Guidelines For Preliminary Design Of Bridges And Culverts

Revised
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Iowa Department of Transportation

Highway Division
Engineering Bureau
Office of Bridges and Structures

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Appendix C – Scour

Following is a set 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 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.

Earlier editions of this document are hereby superseded. Changes in this revised edition include dimensions in English and metric units, and additional information in the appendices.. Also, the June 1995 "Design Aids for Roadway Culvert Designs" is superseded. Its contents have been incorporated into this document.

Culverts

General drainage policy

In the construction of rural highways in Iowa it is of primary importance that there be minimal diversion of surface water. Water entering the highway right of way in a draw (swale or ditch) should generally be carried through the highway embankment and discharged into the same draw. Although it is not possible to leave unchanged every square foot of watershed, this policy of "minimal diversion" shall be adhered to as closely as practical.

The term "minimal" is difficult to quantify but may be viewed in terms of percentage change and of potential impacts to affected properties. For example, altering a 150-acre watershed to 152 acres may have minor effects on peak flow, but altering a 5-acre watershed to 10 acres may adversely affect farming practices on a given property. In much rarer instances, <u>decreasing</u> drainage area may also have an adverse impact. One actual example is a 7-acre watershed that was diverted to a much larger basin. During construction, the landowner made IDOT aware that the 7-acre watershed was a significant water supply source to a pond used for watering livestock.

On highway relocations, be aware that field fences may have enough soil built up to create a "ridge" where water does not cross. In effect, these fences may create distinct watershed boundaries and become as important as any "natural" watershed boundary. Avoiding diversion in these instances must be considered when the highway relocation cuts through these fence "ridges".

Hydrology

<u>Rural</u> For drainage areas less than 1000 acres (400 hectares), use the Iowa Runoff Chart (see Appendix A). For larger drainage areas, use U.S. Geological Survey 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. (An updated USGS report will be published soon and is expected to supersede 87-4132.)

Urban For urbanized areas, use methods such as Rational Formula or NRCS's TR-55.

Design Discharge For the design of crossroad (mainline) culverts, use the 50-year flood. For most sideroad pipes, use a 50-year flood. For entrances, use a 10-year flood unless the mainline is adversely affected. For temporary pipes under a "runaround", generally use the 5-year flood.

Hydraulics

For culvert hydraulics, use FHWA's publication, "Hydraulic Design of Highway Culverts," Hydraulic Design Series No. 5, September 1985. Equivalent computer software such as HY-8 or Haestad Methods' "CulvertMaster" is also acceptable. Check with the Office for approval of other software.

Culverts should generally be designed to have one foot (0.3 m) of head above the top of the opening at the design discharge. This can be exceeded in some instances if the culvert is under high fill and there is minimal flood damage potential upstream. When the upstream terrain is very flat, be aware that a calculated highwater may not be reached due to large available flood storage. In this circumstance, the designer may need to consider less culvert height and more width to accommodate flows at lower water surface levels.

Size

Minimum pipe size for roadways, sideroads and ditch letdowns is 24 inches (600 mm). This provides adequate opening for maintenance inspections and minimizes the potential for plugging with debris.

Preferred minimum size for median pipes in four-lane roadways is 24 inches (600 mm). However, in some instances, the median ditch may be too shallow (approximately one meter or less) to place a 24 inch (600 mm) pipe under the pavement, so an 18 inch (450 mm) pipe may be used.

Minimum pipe size for entrances is 18 inches (450 mm).

Maximum size of concrete pipe culverts is 84 inches (2100 mm). When a larger opening is needed, it is generally more economical to use a cast-in-place reinforced concrete box culvert (RCB). General practice is to use a higher strength pipe (e.g., 3750 D) with Class B bedding before using an RCB.

Cast-in-place RCB standards are available for various sizes ranging from 3’ X 3’ (900 mm X 900 mm) to 12’ X 12’ (3600 mm X 3600 mm) for single barrel, and 8’ X 6’ (2400 mm X 1800 mm) to 12’ X 12’ (3600 mm X 3600 mm) for twin barrels. Standards for triple-barrel RCBs are currently available only in metric, from 3000 mm X 2400 mm to 3600 mm X 3600 mm. Triple standards in English units will soon be available. Check with the Office of Bridges and Structures. These standard sizes should be used whenever practical. No RCBs smaller than a 3’ X 3’ (900 mm X 900 mm) shall be used, except in very unusual situations such as extending a small RCB when no precast options are acceptable.

Standard RCB headwall skews (0°, 15°, 30° and 45°) should be used in almost all cases, even when the barrel is at a non-standard skew to the roadway. For example, if the barrel is skewed 20° to the roadway, use a 15° standard headwall. Exceptions would include when the RCB headwall is near the intersection of two roads, and the slope shaping and safety on both roads need to be considered.

The site history of the existing culvert may provide useful information when sizing a proposed culvert. Survey crews should find this information and note it on the pink sheet. IDOT maintenance personnel may have information related to landowners' complaints or road overtopping, which may indicate a larger structure should be designed or the roadgrade needs to be raised. Any such history should be documented in project files or on the pink sheets.

Type

Concrete culverts (Road Standard RF-1) shall be used under all paved roads, including paved sideroads, and shall have minimum strength of 2000D (100D). The maximum strength is generally 3750D (175D). However, the concrete pipe industry does have a higher strength pipe 4000D/ 200D) that may be used for greater fill heights on a case-by-case basis. Prior approval from the Office of Bridges and Structures is required.

Corrugated metal pipe shall be specified for any temporary pipes (aprons are generally not needed). Unclassified Entrance Pipes shall be specified for entrances. Unclassified Roadway Pipes shall be specified for unpaved sideroads. (When “Unclassified” pipes are called for, the contractor may select the culvert material from the appropriate list in IDOT’s Specification 2422.) Either coated steel or polyethylene shall be specified for letdowns. (See the section “Letdowns” later in this document.)

When available head is limited due to low road fill or very flat ground upstream, several alternatives may be acceptable instead of a single, large, round pipe: an arch pipe, twin pipes, or an “oversized” round pipe with the invert buried. (This latter alternative has an advantage of a lower flowline that could be used in the future for a lower ditch flowline.) Cost of the structure may be a determining factor in the type used. Concerning the spacing of twin pipes, provide approximately 3 feet (0.9 m) between the outside edge of the pipes. Cast-in-place drop inlets (see Appendix A) or Road Design Detail 1407 may also be acceptable solutions when available head is limited.

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. Standards are currently being developed. Check with the Office of Bridges and Structures concerning availability and usage. The use of precast RCBs is limited to fill heights from 2 feet (0.6 m) to 14 feet (4.3 m) and expected settlements of 6 inches (0.15 m).

Stockpasses are not typically 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. (The Office of Right of Way will coordinate this with the affected landowner.) For new stockpasses, a 4 foot X 6 foot (1200 mm x 1800 mm) barrel is the preferred size for cattle; a 5 foot X 7 foot (1500 mm x 2100 mm) barrel is used for a horse pass. See Road Standard RF-8.

Settlement and Camber

See Office of Bridges and Structures' Final Design Manual for guidance on the use of camber and bell joints on cast-in-place RCBs. Soils Design Section of the Office of Design will provide the final recommendation for bell joints. Soils Design's estimated settlements for all culverts (both precast and cast-in-place) should be equivalent to the camber placed in the culverts. For pipe culverts, this camber should be noted in the appropriate column on the pipe culvert bid tabulation 104-3.

Horizontal Alignment

Generally, culverts should be aligned with the waterway, especially on the outlet end. However, high skews should be avoided where possible to minimize costs. Culvert and excavation costs should be considered when selecting the alignment. The constructability of the culvert during traffic staging, including maintaining drainage during construction, may also be an important factor.

Vertical Alignment

Generally the slope of a pipe or box culvert should approximate the natural ground slope. When the slope of a pipe culvert is 5% or steeper, give consideration to a culvert type such as 1201 or

1501. When the slope of a box culvert exceeds approximately 2%, give consideration to some type of energy dissipater such as a drop inlet or a flume outlet. Also, give consideration to putting in verticals breaks in the slope, such as a “broken back” culvert, to minimize outlet velocities.

Culverts in Series

If two culverts in series are near each other, such as a mainline culvert and a culvert downstream under a ramp, generally keep the slope between the culverts to a minimum, perhaps 1% or less. This helps avoid erosion between the culverts. If a significantly steeper slope is unavoidable, a rock-lined ditch may be needed.

The hydraulics of the culverts in series should be carefully checked to accurately determine the influence of one culvert on any upstream culverts.

Length Determination

The length of culvert is determined by either the clear zone or by matching the proposed cross section, such as the barnroof slope. See Appendix A for design aid "Determining Culvert Lengths” which provides a more detailed explanation of how to determine this length and explains how to use the Computation Section on culvert pink sheets. See Road Typical 4304 and 4311 for foreslope shaping and cover over minimum length culverts.

Calculated concrete pipe lengths will be rounded up to the nearest even-numbered foot. Calculated lengths of Unclassified pipes will be rounded up to the nearest foot.

Slope Tapered Inlets

Slope tapered inlets on cast-in-place RCBs 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, to make construction simpler, the inlet dimensions shall be tapered only in the width, not in the height, e.g., a 12’ X 8’ inlet may be tapered to an 8’ X 8’ barrel section but not to an 8’ X 6’ . See Appendix A for specific design guidelines. Due to high velocities and large drop in elevation, most tapered inlet culverts will need a flume and a basin to dissipate energy.

Design guidelines for slope tapered inlets on concrete pipe culverts are shown in Appendix A.

If adequate fall is not available and inlet efficiency is necessary, side tapered inlets may be used to improve inlet performance.

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

When a pond is created upstream, geotechnical concerns must be considered to ensure that seepage through the embankment is not excessive. Also, for traffic safety considerations, the road embankment should be designed so that a permanent pond is not up against the normal barnroof slope. For example, an earthen “bench”, perhaps 15’ to 30’ wide in cross section , can be built along the foreslope to keep the pond farther away from the highway and errant vehicles.

Drop Inlets

Cast-in-place drop inlets are used for minimum headwater depth situations for both RCB and pipe culverts. Drop inlets also provide good energy dissipation within the culvert. These inlets provide a convenient method of carrying flow from drainage tile across the roadway by discharging the tile through the inlet wall. Generally it is good practice to replace existing drop inlets in-kind in order to prevent an increase in headwater.

See Appendix A for design guidelines, a sample plan and profile, and a typical inlet detail. Design highwater elevation should not exceed the top of the butterfly wing, 3 feet (0.9 m) maximum above the drop inlet [weir] flowline). This wing has two purposes: 1. To hold the foreslope soil, and 2. To serve as an anti-vortex device.

Pipe railings are generally required on all drop inlets, even in rural areas, to prevent pedestrians from inadvertently falling into the culverts. In some urban areas, a grate over the drop inlet may also be needed to prevent deliberate entrance into the culvert, especially where pedestrian traffic is expected to be high or there is a large vertical drop, say greater than 6 feet .

Flumes and Scour Floors

Precast concrete "half-round" flumes (Road Standard RF-13) shall be limited in size to 42 inches (1050 mm) and in length to approximately 24 feet (7.2 m) to prevent the sections from pulling apart due to settlement and erosion. RF-14 pipe connectors shall be used on all half-round joints.

Cast-in-place flumes without basins (stub flumes) may be used when needed on RCBs 4’ X 4’ (1200 mm X 1200 mm) and smaller. Flumes with basins should be used on larger RCBs. The flow lines of stub flumes or basins or the “half-round” RF-13 are usually set approximately 5 feet (1.5 m) 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. Riprap is generally not needed at flumes.

Minimum cast-in-place flume length is determined by the parabolic length, L_3, as shown in OB&S Final Design Manual. Maximum flume lengths should be limited to approximately 60 feet (18 m), if possible, in order to reduce settlement problems and joint separations. See the Final Design Manual for other dimensions and notes.

When less than one meter of drop is needed on the outlet of short lengths of RCB extensions, consider using a “scour floor” in the headwall. See Appendix A for a sample sketch.

Median Pipes

Median drains should be placed to maintain the natural drainage as much as practical. Maximum spacing of median drains is 2000 feet (600 m) in sag vertical curves and 1500 feet (450 m) on tangent grades. For tangent grades greater than 2%, consideration should be given to 300 m-400 m spacing. If 18-inch (450 mm) diameter median drains must be used, spacing should not exceed 1000 feet (300 m).

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 adjacent property.

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

Letdowns

Ditch "letdowns" should be used when the drop in ditch elevations becomes too great to carry the water without eroding the ditch. These pipe letdowns are depicted in the Road Design Details Manual, Items 1401 and 1403. The pipe material should be specified as a polyethylene or coated steel (which includes aluminum coated or polymeric coated per Standard Specification 4141.02).

Designing the outlets of letdowns through an RCB wall or flume wall is not desirable due to potential cracking in these walls. Rather, the outlets can be set beyond the headwall or on top of the wingwall or flume wall. The pipes should be anchored to the wall if resting on top of it.

Although the use of culvert letdowns is dependent on site conditions, a rough rule of thumb is that drainage areas of approximately 2-3 acres (one hectare) or less do not warrant culvert letdowns. The existing site conditions often provide helpful information in deciding if a culvert is necessary. For example, if the existing side ditch does not have a letdown or any erosion problems, then the proposed project may not need one either.

Consideration should be given in some circumstances to sideditch treatments such as sod, jute mesh, erosion stone, or riprap. Cost, type of soil, ditch slope, drainage area, and the preferences of the local DOT maintenance personnel are all factors in determining the proper ditch treatment.

Extensions

Existing RCBs and pipes shall generally be extended with an equivalent size and shape to closely approximate the hydraulic opening. For example, extend a 2’ X 2’ (600 mm X 600 mm) RCB with a 30” (750 mm) pipe, and extend a 3’ X 2’ (900 mm X 600 mm) RCB with a 37” X 23” (925 mm x 575 mm) concrete arch pipe or a 36” (900 mm) pipe.

The pipe and the RF-2 connections should have adequate earth cover and not project up into the subgrade or shoulder. There is not a practical equivalent shape for some existing RCBs (such as a 6’ X 3’ or 4’ X 2’), so consider using the largest practical precast size that provides adequate hydraulic opening. If adequate earth cover is not possible with a precast extension, these RCBs may need to be extended in-kind.

A horizontal or vertical change of alignment between the existing pipe and the pipe extension requires an adapter (RF-2 or RF-13). See the section “Bends and Elbows” for more details on adapters, elbows and “D-sections”

See 1000-Series Typicals for determining and labeling skews of extensions that are skewed to the existing culvert and/ or skewed to the roadway.

Culvert Liners

Common problems with old culverts include corrugated metal pipes that have rusted through, concrete pipes where joints have pulled apart and soil is coming through the joints, and small box culverts with deteriorated floors and walls where concrete is spalling badly and reinforcing steel is highly corroded.

Traditional solutions include open excavation and replacement, or jacking a new culvert alongside the existing one. However, another option is to push a liner, either metal or plastic, through the existing culvert and then grout the voids.

Advantages of these types of liners are as follows:

1. Installation is quick, generally less than a day, which is significantly less than it takes to

excavate, remove, replace, cover, and place new pavement.
2. Traffic disruption is minimal, which is especially important for higher-traffic roads.
3. Equipment needs are minimal compared to conventional cut and cover.
4. Since open excavation is not needed, spot pavement replacement is not needed.
5. Potential settlement caused by excavating and then backfilling is eliminated.
6. Lining a pipe may be less expensive than open excavation or jacking, but comparisons should be made at each site. Obviously, as fill heights increase, the costs of open excavation increase.
7. DOT maintenance forces may be able to install the liner, although contracting this work is also an option.

Disadvantages are as follows:
1. If the culvert has some bends or poorly aligned joints, a liner may not work unless it is significantly smaller than the existing pipe. Metal or PVC liners will bend very little, if at all. Polyethylene liners can bend a small amount, but if bent or kinked too much, the strength of the pipe may be significantly reduced leading to cracking or buckling in the future.
2. Reduced hydraulic capacity is potentially one of the biggest drawbacks to liners. Each site should be reviewed in the field and for existing and proposed hydraulics. Examine the risks of potential flooding upstream, water over the road, and inadvertent diversion of drainage during high flows to a culvert in an adjacent watershed. A full hydraulic analysis of both the existing and liner culverts should be made, including inlet and outlet control calculations. At least one pipe liner manufacturer suggests that a smooth liner with a lower Manning's n-value will give better hydraulics than an existing culvert with a higher n-value. However, this may not be true depending on site conditions, so the full hydraulic analysis is important.
3. Both corrugated metal and plastic liners are defined as flexible pipes and therefore do not have much strength to carry earth pressures without surrounding material, such as grout, to support them. Without this support, the liner can crush or fail over time. If the liner is installed in a concrete pipe where the joints have pulled apart slightly but the pipe itself is still in good condition, the existing concrete pipe may still carry the earth load for many years. However, if the culvert is in very poor structural condition, such as a badly corroded metal pipe, the liner will need to carry all the earth load. Therefore, the backfill material, i.e., grout, is critical. Do not underestimate the importance of this.
4. The life of the liner material may not be as long as the life of a concrete pipe installed by jacking or open excavation.

There are several important factors to consider when designing and installing the liner:
1. The liner must be sized correctly. For hydraulic performance, the pipe may need to be as large as possible. But to push the liner through the existing culvert, it must not be too large. One manufacturer recommends that the outside diameter of the liner be approximately 10% less than the inside diameter of the existing. Bends or misalignments in the existing culvert would also need to be considered. Various materials are available for use as liners: corrugated metal (galvanized or aluminum-coated), polyethylene and PVC. At least one

manufacturer produces a thin, solid-wall polyethylene liner.

2. The existing culvert should be clean enough to easily push the liner through.
3. Using a properly designed grout mix, fill all the voids that surround the liner. Too much sand in the mix or too stiff of a mix may result in voids not completely filled. Too much water in a mix may not provide enough strength for the earth loads on the liner. The DOT's maintenance forces have successfully used the standard mix for flowable mortar, so this mix should be considered.
4. When the grout is pumped into the voids, the liner will float due to buoyancy. If maintaining the existing culvert flowline is critical, a small amount of grout should be placed and then allowed to cure. This process should be continued until the bond between the liner and the grout is enough to resist buoyant forces. Then the remainder of the voids can be filled. Another approach to prevent flotation is to install braces in the top of the existing culvert to hold the liner in place during grouting. However, use this approach with caution since buoyant forces can be significant enough to crush the liner against the braces. A third approach to prevent flotation is to fill the liner with water before grouting the voids.

Minimum Cover

Minimum cover on all pipes is 2 feet (0.6 m), or the top of the structure should be at or below the subgrade elevation. This minimum should be measured within the roadway limits (outside to outside of shoulders). Preferred minimum cover over a roadway pipe in the median is one foot (0.3 m) of soil.

As stated previously, when the 2-foot minimum cover cannot be obtained, consider using arch pipes or twin pipes instead a single, larger diameter round pipe.

Uplift of Culvert Inlets

For corrugated metal or polyethylene pipes with diameters of 48" (1200 mm) and larger, cast-in-place headwalls, precast concrete aprons (Road Standard RF-3), or concrete collars should be considered on the inlet to prevent failure due to uplift forces. For 48" (1200 mm) to 84" (2100 mm) diameter culverts, an alternative is to use a concrete pipe instead of CMP.

Bends and Elbows

For culvert bends in the horizontal plane, the limit at a single bend shall be 20 degrees for pipe culverts and 15 degrees for RCBs. Larger RCB bends up to 20 degrees may be considered on a case-by-case basis. Multiple bends are permitted. Limiting the angle in a bend will minimize hydraulic losses and tendencies for plugging of the bend with debris.

To simplify design and construction, do not use radial designs for RCB bends. Rather, design the barrel in chords. Multiple bend sections should be a minimum 10 feet (3 m) long per section. See the Office of Bridges and Structures' Final Design Manual for a note on curved box culverts.

For horizontal bends in pipes up to 7.5 degrees, use an RF-13 "D" section or an RF-2 Type C-1 or C-2 connection. "D" sections may also be used in series to provide an overall culvert bend of 15, 22.5, 30 degrees, etc.

RF-13 elbows shall generally be specified to the nearest degree.

For small changes in vertical alignment in concrete pipe, use an RF-2 Type C-1 connection if the joint opening will exceed ¾" (20 mm) at the top or ¼" (5 mm) at the bottom.

Road Details (Typicals)

See Appendix A for guidelines on properly using the 1000 Series drainage details from IDOT Road Design Details Manual---"Green Book".

Plan Preparation

The difference in plan details for pipe culverts and for RCB culverts may be confusing, so the following details will provide clarification. The plan and profile drawing for a pipe culvert will be called a plat plan. The plan and profile for an RCB culvert will be called a Situation Plan and, in general, consists of more detail than a plat plan.

A primary purpose of culverts plans is to visually and graphically aid the designer in developing proper lengths and locations of culverts, because individual cross sections commonly do not show the exact drainageway elevations or the alignment of the drainageway. The completed drawings 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 drawings to help determine right of way needs, and the Office of Design uses them as an aid to compute earthwork quantities.

The plat plan or Situation Plan should include enough ground elevations to accurately define the area. All draws, draw junctions, banks, existing structures (including flowlines and lengths), fence lines, tile lines, utilities, and other pertinent existing features should be shown. The proposed structure, including flowlines, lengths, skews and special features should be shown. See Appendix A for a checklist of items to include on plat plans for pipes and Situation Plans for RCBs.

Ground elevations should be shown along the drainageway at least 30 meters upstream and downstream of the culvert. Contours should be clearly labeled. Proposed toe of slope lines (foreslope, ditch lines, backslopes) should be shown at least 45 meters ahead and back of the culvert stationing.

Both the plan and the profile view should be plotted with a 1”=40’ scale for English projects (1:500 for metric projects) as measured on an 11”X17” drawing. (This refers only to the plotted scale and does not refer to any “working scales” as used while actually in a CADD file.) Do **not** use a distorted scale in the profile view. Sample plans may be found in Appendix A for both pipes and RCBs.

For the plan view, the roadway should generally be oriented vertically on the plat.

The profile view should generally be drawn normal to the roadway so that foreslopes are shown as true slopes. Therefore, for skewed culverts, the true length will not be shown.

"Pink" Sheets

Culvert "pink" sheets (IDOT Form 621001) have four primary purposes:

1. Provide field information such as culvert location, drainage area, existing culvert flowlines, etc.
2. Aid in the design process, including the computation of culvert lengths.
3. Develop the culvert bid tabulation for the final road plans.
4. Provide a permanent record for the culvert

Pinks must be filled out completely.

See Appendix A for an explanation on how to properly use the Computation section on the pinks. Consultants should obtain prior approval before using other methods for length computations.

Sample completed pink sheets are also in this appendix. Upon submittal of final grading plans by consultants, the completed pinks and culvert plats shall also be submitted to IDOT and kept as a permanent record.

Approvals

Iowa Department of Natural Resources must approve new culverts if the drainage is greater than two square miles (5.2 square kilometers) in an urban (incorporated) area or 100 square miles (259 square kilometers) in a rural (unincorporated) area. If the project is on a stream with drainage area below DNR's thresholds and if the community (city or county) is participating in the National Flood Insurance Program (NFIP), a hydraulic review and coordination with the community are necessary to ensure compliance with the NFIP.

A sample DNR application letter and form is included in Appendix B.

A Corps of Engineers 404 Permit may be necessary for most stream crossings and road work if a channel change or wetland is involved. IDOT's Office of Environmental Services coordinates this effort.

Bridges

Hydrology

For ungaged rural streams with drainage areas greater than 1000 acres (400 ha), use U.S. Geological Survey (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. (An updated USGS report will be published soon and is expected to supersede 87-4132. Check with the Office of Bridges and Structures concerning this new report.)

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 preferred over those determined from USGS Report 87-4132.

Detailed Flood Insurance Studies (FIS) are available from the Federal Emergency Management Agency (FEMA) for many cities and 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 preferred over other sources.

Miscellaneous flood studies by the Corps of Engineers, Iowa Department of Natural Resources (DNR) and USGS have been developed over the years and can be valuable supplemental information when evaluating discharges and water surface elevations. See Appendix B for lists of some studies by the USGS and Corps of Engineers.

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. (See "Approvals" for specific DNR requirements.)

If USGS Report 87-4132 is used to determine Q_{50}, see Appendix B for a chart to estimate Q_{500}.

Hydraulics

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
- 0.060 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.

The USGS water surface profile program WSPRO and the Corps of Engineers' HEC-RAS program may be used to develop natural and backwater elevations. FHWA's “Hydraulics of Bridge Waterways,” Hydraulic Design Series No. 1, 1978, may also be used to estimate bridge backwater.

Superstructure

Three-span continuous concrete slab bridges are commonly used in lengths from 70’ (21 000 mm) to 130’ (39 000 mm). See Appendix B for a list of standard slab bridge lengths.

Four series (A through D) of pretensioned prestressed concrete beams are available for use in structures. Each series has a different beam depth. See Appendix B for standard lengths available. Pretensioned prestressed "bulb-tee" concrete girders (1800 mm depth) may be considered for spans up to 42 500 mm in length. (Additional standard bulb-tee beam depths and lengths are being designed. Check with the Office of Bridges and Structures for availability.) Continuous welded plate girders are generally used when longer span lengths or shallower girder depths are needed.

Substructure

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 (130 square kilometers).) For those smaller streams where the chance for debris or ice loads is higher, a fully-encased pile bent may be considered. On larger streams, tee piers (hammerhead) should be considered. On grade separation structures (bridges over roadways or railroads), usually frame-type piers with individual footings are used.

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

Skew	Bridge Lengths	Remarks
0 - 30° incl.	0 – 300 feet (0 - 91 500 mm)	Use integral abutments
0 - 30° incl.	300 – 500 feet (91 500 - 152 500 mm)	Show stub abutments on Situation Plan, and include note on plan to investigate during final design for use of integral abutments. Greater length than 500 feet use stub.
30° - 45° incl.	0 – 150 feet (0 - 46 000 mm)	Use integral abutments. Greater length than this use stub.
above 45°	any length	Do not design a bridge with a skew this high.

Width

The width of a bridge on the Primary or Interstate system is generally determined by the approach roadway width, outside-shoulder-to-outside-shoulder. Bridge widths in urban areas will typically be the lane widths plus a 3 foot offset. See Section 1C-1 in the Office of Design's Design Manual for specifics.

For local rural bridges (not in an interchange) over Primary or Interstate highways, in order to allow for wider farm machinery and to be proactive in planning for future growth, use 30 feet (9.0 m). Wider bridges may be justified based on site specifics. Bridge widths less than 30 feet will be evaluated on a case-by-case basis if requested by county or local personnel.

For county road overheads within an interchange, see Section 6B-2 in the Office of Design's Design Manual.

See section "Pedestrian and Trail Structures" below for widths of walkways or trails on a highway bridge.

Pedestrian and Trail Structures

When accommodating pedestrians on a structure, the typical clear width needed between rails or fences is 5 feet (1.5 m). If accommodating a trail, AASHTO guidelines recommend the minimum structure width to be equal to the paved or traveled portion of the trail, not including the shoulders of the trail. AASHTO's desirable structure width is the trail width plus 2 feet (0.6

m) on each side for “shy distance”

Horizontal Curves

When a bridge is in a horizontal curve, a decision must be made as to how the bridge will be designed and built. First, the distance between the chord and arc (defined here as “M”) at the midpoint of the bridge, must be determined. If “M” is less than 4 inches (100 mm), the bridge may be designed on a chord at the designated full shoulder width. If “M” is between 4 inches (100 mm) and 12 inches (300 mm), coordinate with the Office of Bridges and Structures PRIOR to proceeding with design. Consideration will be given to designing the bridge slightly wider and on a chord to provide full shoulder width or greater at all points. If “M” is greater than 12 inches (300 mm), the bridge shall be designed on a horizontal curve.

Stationing of bridge details should be based on the centerline of the road, regardless if the bridge is constructed on a chord or a curve. Do not reference stationing from the centerline of the bridge.

Skew

The maximum bridge skew allowed is 45 degrees. For grade separation structures, if the skew angle of the two roads is less than 45 degrees, design the bridge to the nearest whole degree. (An exception to this may be when designing a new bridge adjacent to an existing bridge on a new four-lane, where it may be desirable to match the skew of the existing.) This rounded skew should be shown in the title block on the Situation Plan. However, the actual intersecting angle should still be labeled on the plan view of the Situation Plan. Exceptions shall be approved by the Office of Bridges and Structures prior to design.

Costs

For preliminary cost estimating, multiply the unit cost for the structure type times the bridge deck area, measured from gutterline-to-gutterline and abutment centerline-to-abutment centerline. Use unit costs of $40/square foot ($430/square meter) of bridge deck for continuous concrete slab bridges, $45/square foot ($480/square meter) for prestressed concrete beam bridges, and $50/square foot ($540/square meter) for continuous welded plate girder bridges. These unit costs do not include removal of old structure, mobilization, contingencies, staging, large quantities of riprap used for streambank protection well-upstream of bridge, and unusual structural features.

Unit costs for bulb tee bridges are unavailable at this time.

All costs above may need to be increased $5/square foot ($50/square meter) or more when the complexity of the structure is higher, such as with a curved or variable-width bridge, or when the structure is in a geographic area with higher labor rates, such as Polk or Scott County. If the bridge must be stage constructed, add 30% to the cost. For widening a bridge, use $100/square foot ($1080/square meter) of the widened portion. This widening cost already includes removal and staging.

Grade Separations

Vertical Clearance   Minimum vertical clearance is measured over the entire roadway, which includes the traffic lanes **and** the shoulders. The minimum clearance over a Primary or Interstate highway is 16.5 feet (5.1 m). For Primary or Interstate highways over local roads, use a minimum of 15.0 feet (4.6 m). For clearance over a county road in an interchange, Section 6B-2 in the Office of Design's Design Manual states to use the design criteria of a rural non-NHS road as described in Section 1C-1. This results in a vertical clearance of 16.5 feet (5.1 m) over the county road in the interchange.

Horizontal Clearance   Horizontal clearance requirements for bridges over roadways are determined from Table 1 in Section 1C-2 in the Office of Design's Design Manual. Clear zone is measured from edge of driving lane (typically 12 feet (3.6 m) from centerline), **not** from edge of poured slab which may be wider than the driving lane. These clear zone distances apply to both the bridge pier and berm slope together (when a side pier is proposed). However, clear zone does not apply to the berm slope alone (when there will be no side pier). Therefore, for bridges over four-lane highways, consideration should be given to designing two-span, rather than four-span, structures in order to eliminate the side pier hazard. For the two-span only, the toe of the berm can be placed at or beyond the edge of the outside shoulder. A preliminary cost comparison should be made between a two-span and a four-span alternative.

Similarly, for a grade separation over a two-lane roadway, a single-span instead of a three-span bridge may be feasible in some situations.

Drainage   If drainage must be carried through the approach fills of a grade separation structure (highways or railroads), this should be accomplished by using a culvert, not by using an open ditch which increases the bridge length and cost.

Embankment Shaping at Two-Span Overheads   For two-span (and single-span) overhead bridges, special embankment shaping may be needed to provide greater safety for traffic on the road going under the bridge. See Road Design Typical 4310.

Railroads

Clearances For bridges over railroads, pier placement must allow adequate clearance for off-track railroad equipment. Therefore, for bridges over Union Pacific (UP) tracks, it is preferable to have a horizontal clearance of at least 25 feet (7.62 m) if there is an access road or 18 feet (5.49 m) if there is not an access road. For bridges over other railroads, the minimum is 18 feet (5.49 m) on one side of the track and 12 feet (3.66) m on the other. These distances are measured from the centerline of the tracks to the face of either pier. It is generally feasible to provide more clearance than this without changing the beam type or overall bridge cost.

When the face of the pier is located 25 feet (7.62 m) or less from the centerline of the tracks, a crashwall shall be proposed on new bridges.

Minimum vertical clearance requirement over a railroad is 23 feet (7.01 m) from top of rail to low superstructure.

Length of Bridge To determine the bridge length needed in most situations, the bridge berms must be properly located. At the top-of-rail elevation, extend a horizontal line perpendicular to the tracks 23 feet (7.01 m) from the centerline of the track (or nearest track) to the face of the 2.5:1 slope berm. The berms should be no closer than this dimension.

Pier Footings For bridges over UP tracks, top of pier footings shall be a minimum of six feet (1.83 m) below the top of rail elevation. This provides UP adequate depth for future drainage or utility improvements. For bridges over other railroads, top of pier footing shall be a minimum of one foot below finished ground line.

Safety Fences and Splashboards For bridges over UP tracks, a 44 inch (1.12 m) high concrete barrier rail shall be provided as a “splashboard” to minimize snow from being inadvertently “splashed over” by snowplows. For bridges over other railroads, use a standard F-shape rail. The need for “safety fences” on bridges over UP tracks will be determined by UP on a case-by-case basis. When the bridge has a sidewalk or trail, an 8 foot high (2.44 m) curved fence or a 10-foot high (3.05 m) straight fence shall be proposed.

Slope Protection For bridges over UP tracks, provide slope protection on the berms. For other railroads, do not provide slope protection on the berms unless it is requested. Macadam stone is generally proposed instead of poured concrete.

Freeboard

Freeboard is the vertical clearance measured between the bottom of the superstructure and the top of the natural (not including backwater) 50-year flood elevation. This clearance is typically measured at the middle of the channel. The purpose of freeboard is to provide adequate clearance for passage of debris and ice during high flows and to reduce the potential of superstructure submergence. Debris and ice jams can create horizontal and buoyant forces on the bridge superstructure and can reduce the bridge waterway opening resulting in increased velocity, scour, and upstream flood levels.

For streams draining more than 100 square miles (259 square kilometers) in rural areas, the required Iowa Department of Natural Resources clearance between a 50-year flood and the low superstructure is 3.0 feet (0.91 m) of freeboard measured near the center of the stream. For streams less than 100 square miles in rural (unincorporated) areas, no DNR permit is needed, so freeboard of 3.0 feet is not required but still is desirable. In urban (incorporated) areas, the threshold is two square miles (5.18 square kilometers). Occasionally, a variance to DNR's criteria can be obtained where one or more of the following conditions are present:

1. The bridge is a floodplain overflow bridge.
2. Streams where ice or debris are not expected to be a problem.
3. Where roadgrade overflow readily provides relief in the event the bridge opening is obstructed.
4. Where raising an existing grade will result in excessive costs or damages, as in heavily developed urban areas.

Roadgrade Overflow

New roadgrades should generally be designed to a minimum of the 50-year flood elevation plus 1.0 feet (0.3 m). Recognize, however, that if the roadgrade is much higher than this minimum, it eliminates the "relief valve" for a bridge during an extreme flood.

Erosion

Factors to determine the need for stream bank protection are as follows:

1. When stream velocities exceed 8 to 10 feet per second (2.4 to 3.0 meters per second), riprap may be considered.
2. The condition of the existing banks or bridge opening is a good indicator as to the need for protection, e.g., if the existing bridge is stable without riprap, then the proposed bridge may also be adequate without it.
3. Examine past aerial photos to determine an approximate rate of erosion.

A common design for riprap as bank protection is engineering fabric, a two foot (0.6 meter) thick layer of Class E riprap, and adequate protection at the toe of the bank. The bank slope should generally be 2.5:1 (horizontal to vertical), but no steeper than 2:1.

Riprap at culvert outlets is generally not needed, unless there is a special problem such as right of way concerns in an urban area. In unusual situations, a heavier rock gradation such as Class B specification may be needed.

Scour

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

Abutment Berm Slopes

Soils Design Section in the Office of Design will make final determinations for berm stability on all bridges. In general, the steepest berm slope allowed on most bridges is 2.5:1. Where special soil problems exist and for fill heights greater than 40 feet (12.0 m) from the roadgrade to natural ground, a 3:1 slope should be assumed until verified by Soils Design. For fill heights from 30 to 40 feet (9.0 to 12.0 m), contact Soils Design for a preliminary slope estimate.

Wing Dikes

The use of wing dikes (also called spur dikes or guide banks) shall be considered at any bridge site that has appreciable overbank discharge. Wing dikes help minimize backwater and scour effects. See Appendix B for a table on selecting appropriate lengths of wing dikes and Road Standard RL-3 for construction details.

Situation Plan Preparation

Sample Situation Plan drawings, also referred to as bridge plan-and-profiles, can be obtained from IDOT. Situation Plans should be prepared for all new bridges and for all bridges that are to be widened or remodeled.

See Appendix B for a checklist of details that are needed on a Situation Plan.

Both the plan and profile views should be plotted on a 1 inch = 40 feet (1:500 for metric plans) scale on an 11"X17" drawing. (This refers only to the plotted scale and does not refer to any "working scales" used while actually in a CADD file.) For long bridges, a different plotted scale may be desirable, but obtain prior approval from the Office of Bridges and Structures.

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

Situation Plan submittal information to IDOT should include the Situation Plan, hydraulic calculations, surveyed valley cross section, and completed form "Field Survey Notes for Bridges and Large Culverts" (Form 621004M). The form "Risk Assessments for Bridges" (Form 621012) needs to be submitted only on stream bridges that need FHWA approval (see discussion below). For a “bridge-size RCB”, i.e., an RCB with total spans of 20 feet (6.1 m) or more, such as a twin 10’ X 10’, length calculations shall be provided, either shown on a pink sheet or some other format.

Scour calculations should also be submitted.

Approvals

A DNR Flood Plain Development Permit approval is required for all bridges that cross streams with drainage areas more than 100 square miles (259 square kilometers) in rural (unincorporated) areas or 2 square miles (5.18 square kilometers) in urban (incorporated) areas. When the upstream flood damage potential is low (e.g., crops, pasture, and no buildings), then DNR's limit on backwater is 0.75 feet (0.23 m) for Q_{50} and 1.5 feet (0.46 m) for Q_{100}. When the upstream damage potential is moderate to high (e.g., garages, residential and commercial buildings), the backwater limit is 0.75 feet (0.23 m) for Q_{50} and 1.0 feet (0.30 m) for Q_{100}. As mentioned previously, DNR's freeboard requirement is 3.0 feet (0.91 m) clearance above the Q_{50} elevation. DNR also ensures that these projects meet the requirements of the Flood Insurance Studies (FIS) of communities (city or county) participating in the National Flood Insurance Program (NFIP).

Any project on a stream below DNR's drainage area thresholds does not need approval from DNR. However, if the project is in a community that is participating in the NFIP, a hydraulic review and coordination with that community are necessary to ensure compliance with NFIP. This is considered only a coordination effort and not a permit from the community.

DNR may require flowage easements when the structure exceeds DNR backwater criteria or NFIP requirements.

For road projects, a DNR floodplain permit may be needed for channel changes on streams that drain more than 10 square miles (25.9 square kilometers) in a rural area or 2 square miles (5.18 square kilometers) in an urban area. Approval for channel changes in rural areas is <u>not</u> needed if both of the following conditions are met:

1. Less than a 500 feet (152 m) length of the existing channel will be altered.
2. The length of existing channel being altered is reduced by less than 25%.

DNR classifies some streams in Iowa as “Protected Streams”, and channel changes may be prohibited, regardless of drainage area. See DNR rules for a list of these protected streams and the specific rules.

Portions of some of the larger rivers are legally classified as “Meandered”, which means the State of Iowa owns the streambed and streambanks. A DNR Construction Permit is needed for bridge or channel work on these reaches of rivers. See Appendix B for a list of Meandered Rivers.

Other highway work, such as a borrow site or levee, that is in the flood plain of a stream may also require DNR approval.

See Appendix B for a sample cover letter and application form (and blank form) for a DNR permit.

All bridges over railroads shall be reviewed and approved by the railroad company. The appropriate office in IDOT will coordinate this review process.

Corps of Engineers 404 Permits are needed for almost all bridges over water, major highway projects, and many streambank erosion repair projects. Many of these projects will qualify for one of several types of Nationwide 404 Permits; the remaining projects will need an individual 404 Permit. Situation Plans should be forwarded to the Office of Environmental Services who will obtain necessary permits.

FHWA approval is required for all bridge-size structures (total spans of 20 feet (6.1 m) or greater) on or over the Interstate System. Approval is also needed on the National Highway System (NHS) when the bridge construction contract is anticipated to be over $10,000,000. This applies to projects actually on an NHS route, even if the project number is “BRF” or some other funding designation. Sideroads over an NHS route, even in an interchange, do not need approval unless the sideroad itself is also on an NHS route. Any projects that are not on the NHS do not need FHWA approval regardless of the estimated project cost. The Office of Bridges and Structures will generally administrate all FHWA approvals.