocity correction factor, = 1.7 if pier is within main channel (and the section is not trapezoidal), or = 1.0 if pier is located within a trapezoidal channel section or in the overbank areas	1.0
(3) Velocity for pier scour computation = V_b x factor = (1) x (2) (fps)	V_1 = 6.1
(4) Water Surface Elevation at Bridge (computed headwater) (feet)	439.63
(5) Natural ground elevation at the base of the bent (feet)	435
(6) Depth of flow at the pier = (4) - (5) (feet)	y_1 = 4.6
(7) Pier width (feet)	a = 1.25
(8) Enter pier scour nomograph C-1 with items (3), (6), and (7) and determine the maximum estimated unadjusted pier scour depth (feet)	y_s = 2.8
(9) Pier Length (feet) (See 3.3)	L = 38.5
(10) Angle of Attack on the piers (degrees)	0
(11) See Appendix E for K_1 based on the pier shape	K_1 = 1.0
(12) See Appendix E for K_2 based on the angle of attack if (10) is greater than 0.0, otherwise = 1.0	K_2 = 1.0
(13) Estimate maximum adjusted pier scour = (8) x (11) x (12) (feet)	y_{ps} = 2.8
(14) Maximum allowable scour from Worksheet 1 item (10) (feet)	y_a = 8.5
(15) Maximum allowable contraction scour (14) - (13) (feet), if (13)≥(14) use y_c=0 and see instructions in step 3.4	y_c = 5.7

Secondary Scour Evaluation
WORKSHEET 2
MAXIMUM PIER SCOUR

Bent No. 2 located in Main Channel/Left Overbank/Right Overbank/Relief Bridge (circle one):

(1) Average through bridge velocity (fps)	V_b = 6.1
(2) Velocity correction factor, = 1.7 if pier is within main channel (and the section is not trapezoidal), or = 1.0 if pier is located within a trapezoidal channel section or in the overbank areas	1.7
(3) Velocity for pier scour computation = V_b x factor = (1) x (2) (fps)	V_1 = 10.4
(4) Water Surface Elevation at Bridge (computed headwater) (feet)	439.63
(5) Natural ground elevation at the base of the bent (feet)	427
(6) Depth of flow at the pier = (4) - (5) (feet)	y_1 = 12.6
(7) Pier width (feet)	a = 1.25
(8) Enter pier scour nomograph C-1 with items (3), (6), and (7) and determine the maximum estimated unadjusted pier scour depth (feet)	y_s = 5.5
(9) Pier Length (feet) (See 3.3)	L = 38.5
(10) Angle of Attack on the piers (degrees)	0
(11) See Appendix E for K_1 based on the pier shape	K_1 = 1.0
(12) See Appendix E for K_2 based on the angle of attack if (10) is greater than 0.0, otherwise = 1.0	K_2 = 1.0
(13) Estimate maximum adjusted pier scour = (8) x (11) x (12) (feet)	y_{ps} = 5.5
(14) Maximum allowable scour from Worksheet 1 item (10) (feet)	y_a = 8.5
(15) Maximum allowable contraction scour (14) - (13) (feet), if (13)≥(14) use y_c=0 and see instructions in step 3.4	y_c = 3.0

Secondary Scour Evaluation
WORKSHEET 3
MAXIMUM CONTRACTION SCOUR

(1) Average through bridge velocity (fps) (item (1) on worksheet 2)	$V_b = 6.1$
(2) Average unconstricted velocity (fps)	$V_c = 1.6$
(3) Is $V_b > V_c$? ("Yes" or "No") If "No", contraction scour does not need to be computed and proceed to reporting procedures, otherwise continue.	YES
(4) See Appendix F and determine the maximum non-scour velocity (fps)	$V_a = 4.6$
(5) Is $V_b > V_a$? ("Yes" or "No") If "No", contraction scour does not need to be computed and proceed to reporting procedures, otherwise continue.	YES
(6) Depth of flow in left overbank (in feet if applicable)	$y_l = 4.6$
(7) Depth of flow in main channel (in feet if applicable)	$y_m = 12.6$
(8) Depth of flow in right overbank (in feet if applicable)	y_r = N/A
(9) See Appendix F for typical d_{50} size based on bed material (feet)	$d_{50} = .00328$
(10) Compute critical shear velocity for left overbank (if applicable) refer to equation 3 in step 4.5 (which is repeated below) using items (6) and (9)	$V_{crl} = 2.2$
(11) Compute critical shear velocity for main channel (if applicable) refer to equation in 3 in step 4.5 (which is repeated below) using item (7) and (9)	$V_{crm} = 2.6$
(12) Compute critical shear velocity for right overbank (if applicable) refer to equation 3 in step 4.5 (which is repeated below) using item (8) and (9)	V_{crr} = N/A
Determine type and locations of contraction scour:	
(13) If (10) < 0.7 x (2) consider scour in the left overbank as live-bed (LB), otherwise clear water (CW) - respond "LB" or "CW"	CW
(14) If (11) < (2) for rectangular or trapezoidal section, or (11) < 1.7 x (2) for other sections, consider scour in the main channel as live-bed (LB), otherwise clear-water (CW) - respond "LB" or "CW"	LB
(15) If (12) < 0.7 x (2) consider scour in the right overbank as live-bed (LB), otherwise clear water (CW) - respond "LB" or "CW"	N/A

Secondary Scour Evaluation
WORKSHEET 4
MAXIMUM LIVE-BED CONTRACTION SCOUR

See Appendix D for assumptions for application

(1) Allowable Contraction Scour Depth from worksheet 2 item (15)	$y_c = 3.0$
(2) Width of main channel approximately one bridge length upstream of the bridge (feet)	$W_1 = 58$
(3) Width of main channel at the bridge - width of piers in main channel (feet)	$W_2 = 58 - 1.25$
(4) Width ratio = (2) / (3). If less than 1.0 use 1.0	$w = 1.02$
(5) Depth of flow (feet) (computed highwater - flowline)	$y_1 = 12.6$
(6) Depth of flow + contraction scour (feet) (1) + (5)	$y_2 = 15.6$
(7) Use the Live-bed contraction scour nomograph C-2 with items (4), (5) and (6) to determine the maximum allowable discharge ratio that would yield the scour depth in item (1)	$q_a = 1.2$
(8) Weighted "n" value through the bridge opening	$n_b = .04$
(9) Weighted "n" value through the unconstricted (natural) section	$n_c = .04$
(10) Average through bridge velocity from worksheet 3 item 1	$V_b = 6.1$
(11) Average unconstricted channel velocity from worksheet 3 item 2	$V_c = 1.6$
(12) Estimated wetted perimeter through the bridge opening	$P_b = 120$
(13) Estimated wetted perimeter in the unconstricted (natural) section	$P_c = 1400$
(14) Estimate the actual discharge ratio = $q=(\frac{(8)}{(9)})\times(\frac{(10)}{(11)})^{\frac{5}{3}}\times(\frac{(12)}{(13)})^{\frac{2}{3}}$ Equation (5)	$q = 1.8$
(15) Is $q < q_a$ ("Yes" or "No") If "No" then there is a potential for unstable conditions, otherwise the section of the bridge can be considered stable. Proceed to worksheet 5 (if necessary) or go to Reporting Procedures.	NO

Secondary Scour Evaluation
WORKSHEET 5
MAXIMUM CLEAR WATER CONTRACTION SCOUR

(1) Allowable Contraction Scour Depth from worksheet 2 item (15)	$y_c = 5.7$
(2) Width of channel or overbank area (feet), whichever may be experiencing clear water scour	W = 30
(3) Depth of flow (feet)	$y_1 = 4.6$
(4) See Appendix F for typical d_{50} size based on bed material (feet)	$d_{50} = .003281$
(5) Area of flow in the applicable section under the bridge (sf)	A = 161
(6) Average through bridge velocity (item 1 from worksheet 3) (fps)	$V_b = 6.1$
(7) Discharge through clear water section = (5) x 0.7 x (6) (cfs)*. For a relief bridge use entire discharge through the bridge.	Q = 687
(8) Discharge-width ratio = (7) / (2)	Q/W = 22.9
(9) Use the clear water scour nomograph C-3 with items (4) and (8) to determine a value for y_2 (feet)	$y_2 = 9.5$
(10) Determine the estimated scour due to clear water = (9) - (3) (feet)	$y_{cs} = 4.9$
(11) Is $y_{cs} > y_c$ ("Yes" or "No") If "No" the section of the bridge can be considered stable, otherwise the bridge may be unstable. Complete worksheet 5 for any other relevant clear-water scour portions, otherwise go to Reporting Procedures.	NO

* See 4.7a for when to drop factor of 0.7.

PERCENTAGE OF BASIC FLOOD OVER ROAD =52.71%


```
$*****************************************************************
$          25 YEAR ANALYSIS FOR THE PROPOSED FUTURE BRIDGE
$*****************************************************************
CULBRG                ANALYSIS  BRIDGE              SINGLE
SUPPLY Q=   4797      CFS       TW ELEV =   439.10  FREQUENCY=  25 YRS
BRDG  ALN MAX AVERAGE VELOCITY  6.000   MIN AVERAGE VELOCITY  4.000   FT/SC
BRDG  ALN LEFT S.S. 2.0         RIGHT S.S 2.0       LOOKING DNSTREAM    DNSTM
FL-DV ALN SECX DS40 FRM X DIS 25216.00  TO X DIST  25315.
FREQ=100  Q=  7241 CFS  TW= 440.40  CLEAR ELEV=  440.25
RD PROFILEX 24051.6 Y  443.62 X 24148.2 Y  442.90 X 24278.8 Y  442.13
RD PROFILEX 24341.3 Y  441.27 X 24437.9 Y  440.52 X 24534.5 Y  440.29
RD PROFILEX 24631.1 Y  440.17 X 24727.7 Y  440.03 X 24824.3 Y  440.00
RD PROFILEX 24920.9 Y  440.29 X 24969.2 Y  440.89 X 25017.5 Y  441.42
RD PROFILEX 25065.8 Y  441.91 X 25114.1 Y  442.27 X 25162.4 Y  442.50
RD PROFILEX 25307.3 Y  442.59 X 25355.6 Y  442.47 X 25403.9 Y  442.23
RD PROFILEX 25452.2 Y  441.87 X 25500.4 Y  441.40 X 25548.7 Y  440.81
RD PROFILEX 25597.0 Y  440.11 X 25693.6 Y  440.00 X 25790.2 Y  440.00
RD PROFILEX 25886.8 Y  440.00 X 25983.4 Y  440.00 X 26080.0 Y  440.00
RD PROFILEX 26176.6 Y  440.45 X 26273.2 Y  442.26 X 26369.8 Y  444.44
ENDATA
```


SINGLE OPENING BRIDGE ANALYSIS

SECTION DS40 AT STATION -NONE-

DESIGN FLOW = 4797 CFS

WATER SURFACE ELEVATION = 439.10

FREQUENCY = 25 YEAR

HYDRAULICS USED FOR SCOUR COMPUTATIONS

LOCATION OF TOE OF LEFT HEADER 25216

LOCATION OF TOE OF RIGHT HEADER 25315

LENGTH BETWEEN HEADERS AT WATER SURFACE = 112.93 FT.

BACKWATER HEAD = .53 FT.

AVERAGE THRU-BRIDGE VELOCITY = 6.07 FPS

AVERAGE UNRESTRICTED VELOCITY = 1.58 FPS

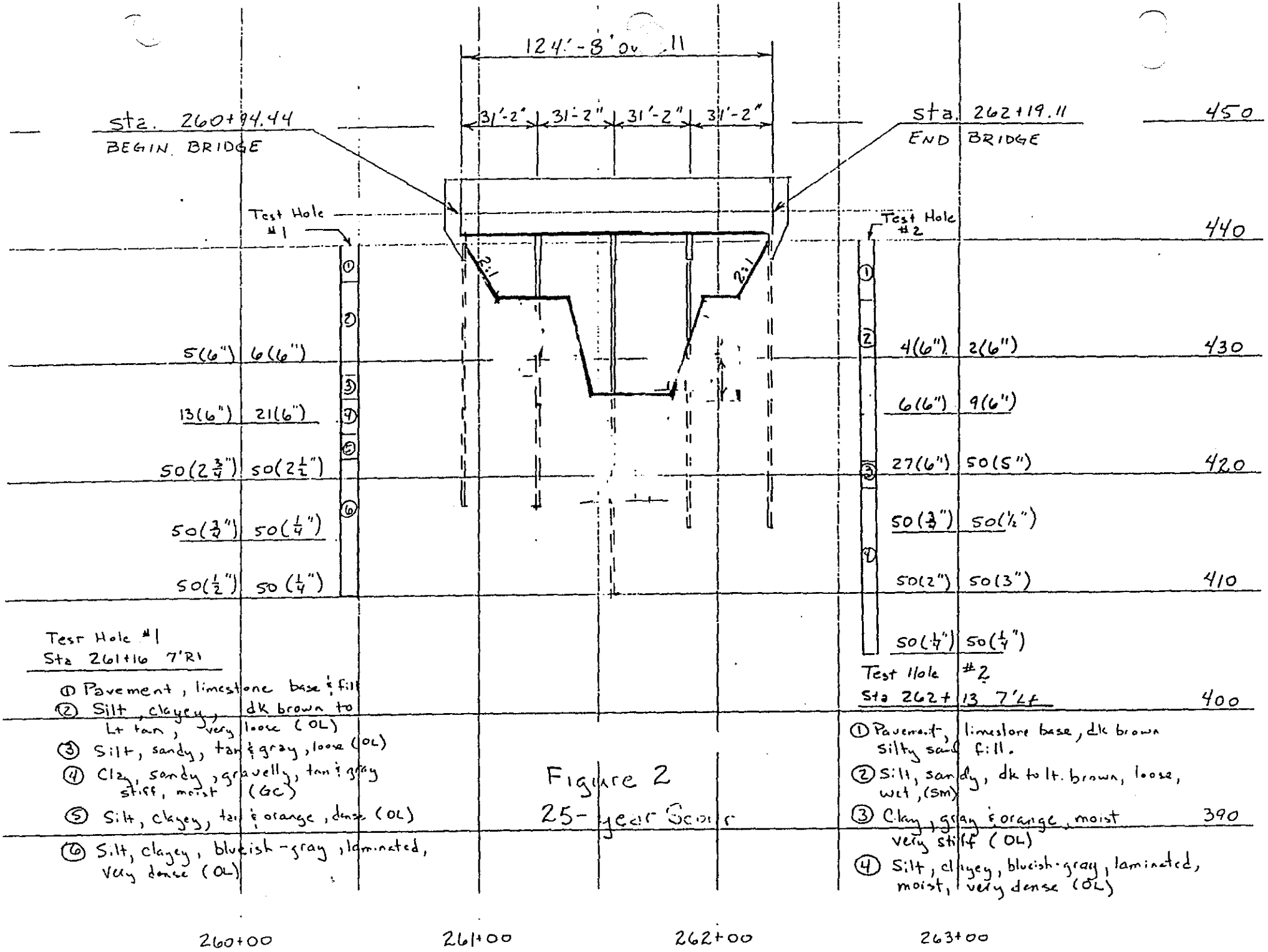


Figure 2
25-year Scour

24396.42	441.50
24619.55	438.40
24795.34	436.60
24920.92	437.00
24969.21	436.70
25017.51	436.80
25065.80	436.50
25114.10	436.50
25162.40	436.10
25230.01	435.60
25235.81	434.70
25242.57	434.30
25256.09	427.00
25271.55	427.00
25281.21	425.40
25283.14	427.00
25286.04	427.00
25300.53	434.20
25303.42	435.40
25320.81	435.60
25355.58	436.50
25403.88	437.40
25452.18	437.50
25500.47	437.60
25548.77	437.40
25597.06	437.40
25693.66	438.00
25790.25	438.00
25886.84	438.20
25983.44	439.80
26080.03	439.40
26176.62	441.50

UNCONSTRICTED CROSS-SECTION USED FOR WETTED PERIMETER ESTIMATION.

'N' VALUE INFORMATION

FROM X	TO X	'N' BELOW	ELEVATION	'N' ABOVE
24396.42	25630.87	.090	441.50	.090
25630.87	25653.09	.040	441.50	.040
25653.09	25688.83	.030	441.50	.030
25688.83	26176.62	.090	441.50	.090

RESULTS OF ONE SECTION METHOD CALCULATIONS

SLOPE = .00190 FT/FT

ORIGINAL SECTION IS D350
ORIGINAL STATION IS 1523.00

STATION WHERE ANSWER APPLIES IS 1000.00

W.S. ELEVATION	Q	VELOCITY
424.75	2.	.61
425.00	10.	1.15

References

1. Hydraulic Engineering Circular No. 18. Publication No. FHWA-IP-90-017. February 1991. Federal Highway Administration.

2. Highways in the River Environment. Publication No. FHWA-HI-90-016. February 1990. Federal Highway Administration.

3. Division of Bridges and Structures Hydraulic Manual, Third Edition, December 1985. Texas Department of Transportation.

4. Texas Hydraulic System (THYSYS) User Manual, 1977. Texas Department of Transportation.

5. Federal Highway Administration Technical Advisory T 5140.23 "Evaluating Scour at Bridges". October 28, 1991.

TEXAS DEPARTMENT OF TRANSPORTATION
DISTRICT NO. 18
OCT 31 1994
Dallas, Texas
RECEIVED

Texas Department of Transportation

MEMORANDUM

TO: District Engineers
Attention: Scour Coordinators

DATE: October 28, 1994

FROM: Design Division

Originating Office
Hydraulics Section

SUBJECT: Texas Secondary Evaluation and Analysis for Scour (TSEAS)

The Secondary Scour Evaluation was developed to simplify the scour calculations . However, some misinterpretations have been pointed out by the districts and require additional explanation.

In the calculation of item 9 (Allowable scour depth based on lateral stability) on worksheet 1, the distance may take into account a tie beam, web wall or pile cap lateral support if applicable. Item 4 should then be the elevation from the bottom of the tie beam, web wall or pile cap.

Should you have any concerns regarding selection of allowable scour depths on a specific structure, please contact the Design Division for further review.

See attached figures.

If you have any questions, please feel free to contact the Hydraulic Section.

Jay Vose, P.E.
Acting Engineer of Hydraulic Design

( ) Dist. Engr. ( )
( ) Asst. Dist. Engr. ( )
( ) ( ) Action
( ) ( ) Advise
( ) ( ) Comment

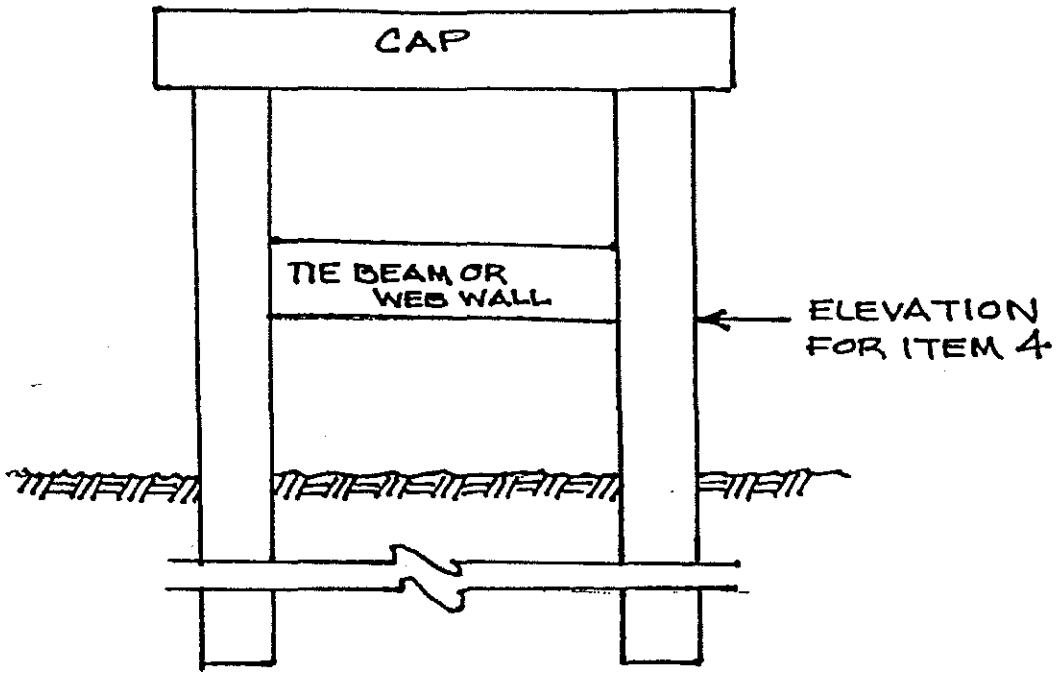
Blair McElroy

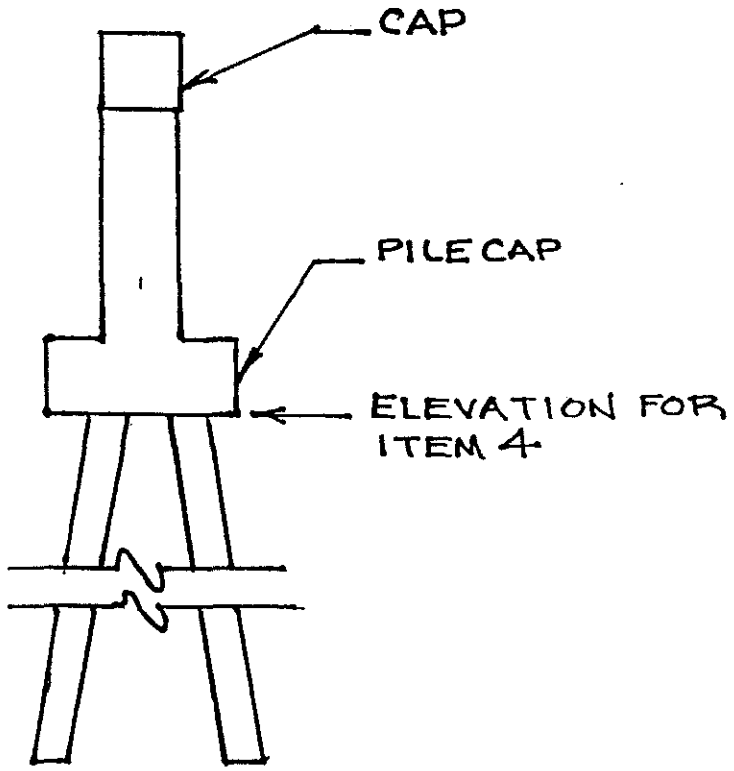
FILE

Distrib.
Carroll

Form 1284A

TEXAS DOT DIVISION OF BRIDGES and STRUCTURES	County ..... Highway ..... Design ..... Date ..... C-S-J ..... Ck Dsn ..... Date ..... Structure ..... Design for ..... Sheet ..... of .....





Texas Department of Transportation

MEMORANDUM

TEXAS DEPARTMENT OF TRANSPORTATION
DISTRICT NO. 18
OCT 14 1993
Dallas, Texas
RECEIVED

TO: All District Engineers

DATE: October 12, 1993

FROM: Robert L. Wilson, P.E.

Originating Office
Design Division
Hydraulics Section

SUBJECT: Revised Texas Secondary Evaluation and Analysis for Scour (TSEAS)

Please find enclosed Appendix "C" to be included in the latest version (September 1993) of the referenced document. This appendix was inadvertently left out of the printing you received (memo dated October 8, 1993).

Please contact Messrs. Peter Smith, P.E. at 512/416-2262 or Jay Vose, P.E. at 512/416-2271 if you have any questions.

Ashley B. Lewis, P.E.
for RLW

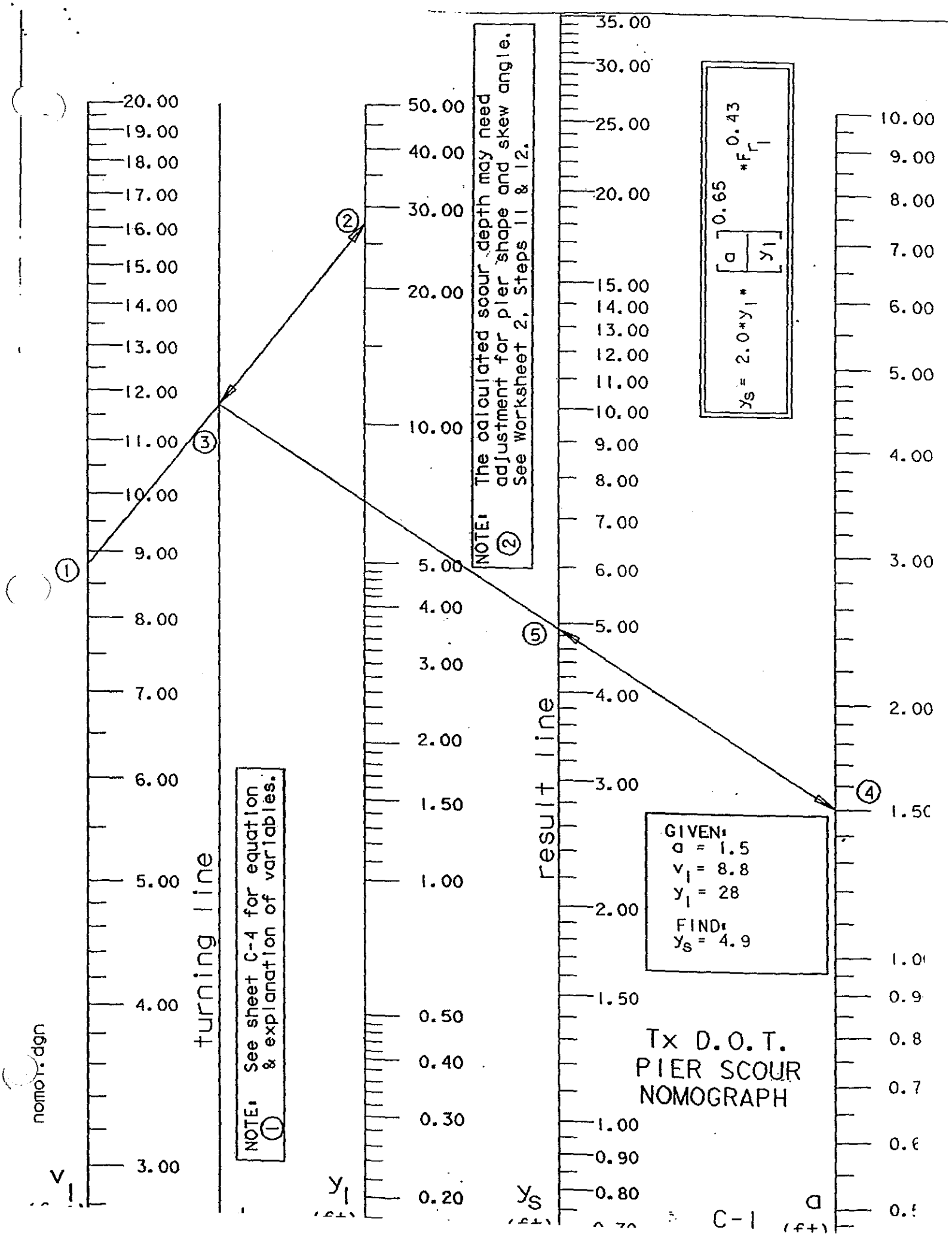
Encl.

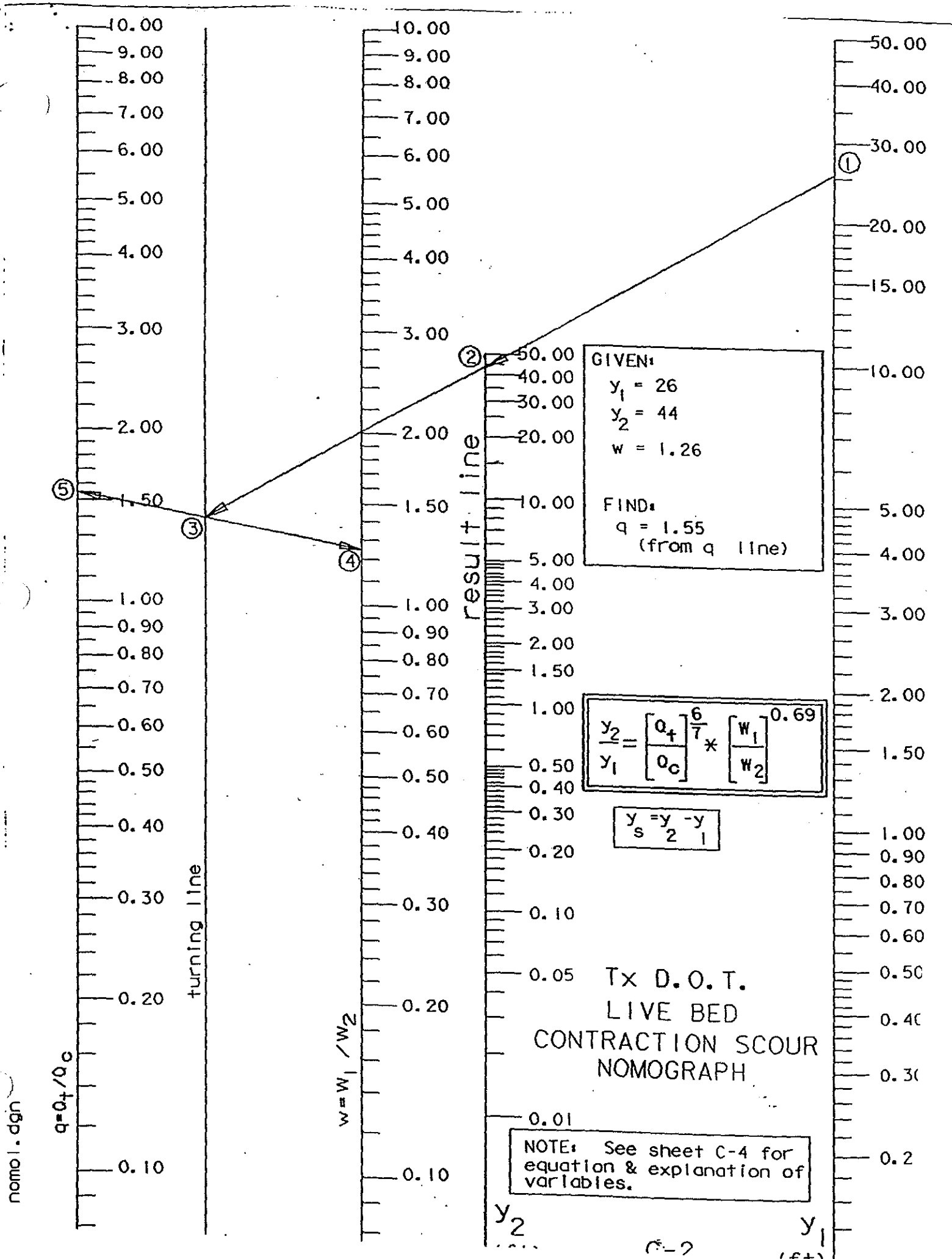
( ) Dist. Engr. _____ ( )
( ) Asst. Dist. Engr. _____ ( )
( ) ( ) Action
( ) ( ) Advise
( ) Blain ( ) Comment

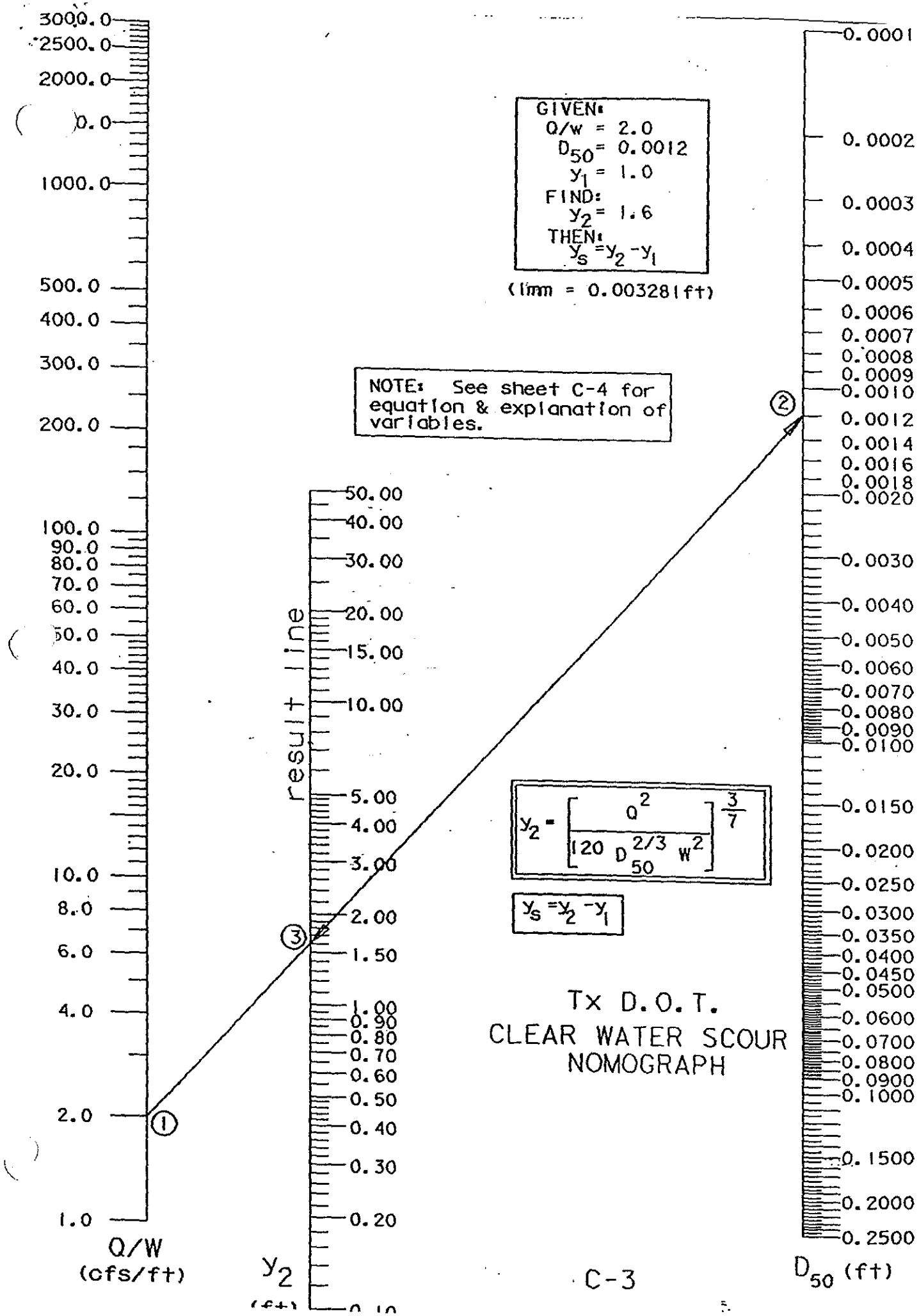
FILE

Tucker
Sakina Gms
Thompson

Roadway Dist C-5


Tx D.O.T.
PIER SCOUR
NOMOGRAPH
$y_s = 2.0 * y_1 * \left[\frac{a}{y_1}\right]^{0.65} * F_{r_1}^{0.43}$
GIVEN:
a = 1.5
v_1 = 8.8
y_1 = 28
FIND:
y_s = 4.9
NOTE: ② The calculated scour depth may need adjustment for pier shape and skew angle. See Worksheet 2, Steps 11 & 12.
NOTE: ① See sheet C-4 for equation & explanation of variables.
turning line
result line
v_1
y_1 (ft)
y_s (ft)
a (ft)
C-1
nomo1.dgn


q=Qt/Qc
turning line
w=W1/W2
result line
y2
y1
(ft)
GIVEN:
y1 = 26
y2 = 44
w = 1.26
FIND:
q = 1.55
(from q line)
y2/y1 = [Qt/Qc]^(6/7) * [W1/W2]^0.69
ys = y2 - y1
Tx D.O.T.
LIVE BED
CONTRACTION SCOUR
NOMOGRAPH
NOTE: See sheet C-4 for equation & explanation of variables.
nomol.dgn


GIVEN:
Q/w = 2.0
D50 = 0.0012
y1 = 1.0
FIND:
y2 = 1.6
THEN:
ys = y2 - y1
(1mm = 0.003281ft)
NOTE: See sheet C-4 for equation & explanation of variables.
result line
y2 = [Q^2 / (120 D50^2/3 W^2)]^3/7
ys = y2 - y1
Tx D.O.T.
CLEAR WATER SCOUR
NOMOGRAPH
Q/W (cfs/ft)
y2 (ft)
D50 (ft)
C-3

PIER SCOUR

$$y_s = 2.0 * y_1 * \left[\frac{a}{y_1}\right]^{0.65} * F_{r_1}^{0.43}$$

where:

y_s = pier scour depth
L = pier length

a = pier width

V_1 = velocity upstream of pier (BRIDGE section)

y_1 = flow depth upstream of pier (BRIDGE section)

g = 32.2 ft/sec^2 (accel. due to grav.)

$$F_{r_1} = \frac{V_1}{\sqrt{g * y_1}}$$ = Froude number upstream of pier

Top Width of scour hole = $2.0(y_s)$

LAURSEN'S LIVE BED CONTRACTION SCOUR

$$\frac{y_2}{y_1} = \left[\frac{Q_t}{Q_c}\right]^{\frac{6}{7}} * \left[\frac{W_1}{W_2}\right]^{0.69}$$

$y_s = y_2 - y_1$

where:

y_s = contraction scour depth

y_1 = average depth in main channel upstream of contracted section. (APPROACH section)

y_2 = average depth in contracted section including contraction scour.

W_1 = bottom width of main channel upstream of contracted section. (APPROACH section)

W_2 = bottom width of contracted section (BRIDGE section) less the cumulative width of piers in the main channel.

Q_c = main channel flow upstream of contracted section (APPROACH section.)

Q_t = main channel flow in contracted section (BRIDGE section) upstream of contracted section.

CLEAR WATER CONTRACTION SCOUR

$$y_2 = \left[\frac{Q^2}{120\, D_{50}^{2/3}\, W^2}\right]^{\frac{3}{7}}$$ HEC-18, Eqn. 2a, Pg. 14.

$y_s = y_2 - y_1$

where:

y_s = contraction scour depth

y_1 = depth of flow in the overbank at the approach section.

y_2 = depth of flow in the overbank in the contracted section.

Q = discharge in the overbank in the contracted section (BRIDGE SECTION).

D_{50} = median diameter of the bed material in the opening.

W = distance the abutment is from the main channel les the width of piers.