GUIDELINES
FOR PRELIMINARY DESIGN
OF BRIDGES AND CULVERTS

June 1992

Office of Bridge Design
Iowa Department of Transportation

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Following is a list of guidelines to aid in the development of type, size and location (TS&L) plans for bridges and large culverts and in the preparation of pink sheets and 20-scale plats for small culverts. Please note that most of this material are guidelines, not policies. Sound engineering judgment, including technical and economic analysis, must be applied in all situations.

Culverts

1. General drainage policy

   In the construction of rural highways in Iowa it is of primary importance that there be no diversion of surface water. Water entering the highway right of way in a draw (swale or ditch) should be carried through the highway embankment and discharged into the same draw. There should be no (or minimal) increase to the drainage area of the draw.

   This policy shall be adhered to as closely as practical.

2. Types and sizes

   a. Minimum pipe size for roadways, sideroads and ditch letdowns is 24".

   b. Preferred minimum size for median pipes in four-lane roadways is 24". However, in some instances, the median ditch is too shallow (less than three feet) to place a 24" pipe under the pavement, so an 18" may be used.

   c. Minimum pipe size for entrances is 18".

   d. Maximum size of precast concrete pipe culverts is 84". When a larger opening is needed, it is generally more economical to use a cast-in-place reinforced concrete box culvert (RCB).

   e. When designing replacement culverts, the size of the existing culvert is a good "common sense" guide when sizing the proposed one. IDOT maintenance personnel may have information related to landowners' complaints or road overtopping, which may indicate a larger structure should be designed.

   f. Cast-in-place RCB standards are available for various sizes ranging from 3 x 3 to 12 x 12 for single barrel and 8 x 6 to 12 x 12 for twin barrels. These standard sizes should be used whenever possible. No RCBs smaller than a 3 x 3 shall be used. Bell joints are recommended when expected settlement exceeds 0.5 feet or when the fill exceeds 20 feet for single RCBs and 15 feet for twin RCBs.

   g. Precast RCBs are generally more expensive than cast-in-place RCBs in Iowa but may be used if sufficient justification (e.g. construction time and traffic restrictions) can be given. The use of precast RCB's is limited to fill heights of 2' and 10' and expected settlements of 0.2'.

h. Precast stockpasses shall not be installed under four-lane highways since the long sections of barrel inhibit cattle from using the structures. Existing stockpasses under two-lane roadways should be eliminated whenever possible based on present right of way needs and drainage concerns. For new stockpasses, the 4X6 precast barrel is the preferred size for cattle; the 5X7 is used for a horse pass.

i. Concrete culverts shall be used under all paved roads, including paved sideroads. Corrugated metal shall be specified for uses such as ditch letdowns and any temporary pipes. Unclassified pipes shall be specified for all other situations such as entrances and unpaved sideroads.

j. Existing RCBs and pipes shall be extended with an equivalent size and shape to closely approximate the hydraulic opening, e.g. extend a 2 x 2 RCB with a 30" pipe (provided the pipe and the RF-2 connections will have adequate earth cover), and extend a 3 x 2 RCB with a 37" x 23" concrete arch pipe or a 36" pipe. There is not a practical equivalent shape for some existing RCBs (such as a 6 x 3 or 4 x 2), so these will need to be extended in-kind.

k. Median drains should be placed to maintain the natural drainage as much as practical. Maximum spacing of median drains is 2,000 feet in sag vertical curves and 1,500 feet on tangent grades. For tangent grades greater than 2%, consideration should be given to 1000' - 1200' spacing. If 18" diameter median drains are used, spacing should not exceed 1000'.

l. For safety and settlement reasons, median drains should be placed transverse to the centerline of the roadway rather than "teed" into a crossroad pipe. These drains should generally outlet to the upstream side of the highway, when practical, so that outlet velocities and erosion is confined to the highway right of way and will not adversely affect and adjacent property.

Vertical riser pipes into RCBs or pipes are generally not preferred.

m. Tapered inlets on cast-in-place RCB's should be considered in some situations to reduce culvert costs and/or to create ponds for upstream landowners. The barrel size shall not be less than 50% of the inlet size. Also, the inlet dimensions shall be tapered only in the width, not in the height, e.g. a 12x8 inlet may be tapered to an 8x8 or 6x8 barrel section but not to an 8x6 or 6x6. See Appendix A for a sample sketch of a tapered inlet.

If a large pond is created, the Iowa Department of Natural Resources may consider it as a dam and therefore have certain design requirements for the culvert and the embankment.

n. Flumes without basins (stub flumes) may be used when needed on RCBs 4x4 and smaller. Flumes with basins should be used on larger RCBs. The flow lines of stub flumes or basins are usually set about five feet below the bed of the waterway. This allows for the natural development of a scour hole which helps dissipate energy. An estimate of the scour hole size should be made to ensure that adequate right of way is purchased.

Flume chute lengths should be limited to 60 feet, if possible.

o. Precast concrete "half-round" flumes (Road Standard RF-130 should be limited in size to 42" and in length to 24 feet to prevent the sections from pulling apart as settlement and erosion occur.

p. When available head is limited due to low road fill or very flat ground upsteam, arch pipes or twin pipes are acceptable instead of a large, single, round pipe. Cast-in-place drop inlets (see Appendix A) or Road Standard Item 1407 may also be acceptable solutions.

q. For corrugated metal pipes with diameters of 48" and larger, cast-in-place headwalls or concrete collars are necessary on the inlet to prevent failure due to uplift forces.

r. Ditch "letdowns" should be used when the drop in ditch elevations becomes too great to carry the water without eroding the ditch. These letdowns are corrugated metal pipes, as depicted in the Road Design Details Manual, Items 1401 and 1403.

s. Designing letdown outlets through the RCB or flume walls is not desirable due to potential cracking in the walls. Rather, the outlets can be set at the end of the headwall or on top of the wingwall or flume wall. The pipes should be anchored to the walls.

t. Culvert bends in the horizontal plane shall be accomplished by using elbows in pipe culverts and special bend sections in RCBs. Limits at a single bend shall be 20° with multiple bends permitted to 50° maximum. This will minimize hydraulic losses and tendencies for plugging of the bend with debris.

3. Lengths

a. The minimum allowable length of all culverts is determined from AASHTO's IDOT Roadside Design Guide, 1988 edition. Table 3.1 in this publication gives a range of minimum clear zone distances which are acceptable for safety. The designed culvert length may actually need to be longer than this minimum in order to maintain the typical cross section, such as a "barn roof" section. However, in no circumstances shall any replacement or extended culvert be shorter than required by Table 3.1 (except for the inlet end of a median drain).

4. Road standards from IDOT Road Design Details Manual ("Green Book")

Item	Discussion
1101	Very commonly used for culverts under pavement.
1102	Teed pipes are generally not recommended except in a side ditch outside the clear zone.
1201	May be used as a cross road pipe if the slope of an 1101 would be steeper than approximately 5%.
1202	Same as 1102
1301	Commonly used to extend existing structures.
1302	Same comment as 1301.

1303	May be used for extensions if the slope of a straight extension would be greater than approximately 5%. The diameter is limited to 42 "and the length is limited to approximately 24 feet of "half-round" RF-13. Using 1305 is often a good alternative to 1303.
1304	Same comments as 1303.
1305	Commonly used for extensions. The minimum earth cover is shown as two feet. The recommended cover is equal to the diameter of the pipe, e.g. a 42" pipe should have approximately 42" of cover. This helps resist uplift forces.
1401	May be used as a side ditch letdown. See comments on 1305 for recommended earth cover.
1402	Do not use this item.
1403	Same comment as 1401.
1407	May be used when inlet elevation must be lowered due to limited available earth cover. Maximum height of the wall is dimension "A" on the RF-3 standard for aprons.
1501	This is similar to 1305 except this is for an all-new structure.
1502	Same comment as 1102
1503	This is used under pavements. Conditions of use are similar to a 1303.
1504	Do not use this item.
1601	This is used primarily for unpaved roads.
1602	Same comment as 1601.

5. Hydrology

   a. For drainage areas less than 1,000 acres, use the Iowa Runoff Chart (see Appendix A). For larger drainage areas, used USGS Report 87-4132, "Method for Estimating the Magnitude and Frequency of Floods at Ungaged Sites on Unregulated Rural Streams in Iowa", by Oscar G. Lara, 1987.

   b. For the design of crossroad culverts, use the 50-year flood. For temporary pipes under a "runaround", use the 5-year flood.

6. Hydraulics

   a. For culvert hydraulics, use FHWA's publication, "Hydraulic Design of Highway Culverts", Hydraulic Design Series No. 5, September 1985. Equivalent computer software is also acceptable.

   b. Culverts should generally be designed to have one foot of head above the top of the opening. This can be exceeded in some instances if the culvert is under high fill and there is minimal flood damage potential upstream.

7. Approvals

   a. Iowa Department of Natural Resources (DNR) must approve new culverts if the drainage is greater than two square miles in an urban area or 100 square miles in a rural area.

   b. A Corps of Engineers 404 Permit may be necessary for most stream crossings or if a channel change or wetland is involved.

8. 20 scale plats

   a. The primary purpose of 20 scale plats is to visually and graphically aid the designer in developing proper lengths and locations of culverts. The proposed structure should be drawn on the plat. Design details such as flowlines, lengths, skews and special features should be shown.

   b. The completed plats are often used during construction or in later years if drainage complaints arise. During the project design, the Office of Right of Way also uses the completed plats.

   c. The plat should include enough ground elevations to accurately define the area. Sample plats are available from IDOT. All draws, draw junctions, banks, present structures (including flowlines and lengths), fence lines, tile lines, and other pertinent existing features should be shown.

   d. Both the plan and the profile view should be shown in a 1" = 20' scale.

9. Pink sheets

   a. These sheets are used to document information such as culvert location, drainage area, benchmarks, etc. The sheets are also used for the design process, including the computation of culvert lengths. Information on the pink sheets is used to develop the tabulations for the road plans. Pinks must be filled out completely.

   b. Sample completed pink sheets are available from IDOT.

   c. The completed pinks and 20 scale plats shall be kept by IDOT as a permanent record.

10. Miscellaneous

    a. Minimum cover on all pipes is two feet.

Bridges

1. Types and sizes

   a. Three-span continuous concrete slab bridges can be used in lengths from 70 feet to 135 feet.

   b. Four series of pretensioned prestressed concrete beams are available for use in structures. Each series has a different beam depth. Standards are available in these four series in lengths ranging from 30 feet to 110 feet. When span lengths greater than these are needed, continuous welded plate girders are generally used. Pretensioned prestressed "bulb-tee" concrete girders may be considered for use in spans up to approximately 140' length.

   c. On smaller streams, pile bent piers should be considered unless soil conditions, unsupported length or a history of debris and ice problems prohibit their use. (A rule-of-thumb to define "smaller stream" is a drainage area less than 50 square miles.) On larger streams, "tee" piers (hammerhead) should be considered. On grade separation structures, usually frame-type piers with individual footings are used.

   d. The use of integral abutments is preferred over stub abutments, if possible, in order to eliminate the maintenance problems associated with expansion joints. In general, use the following table to determine which abutment type applies.

Skew	Bridge Lengths	Remarks
0° - 30° incl.	0' - 300'	Use integral abutments
0° - 30° incl.	301' - 500'	Investigate during final design for use of integral abutments.
30° - 45° incl.	0' - 150'	Use integral abutments.
above 45°	any length	Generally do not design a bridge with this high of a skew.

2. Costs

   a. For preliminary cost estimating, use unit costs of \$35/square foot for continuous concrete slab bridges, \$40/square foot for prestressed concrete beam bridges, and \$45/square foot for continuous welded plate girder bridges. These costs may need to be increased \$5/square foot or more when the complexity of the structure is higher, such as with a curved, variable-width bridge, or when the structure is in a geographic area with higher labor rates, such as Scott County. If the bridge must be stage constructed, add 30% to the cost. For widening a bridge, use \$100/square foot of the widened portion.

3. Clearances

a. For streams draining more than 100 square miles in rural areas, the required Iowa Department of Natural Resources clearance between a 50-year flood and the low superstructure is three feet of freeboard measured near the center of the stream. For steams less than 100 square miles in rural areas, freeboard between zero and three feet is desirable but not required. In urban areas, the threshold is 2 square miles.

b. Vertical clearance requirement over a Primary Highway is 16.5 feet. Over local roads, 14.5 feet is usually required unless it is in an interchange. Vertical requirement over a railroad is 23.0 feet.

c. Horizontal clearance requirements for bridges over roadways are determined from Table 3.1 of AASHTO's Roadside Design Guide, 1988. These clear zone distances apply to bridge piers but not to the 2.5:1 berm slope. Therefore, for bridges over four-lane highways, consideration should be given to designing two-span, rather than four-span, structures. The toe of the berm can be placed at the edge of the outside shoulder. A preliminary cost comparison should be made between a two-span steel or concrete bridge and a four-span concrete alternative.

d. If drainage must be carried through the approach fills of a grade separation structure, this should be accomplished by using a culvert, not by using an open ditch and thus increasing the bridge length and cost.

e. For bridges over railroads, pier placement must allow adequate clearance for off-track railroad equipment. Therefore, the minimum horizontal clearance is 18 feet on one side of the track and 12 feet on the other. This distance is measured from the centerline of the tracks to the face of either pier. Generally it is desirable and economically feasible to provide more clearance than this minimum without changing the type of beam or increasing the overall cost. See Appendix B for a sketch showing these clearances.

f. The bridge berms adjacent to a railroad are usually located by starting at the centerline of the tracks at the top-of-rail elevation, then extending a horizontal line 23 feet perpendicular to the tracks. The end of this line should intersect the face of the 2.5:1 berm. See Appendix B.

g. Piers located approximately 25 feet or less from the centerline of the tracks may need a crashwall if the railroad company requests it. If feasible, locate the piers farther than this 25 foot dimension.

4. Hydrology

a. For ungaged streams with drainage areas greater than 1,000 acres, use USGS Report 87-4132, "Method for Estimating the Magnitude and Frequency of Floods at Ungaged Sites on Unregulated Rural Streams in Iowa", Oscar G. Lara, 1987. Care should be taken when using this publication to ensure that the correct topographic region is used in estimating discharges. Examining USGS topographic maps can help determine the appropriate region.

b. Stream gage information is available from the USGS for many sites in Iowa. If adequate years of record are available at a given gage, the resulting peak discharges are generally preferred over those determined from USGS Report 87-4132.

c. Detailed Flood Insurance Studies (FIS) are available from the Federal Emergency Management Agency (FEMA) for more than 100 cities and a dozen counties in Iowa. The peak discharges and flood elevations in a FIS are usually binding and are used by DNR when issuing flood plain permits. This information, if available, is generally preferred over other sources.

d. Miscellaneous flood studies by the Corps of Engineers, DNR and USGS have been developed over the years and can be valuable supplemental information when evaluating discharges and elevations.

e. The 50-year flood shall generally be the design discharge. When DNR flood plain approval is needed, the 100-year flood shall also be considered.

5. Hydraulics

a. Manning's equation shall be used to develop stage-discharge information. Typical roughness coefficients (n-values) are as follows:
   - 0.025 to 0.035 for larger streams
   - 0.035 to 0.045 for smaller streams
   - 0.065 to 0.085 for overbank (cultivated and pasture)
   - 0.090 to 0.150 for overbank (heavy brush and timber)

These values are compatible with past DOT and DNR practice, as well as the practice of other agencies such as the USGS and Corps of Engineers.

b. FHWA's Hydraulics of Bridge Waterways, Hydraulic Design Series No. 1, 1978, may be used to estimate bridge backwater.

c. The USGS water surface profile program WSPRO may be used to develop natural and backwater elevations. The Corps of Engineers HEC-2 program is also acceptable.

6. Scour

Scour calculations should be made for all new bridges. See Appendix C for specifics on scour design.

7. Approvals

a. DNR approval is required for all bridges that cross streams with drainage areas more than 100 square miles in rural areas or two square miles in urban areas. When the upstream flood damage potential is low (e.g. crops, pasture, no buildings), then DNR's limit on backwater is 0.75 feet for Q50 and 1.50 feet for Q100. When the upstream damage potential is moderate to high (e.g. garages, residential and commercial buildings), the backwater limit is 0.75 feet for Q50 and 1.0 feet for Q100. As mentioned previously, DNR's freeboard requirement is 3.0 feet clearance above the Q50 elevation. Streams below DNR's drainage area thresholds do not need approval.

b. Corps of Engineers 404 Permits are needed for almost all bridges over water. Most of these bridges will qualify for one of several types of Nationwide 404 Permits; the remaining bridges will need an individual 404 Permit.

c. FHWA approval is required on all structures with length 20 feet or greater (as measured parallel to the highway) if federal funds will be used for construction.

8. TS&L preparation

a. Sample TS&L (Type, Size and Location drawings), also referred to as bridge plan-and-profiles or situation plans, can be obtained from IDOT. TS&L's should be prepared for all structures with length 20 feet or greater (as measured parallel to the highway), and for all bridges that are to be widened or remodeled.

b. Details to be shown on the TS&L are as follows: beam type, span lengths, typical approach roadway, roadway geometry, skew angle, centerline elevations, minimum vertical clearance and location, benchmark descriptions, ground elevations and topography, existing structures, proposed embankment shaping, and hydraulic data.

c. Both the plan and profile views should be drawn to the scale of 1" = 20'. For long bridges, a scale of 1" = 30' may be necessary.

d. Detailed structural design is generally not required for TS&L preparation. This includes foundation design (pier and abutment details, pile types and lengths) and beam spacing, unless this information is needed to determine clearance or constructibility or if the resultant information affects the type of beam used or length of structure.

e. TS&L submittal information to IDOT should include the TS&L, hydraulic calculations, surveyed valley cross section, and completed forms "Field Survey Notes for Bridges and Large Culverts" and "Risk Assessments for Bridges." Scour calculations should also be submitted.

9. Miscellaneous

a. The steepest berm slope allowed on all bridges is 2.5:1. If special soil problems exist, a flatter slope, such as 3:1, may be required.

b. Maximum bridge skew is 45 degrees.

c. The use of spur dikes (also called wing dikes or guide banks) shall be considered at any bridge site that has appreciable overbank discharge. Spur dikes help minimize backwater and scour effects. See Road Standard RL-3 for details.

Miscellaneous

1. Approvals

   a. For road projects, a DNR floodplain permit may be needed for channel changes on streams that drain ten or more square miles in a rural area or two square miles in an urban area. Approval in rural areas is not needed if both of the following conditions are met: a) less than a 500 foot length of the existing channel will be altered, and b) the length of existing channel being altered is reduced by less than 25%.

   b. Other highway work, such as borrow sites and levees, that is in the flood plain of a stream may also require DNR approval.

   c. Any highway project that affects streams or wetlands may need a 404 Permit from the Rock Island District Corps of Engineers.

2. Erosion

   a. Factors to determine the need for bank protection are as follows: a) when stream velocities exceed 8 to 9 feet per second, riprap may be considered; b) the condition of the existing banks or bridge opening is a good indicator as to the need for protection; and c) examine past aerial photos to determine an approximate rate of erosion.

   b. A common design for riprap as bank protection is engineering fabric, a two-foot-thick layer of Class E riprap, and adequate protection at the toe of the bank. The steepest bank slope shall be 2:1 (horizontal to vertical).

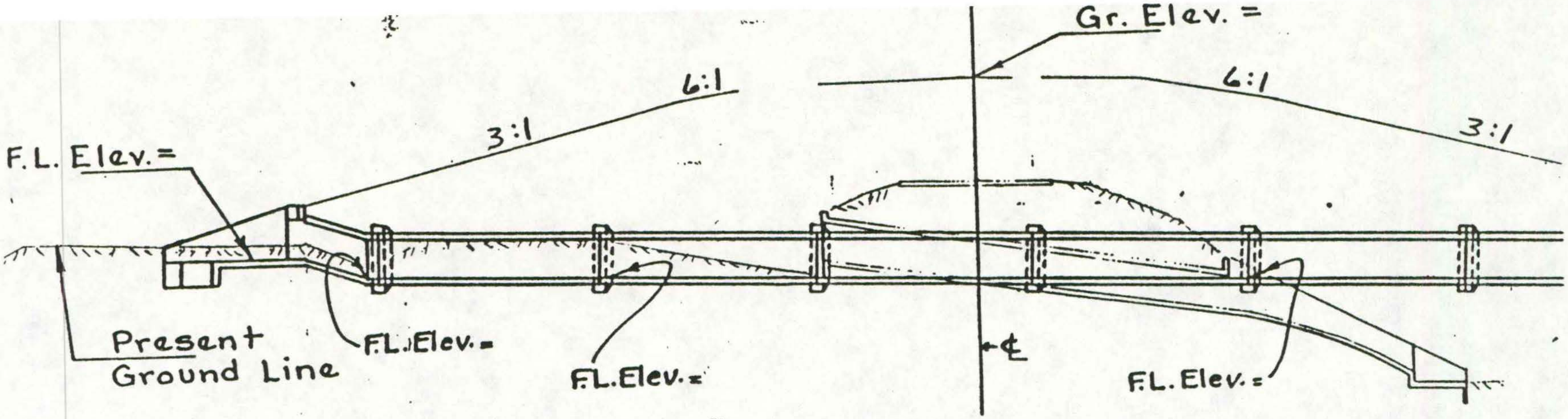
   c. Riprap at culvert outlets is generally not needed, unless there is a special problem such as right of way concerns in an urban area. If riprap is needed at a culvert that has high outlet velocities, such as at a flume, the rock gradation may need to be heavier than the standard Class E specification.

3. Roadgrade

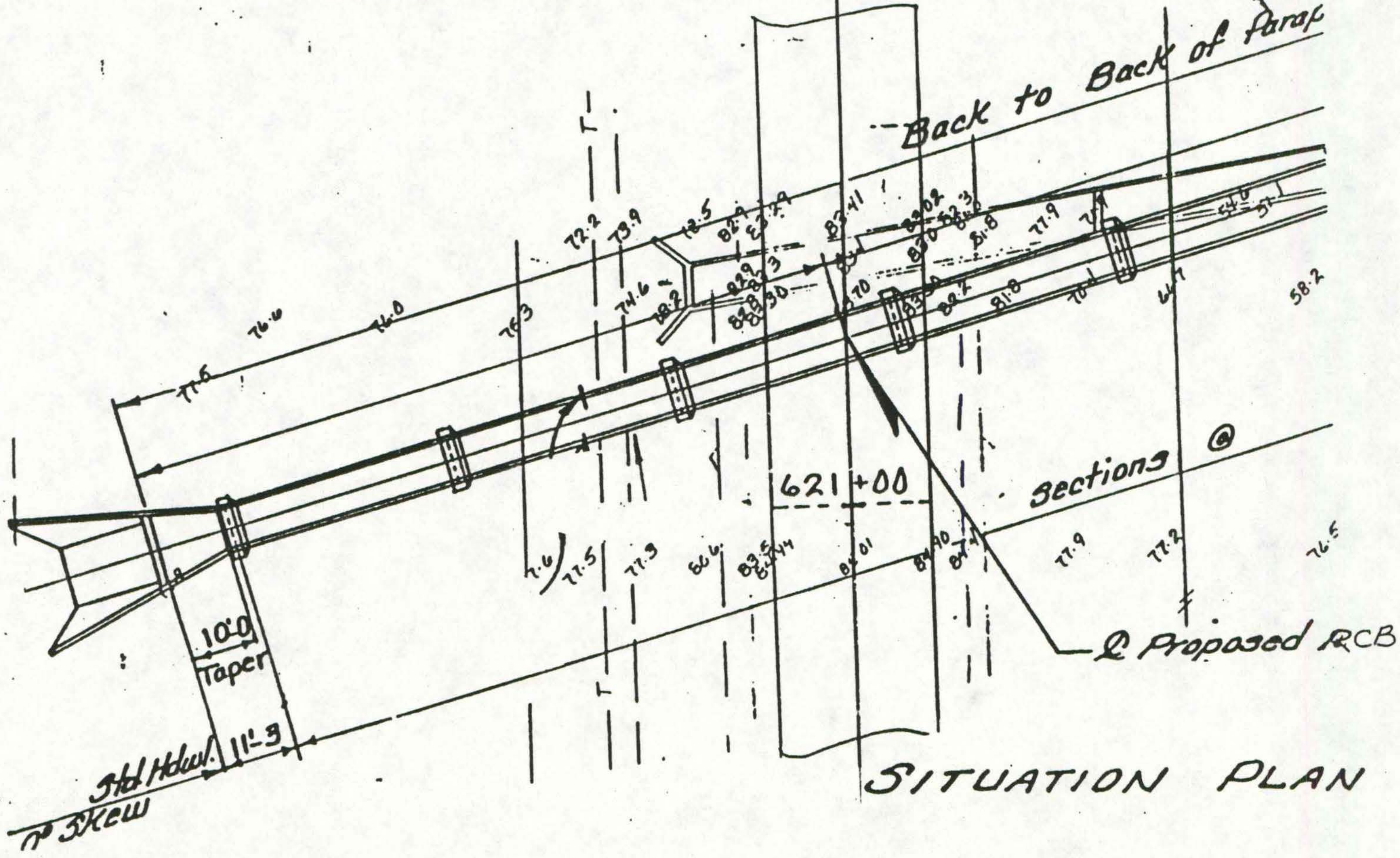
   a. The low roadgrade should generally be designed to a minimum of the 50-year flood elevation plus one foot. Recognize, however, that if the roadgrade is much higher than this minimum, it eliminates the "relief valve" for a bridge during an extreme flood.

Appendix A

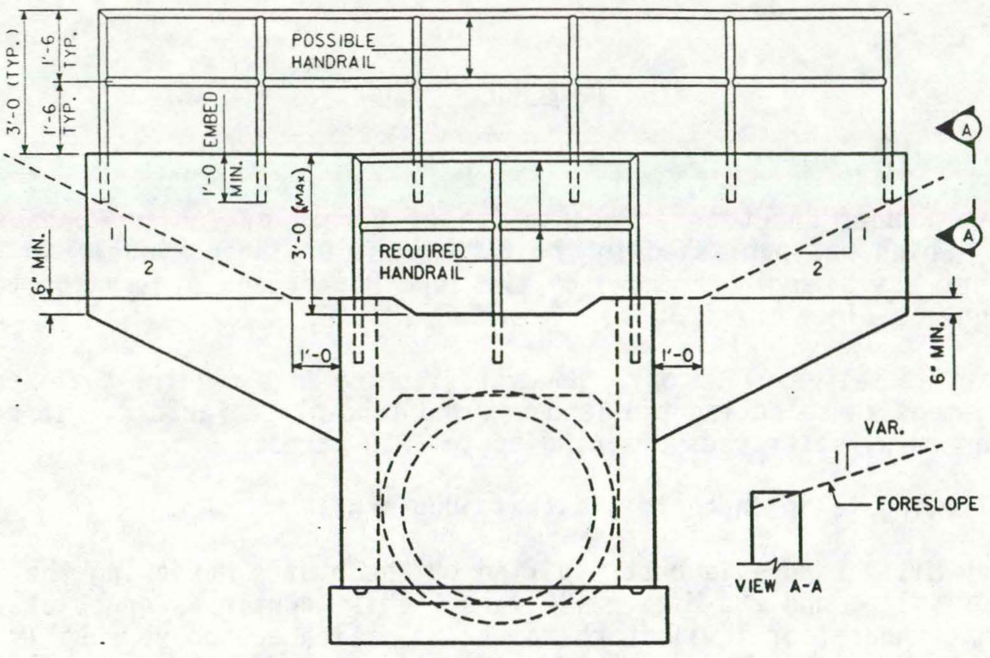
Culverts



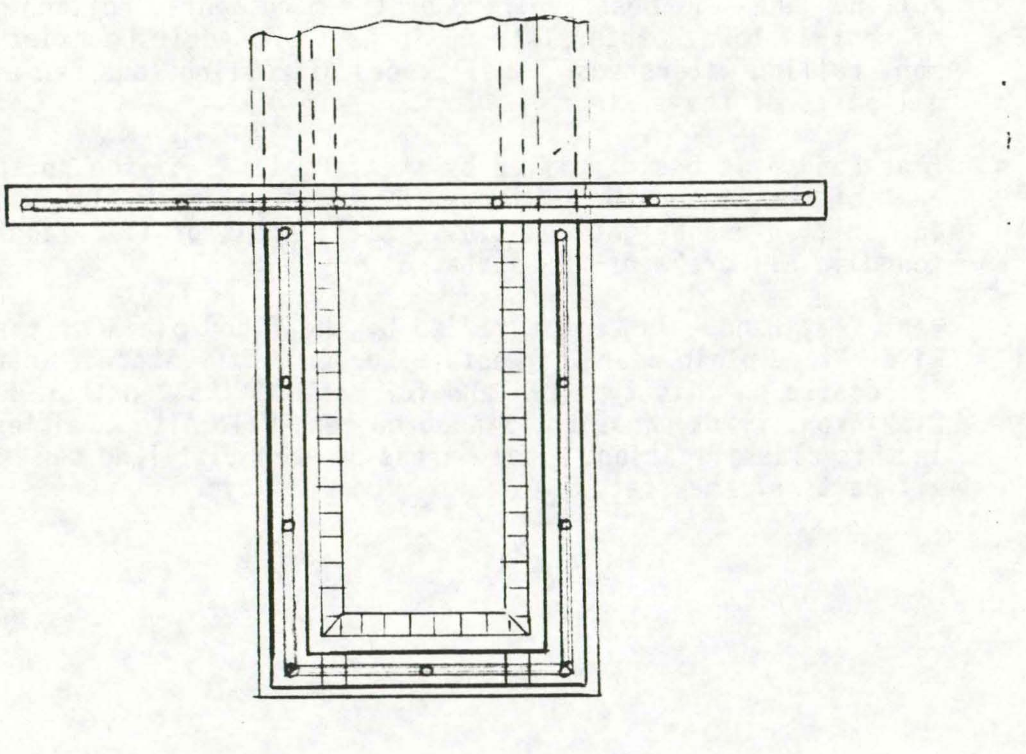
LONGITUDINAL SECTION ALONG ℄ CULVERT



SITUATION PLAN



DROP INLET WING DETERMINATION



PLAN

The Iowa Runoff Chart

The Iowa Runoff Chart is an adaptation of Bureau of Public Roads Chart 1021.1, which was published in their "Highway Drainage Manual" in 1950. The chart has been widely used by the Iowa Department of Transportation and counties since the 1950's.

The chart is self-explanatory. However, its use does require the exercise of judgement in selecting the land use and land slope factors. It can be used for rural watersheds draining up to 1000 acres.

The following is intended to aid that judgement.

1. Very Hilly Land - is best typified by the bluffs bordering the Mississippi and the Missouri Rivers. This terrain is practically mountainous (for Iowa) in character. Small areas of very hilly land can be found in all parts of the state. Typically, they can be found near the edge of the flood plains of the major rivers.

2. Hilly Land - is best typified by the rolling hills of south central Iowa. Interstate 35 in Clarke and Warren Counties traverses many hilly watersheds. Small areas of hilly land can be found in all parts of the state.

3. Rolling Land - is best typified by the more gently rolling farm lands of central Iowa. Interstate 80 in Cass and Adair Counties traverses many rolling watersheds. Small areas of rolling land can be found in all parts of the state.

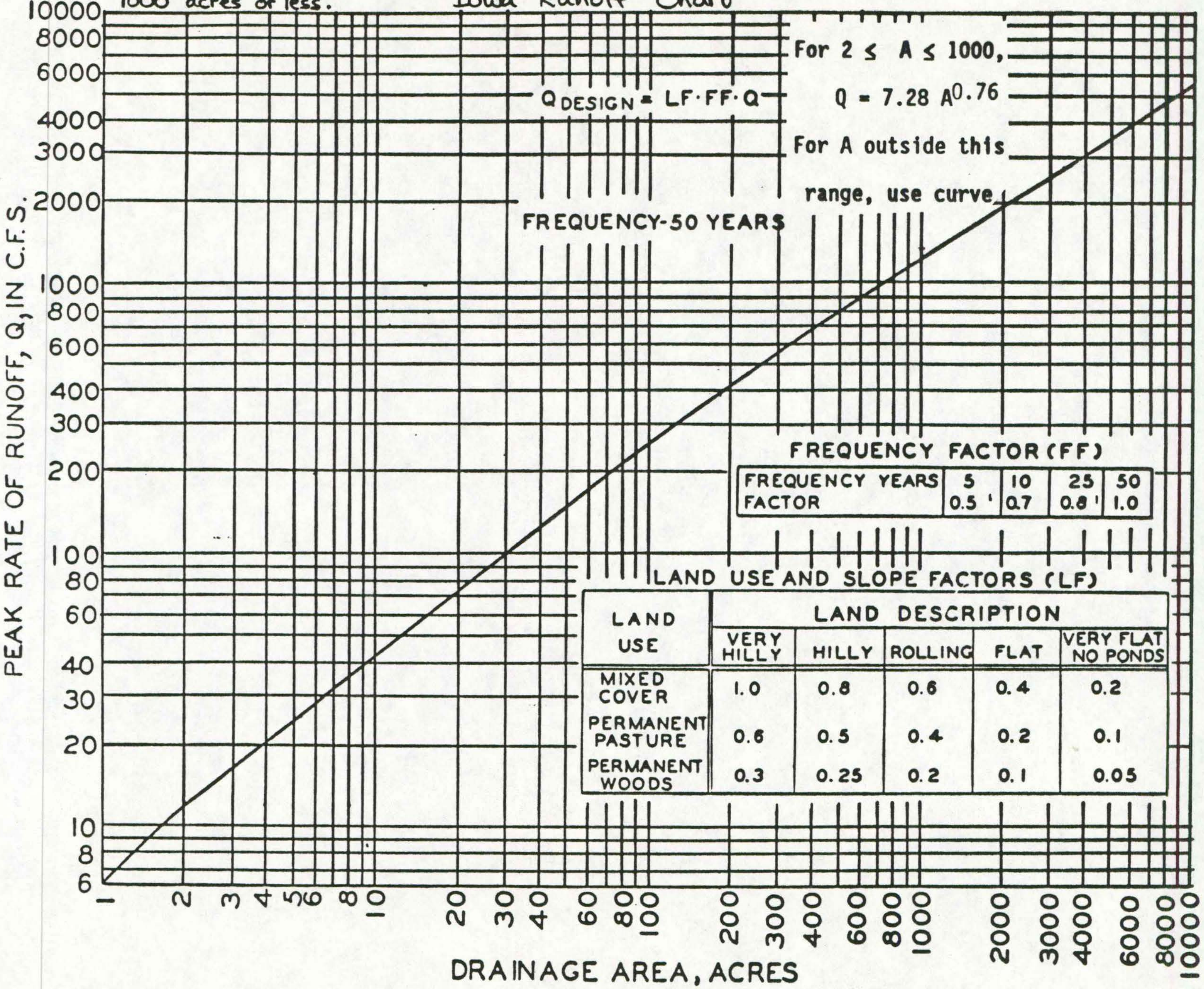
4. Flat Land - is best typified by the farm lands of the north central part of the state. U.S. Highway 69 traverses many flat watersheds in Hamilton and Wright Counties. Small areas of flat land can be found in all areas of the state.

5. Very Flat Land - is best typified by the flood plain of the Missouri River flood plain near the western border of the State. Interstate 29 is located on this type of land for most of its length. Much of Dickinson, Emmet, Kossuth, Winnebago, and Palo Alto counties are also in this classification. Small areas of very flat land can be found in all parts of the state.

Use for drainage areas approximately 1000 acres or less.

PEAK RATES OF RUNOFF

"Iowa Runoff Chart"



$Q_{DESIGN} = LF \cdot FF \cdot Q$

For $2 \leq A \leq 1000$,

$Q = 7.28\ A^{0.76}$

For A outside this range, use curve.

FREQUENCY FACTOR (FF)

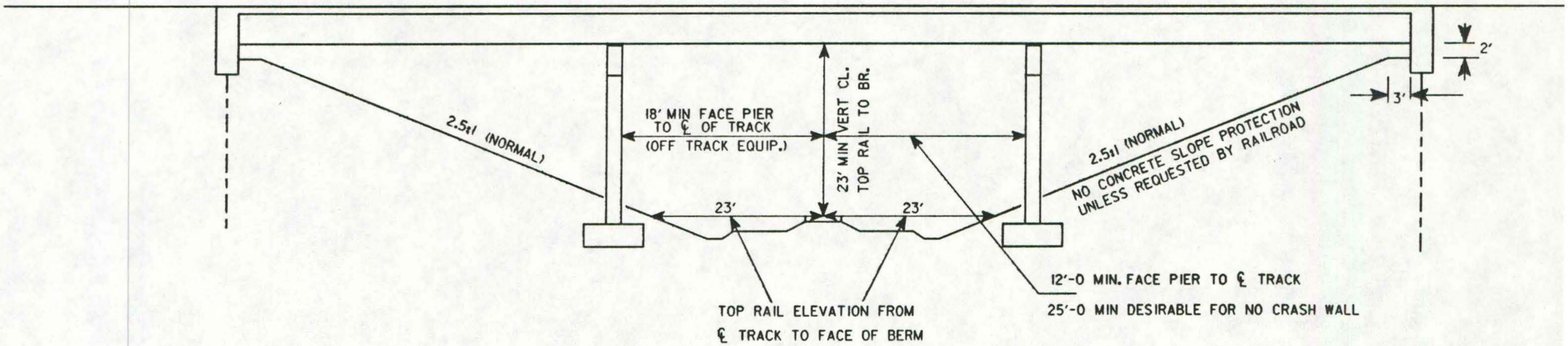
FREQUENCY YEARS	5	10	25	50
FACTOR	0.5	0.7	0.8	1.0

LAND USE AND SLOPE FACTORS (LF)

LAND USE	LAND DESCRIPTION				
	VERY HILLY	HILLY	ROLLING	FLAT	VERY FLAT NO PONDS
MIXED COVER	1.0	0.8	0.6	0.4	0.2
PERMANENT PASTURE	0.6	0.5	0.4	0.2	0.1
PERMANENT WOODS	0.3	0.25	0.2	0.1	0.05

Appendix B

Bridges



TYPICAL HIGHWAY BRIDGE OVER RAILROAD

Appendix C

Scour

SCOUR

Introduction

Scour at bridge piers and abutments has been a problem and concern for decades. Nationwide, the most common cause of bridge failures stems from floods, and scouring of bridge foundations is, in part, the most common cause of damage to bridges during those floods. The issue was brought to national attention in April 1987 when the Interstate 90 bridge over Schoharie Creek in New York collapsed, killing about 10 highway users. Most bridge failures are not as newsworthy as the I-90 bridge; however, the concern about scour in Iowa is no less important. Loss of life, total bridge failure or major structural damage is a costly and serious problem for the owner of the affected bridge.

It is not economically feasible to design all bridges to resist all conceivable floods; therefore we can expect periodically some bridges will fail or be damaged by scour. However, because of public safety and high replacement and repair costs, the need exists to evaluate or improve current design and maintenance practices concerning bridge foundations.

Objective

Therefore, the objective in this session is to provide the individual with (1) factors that affect scour; (2) a method to estimate scour in existing and proposed structures; and (3) recommendations to reduce or prevent scour effects on existing and proposed bridges.

Definition

A basic definition of scour is the result of erosive action of moving water as it excavates and carries away material from a streambed and banks. There are two types of scour: 1) General scour - the loss of material from most or all the bed and banks, usually caused by the road embankment encroaching onto the flood plain with resulting contraction of the flood flow (often called contraction scour); 2) Local scour - occurs around piers, abutments, spur dikes and embankments.

The effects of scour are a complex problem involving geotechnical, hydraulic, and structural concerns.

Design guidelines and considerations

There are numerous factors that can affect the bed and banks of a stream. Some of these factors are discussed below, with some guidelines and considerations.

1. Soils

Soils with any combination of sand or silt may have potential for scour: sand, silt, sandy silt, sandy silty clay, etc. are examples. As a general rule these soils which have a blow count of ten or less may be particularly susceptible.

Excessive loss of pile bearing due to scour is one cause for bridge damage or failure. However, perhaps a more common cause of failure is due to soil instability associated with the road embankment and bridge berm. Often a bridge berm or fill behind a high abutment is barely adequate for stability. If the equilibrium is disturbed due to a few feet of scour at the toe of the embankment, the soil becomes unstable and a slip failure occurs. Loss of the abutment, pier or approach fill is the probable outcome.

For replacement structures, designing flatter berm slopes and/or moving the abutments farther back will provide a greater safety factor. Then, when scour does occur, the embankment will remain stable. For existing structures, protection of the berm, especially the toe, may be necessary.

2. Substructure

Generally, wider and longer piers have greater scour potential. Deeper footings and longer piles are more resistant to scour. Spread footings should be used only on limestone, shale, etc.

To maintain the integrity of the structure, do not allow scour to reduce pile bearing safety factor below a certain level, such as 1.2. Maintaining this minimum safety factor may require longer piles for bridges in the design phase. If dealing with an existing structure, protection of the piles may be necessary to maintain the safety factor.

Vertical wingwall abutments (high abutments) have a greater potential for general and local scour as compared to the spillthrough type (integral or stub abutments). These high abutments should not encroach on the channel and should be kept as far back from the streambank as possible.

3. Flood discharge

In the publication Evaluating Scour at Bridges, Hydraulic Engineering Circular No. 18, February 1991, the FHWA recommends using a Q100 or lesser discharge, depending on which results in the most severe scour conditions. Usually the overtopping flood results in the worst scour, so check this flood (if less than the Q100) and the Q100.

The discharge used in scour design is generally larger than that used in hydraulic design. For example, hydraulic design guidelines for a bridge may be a Q25 discharge, but the scour design may use a Q100. The rationale for this is that hydraulic design involves backwater and ensures that the bridge size will be adequate under normal flood conditions. In scour design, a higher discharge is used to ensure that the bridge will remain stable and will not fail or suffer severe damage during extreme flood events.

FHWA also recommends checking scour conditions for a superflood, such as a Q500. The safety factors for the bridge should remain above 1.0 under this flood condition. Similar to that mentioned above, if the overtopping flood is less than the Q500, this may be the critical flood.

4. Interaction between road and flood plain

A highly skewed river crossing provides a less hydraulically efficient bridge opening and therefore has a greater contraction scour potential.

High eccentricity of flood flow or a high ratio of over bank flow to main channel flow will result in a greater contraction scour potential.

For the above mentioned situations, scour can be reduced by using spur dikes and/or rip-rap.

Road grade overflow or overflow structures will provide relief for the main channel bridge.

5. Interaction between piers and flood flow

The width, thickness and type of pier (e.g. pile bents, "tee" piers) all have an effect on local scour. The angle of attack of flood flow to the pier can also have a large effect on scour. If this angle of attack increases during the life of the bridge, scour can increase significantly. The stream's history of and future potential for meandering should be examined.

6. Debris and ice

Visual observation can be made and records checked to determine the history of debris and ice on the stream. Debris and ice can snag on the piers or superstructure, placing additional stresses on the bridge as well as promoting local scour. This scour can sometimes be quite significant. Therefore, for new designs, give consideration to raising the low superstructure above the low roadgrade elevation. This will provide hydraulic relief if the bridge opening becomes clogged.

7. Structures and appurtenances.

Overflow bridges can be used on flood plains that have substantial overbank flow. This provides relief for the main channel bridge. However, be aware that these overflow structures are particularly susceptible to deep scour. Twenty to thirty feet of scour is not uncommon.

Sheet piling can be an expensive but often effective method to protect existing piers or abutments with a serious scour problem.

Rip-rap is an easy and often inexpensive way to protect a bridge.

Spur dikes provide for a more hydraulically efficient bridge opening and force the scour to occur on the dike, which is expendable, rather than on the bridge itself.

Estimating scour

Procedures for estimating scour have been researched in the past 40 years in an attempt to develop reliable prediction equations. Some of these equations give reliable results, others do not. The Federal Highway Administration has attempted to find the best equations and published in HEC No. 18, Evaluating Scour at Bridges.

HEC No. 18 contains equations for contraction scour, abutment scour and pier scour. The contraction scour equations are the best available equations of their type and generally provide reliable estimates. The abutment scour equations frequently give questionable estimates. Because of comments similar to this from various states, FHWA is conducting additional research to develop new methods. At this time, do not use FHWA's abutment scour equations.

Concerning pier scour, the equation in HEC No. 18 gives reliable results. However, a much simpler method that gives very similar results is found in Iowa Highway Research Board's Bulletin No. 4, "Scour Around Bridge Piers and Abutments," by Emmett M. Laursen and Arthur Toch, May 1956. This method for estimating pier scour can be used instead of the methods in the FHWA publication.

Scour calculations

1) Contraction scour - use FHWA's Evaluating Scour at Bridges, HEC No. 18.

$$\frac{Y2}{Y1}=\left(\frac{Q_{mc2}}{Q_{mc1}}\right)^{0.86}\left(\frac{W_{c1}}{W_{c2}}\right)^{0.64}\left(\frac{n_2}{n_1}\right)^{K2}$$

$$=\left(\frac{\qquad\qquad}{\qquad\qquad}\right)^{0.86}\left(\frac{\qquad\qquad}{\qquad\qquad}\right)^{0.64}(1)$$

= ______________

$$Ys = Y2-Y1 = Y1\left(\frac{Y2}{Y1}-1\right)$$

$$=\left(\qquad -1\right)=$$ ______________ft of contraction scour.

2) Abutment scour - neglect at this time because of inadequate equations.

3) Pier scour - use IHRB Bulletin No. 4 by Laursen

depth of flow (df) = ______________ft

width of pier (wp) = ______________ft

$\frac{df}{wp}$ = ______________ = ______________

From Fig. 38, $\frac{d's}{wp}$ = ______________

Solve for d's = wp x $\frac{d's}{wp}$ = ____________ x ____________ = ____________ft

Now determine the multiplying factor, either for angle of attack or for shape coefficient. Do not use both factors at the same time.

If **Angle of attack = 0, use Table V for shape coefficient.** Otherwise, use Figure 39.

Ks = (or use $K_{\alpha L}$ =)

ds = Ks x d's = ____________ x ____________ = ______________ft of pier scour

4) Total scour at pier

scour depth = contraction scour + pier scour

= ____________ + ____________

= ____________ft below normal streambed

= elevation ____________ft

Is this scour depth realistic? Is the soil scourable? What is the effect on pile bearing? Are longer piles or a deeper footing needed? Should riprap be used?

5) Total scour at abutment

scour depth = contraction scour + abutment scour

= ____________ + ____________

= ____________ft below normal streambed

= elevation ____________ft

Is this realistic? Is the soil scourable? What is the effect on berm stability? Are flatter berm slopes or a longer bridge needed? Should wing dikes or riprap be used?

Measures to reduce effects on scour

In summary, listed below are some possible considerations to reduce scour on the bridges. Some items may be relevant only to existing bridges; others may be relevant only in the design phase of a structure.

1. Set the pier or abutment footings lower.
2. Use longer piles.
3. Install spur dikes.
4. Place rip-rap around the pier, abutment, berm slope, or spur dike or across the entire streambed.
5. Provide for roadgrade overflow.
6. Keep abutments as far from the streambank as possible.
7. Remove debris from piers.

References

(1) Evaluating Scour at Bridges, Hydraulic Engineering Circular No. 18, Federal Highway Administration, February 1991.

(2) Scour Around Bridge Piers and Abutments, Emmett M. Laursen and Arthur Toch, Iowa Highway Research Board, Bulletin No. 4, May 1956.

(3) Hydraulics of Bridge Waterways, Hydraulic Design Series No. 1, Federal Highway Administration, March 1978.

U.S. Department
of Transportation

**Federal Highway
Administration**

Publication No. FHWA-IP-90-017
February 1991

Hydraulic Engineering Circular No. 18

Evaluating Scour at Bridges

Office of Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

from HEC #18

D. STEP 4. CONTRACTION SCOUR

1. General

Contraction scour can be caused by different bridge site conditions. There are four (4) conditions (cases) which are:

Case 1. Involves overbank flow on a flood plain being forced back to the main channel by the approaches to the bridge.

Very common in Iowa

a. The river channel width becomes narrower either due to the bridge abutments projecting into the channel or the bridge being located at a narrowing reach of the river ($W_{c1} > W_{c2}$).

b. Does not involve any contraction of the main channel, but the overbank flow area is completely obstructed by the embankment ($W_{c1} = W_{c2}$).

c. Abutments set back from the stream channel (($W_{c1} < (W_{c2} + W_{setback}$)).

Case 2. Flow is confined to the main channel; i.e., there is no overbank flow. The normal river channel width becomes narrower due to the bridge itself or the bridge site being located at a narrower reach of the river.

not very common. May be found in Western Iowa.

Case 3. A relief bridge in the overbank area with little or no bed material transport in the overbank area; i.e., clear-water scour. ($W_1 > W_{c2}$)

very common

Case 4. A relief bridge over a secondary stream in the overbank area. (Similar to Case 1).

occasionally

W_{c1} = bottom width of the main channel
W_{c2} = bottom width of the contracted section
W_1 = width of upstream overbank area

These 4 cases are illustrated in Figure 4.1. The equations for solving each case are presented in the following sections.

from HEC #18

2. Estimating Contraction Scour.

a. CASE 1. CONTRACTION SCOUR, OVERBANK FLOW BEING FORCED BACK INTO THE MAIN CHANNEL. (Live-bed scour)

For Cases 1a and 1b use Laursen's 1960 Equation (8) for a long contraction to predict the depth of scour in the contracted section. This equation was given in Chapter 2. It assumes that bed material is being transported in the main channel, but not in the overbank zones.

use 0.64

$$\frac{y_2}{y_1} = \left(\frac{Q_{mc2}}{Q_{mc1}}\right)^{\frac{6}{7}} \left(\frac{W_{c1}}{W_{c2}}\right)^{K_1} \left(\frac{n_2}{n_1}\right)^{K_2} \qquad (1)$$

assume 1.0 ratio

$y_s = y_2 - y_1$ (Average scour depth)

Where:

y_1 = average depth in the main channel
y_2 = average depth in the contracted section
W_{c1} = bottom width of the main channel
W_{c2} = bottom width of the bridge opening
Q_{mc1} = flow in the approach channel that is transporting sediment
Q_{mc2} = flow in the contracted channel which is often Q_{total}, but not always
n_2 = Manning's n for contracted section
n_1 = Manning's n for main channel
assume both are equal
K_1 & K_2 = exponents determined below

V_{*c}/w	K_1	K_2	Mode of Bed Material Transport
<0.50	0.59	0.066	mostly contact bed material discharge
0.50 to 2.0	0.64	0.21	some suspended bed material discharge
>2.0	0.69	0.37	mostly suspended bed material discharge

V_{*c} = $(gy_1S_1)^{0.5}$, shear velocity

w = fall velocity of D_{50} of bed material. (See Figure 4.2)

g = gravity constant

S_1 = slope of energy grade line of main channel

BULLETIN NO. 4

IOWA HIGHWAY RESEARCH BOARD

Scour Around Bridge Piers And Abutments

by

Emmett M. Laursen and Arthur Toch
Iowa Institute of Hydraulic Research
State University of Iowa

Prepared by the
Iowa Institute of Hydraulic Research
in cooperation with
THE IOWA STATE HIGHWAY COMMISSION
and
THE BUREAU OF PUBLIC ROADS
May 1956

PB—C-8314

adapted
from Laursen
Bulletin #4

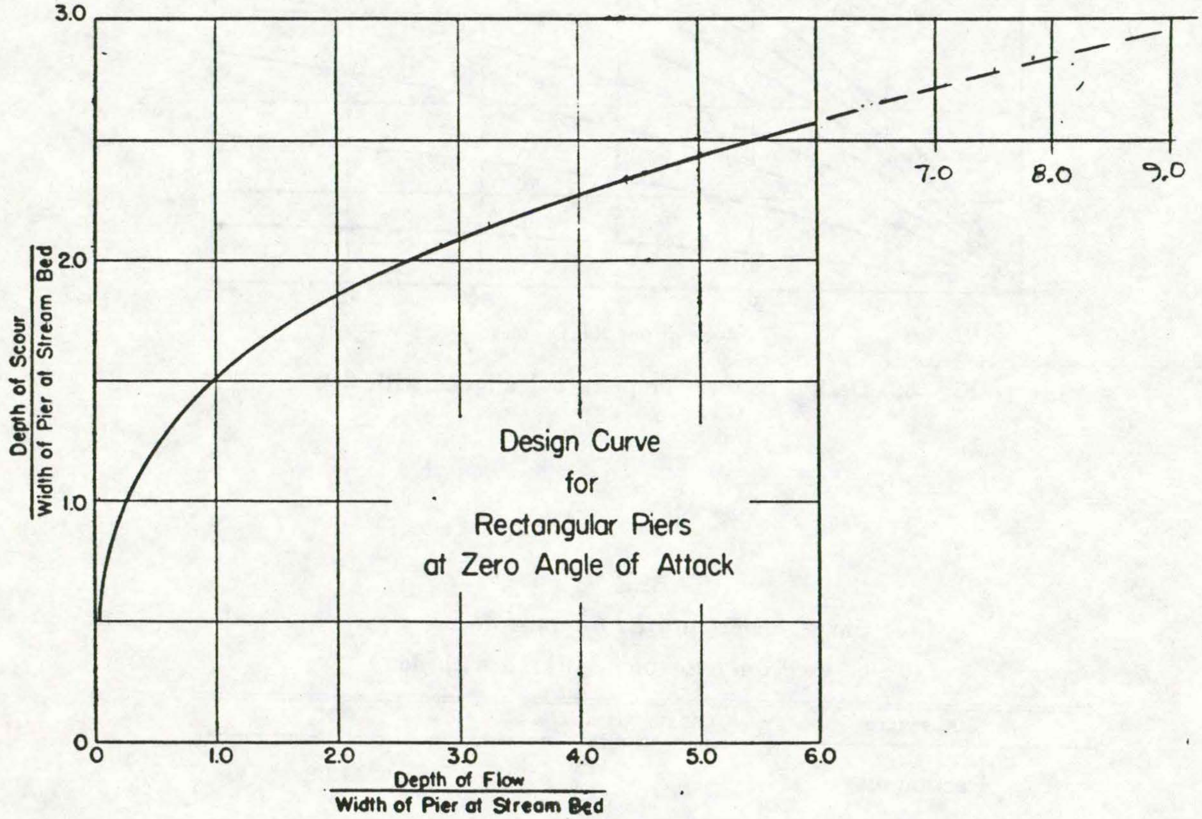


Fig. 38. Basic design curve for depth of scour.

From Laursen
Bulletin #4

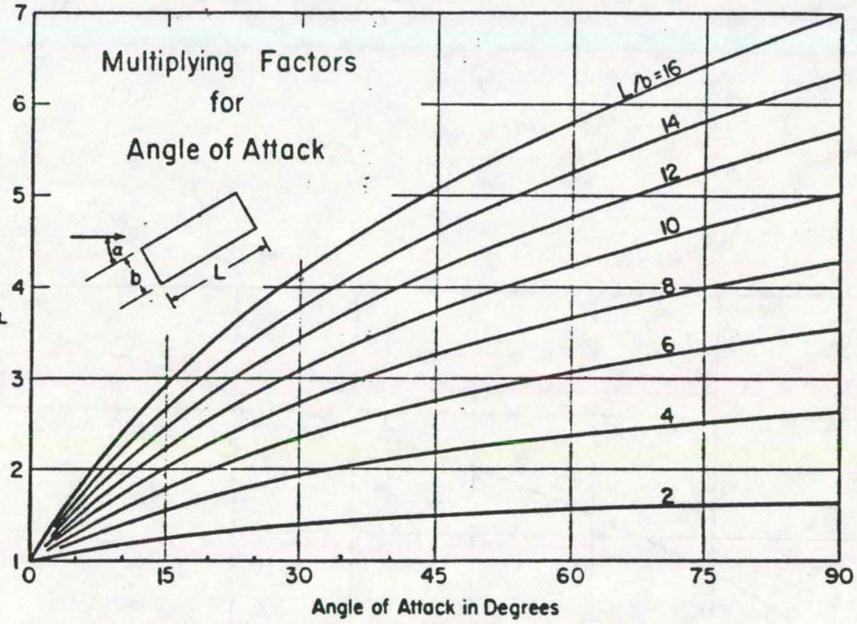
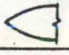


Fig. 39. Design factors for piers not aligned with flow.

TABLE V

Shape coefficients K_s for nose forms

(To be used *only* for piers aligned with flow)

Nose form	Length-width ratio		K_s
Rectangular			**1.00**
Semicircular			**0.90**
Elliptic	**2:1**		**0.80**
	3:1		**0.75**
Lenticular	**2:1**		**0.80**
	3:1		**0.70**