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3.2.7 Substructures

3.2.7.1 Skew

For horizontally straight bridges, skew is measured from centerline of roadway. For horizontally curved bridges, skew may be measured from centerline of roadway, a chord, or a tangent. Generally if the abutments and piers for a curved bridge will be radial it is convenient to measure the skew from the centerline of roadway, and if the abutments and piers will be parallel it is convenient to measure the skew from a chord or tangent. The method for determining skew on curved bridges should be noted on the TS&L.

Except in unusual cases the office limits skew to a maximum of 45 degrees. The office prefers to use integral abutments, and the 45-degree maximum skew will allow use of integral abutments for most bridges. A skew larger than 45 degrees requires approval of the supervising Section Leader. A highly skewed superstructure may require special final design, and the superstructure may require extra maintenance during its service life.

If the bridge will require stub abutments the office prefers that the skew not exceed 30 degrees. Except in unusual cases, the office limits the skew to a maximum of 45 degrees.

The skew for a straight bridge should be the same for all substructure components. If all substructure components have the same skew, beams or girders in the superstructure will be the same length, which will promote ease of fabrication and economy. The designer should seek approval of the supervising Section Leader if skews of substructure components will vary.

The office prefers that the designer set the skew to the nearest whole degree. The designer then should list this rounded skew in the title block for the TS&L but label the actual intersecting angle between the two roads on the plan view. However, if the new grade separation structure is adjacent to an existing structure that will remain in use, if horizontal clearance is limited, if a pier needs to fit a median barrier, or if the bridge is wide, the designer may set the superstructure to the appropriate exact skew angle rather than a rounded angle.

3.2.7.2 Abutments

Because of lower construction and maintenance costs the office prefers integral abutments as shown on standard sheets and standard plans for bridges. Integral abutments are limited by bridge length, end span length, and soil or rock conditions at abutment sites. For most sites, downdrag due to compressible fills will not affect the use of integral abutments because only the top portions of the piles flex, and the downdrag stresses occur below these regions of high bending stresses.

The conditions and table below are summarized from the detailed information in the abutment section of Bridge Design Manual, and that section should be consulted for additional information [BDM 6.5.1.1.1]. Table 3.2.7.2 assumes that a bridge has approximately parallel abutments and piers and that a bridge is straight or horizontally curved with straight beams or girders. The office generally does not use integral abutments for bridges with horizontally curved girders.

Table 3.2.7.2. Bridge length limits for use of integral abutments

Superstructure Type / Typical Pile	**Length and Skew Limits for Standard Integral Abutments**	**Maximum End Span / Prebore Length (2) / Minimum Pile Length**
PPCB / HP 10x57	575 feet at 0-degree skew to 425 feet at 45-degree skew (1)	Maximum A-D and BTB-BTE length / 10 or 15 feet depending on load / 15 feet to bedrock [BDM Table 6.5.1.1.1-1]
CWPG / HP 10x57	400 feet at 0-degree skew to 300 feet at 45-degree skew (1)	120 to 150 feet / 10 or 15 feet depending on load / 15 feet to bedrock [BDM Table 6.5.1.1.1-2]
CCS / HP 10x42	400 feet at 0-degree skew to 300 feet at 45-degree skew (1)	45.5 feet / 10 feet / 15 feet to bedrock

Table notes:

(1) Use linear interpolation of length for intermediate skew.
(2) Prebore depth is related to axial structural resistance of the pile. Final designer may adjust the depth.

If a working integral abutment is feasible at only one end of a bridge, the maximum length limit for the bridge shall be one-half the limit in the table, with no change in maximum end span length. In cases where a MSE retaining wall is used near an integral abutment, each pile shall be sleeved with a corrugated metal pipe (CMP) to control compaction near the pile as the embankment and MSE wall are built. Because the limits in Table 3.2.7.2 are more liberal than past limits, exceptions to these guidelines are not encouraged.

For relatively long, significantly curved, highly skewed, and other bridges that do not meet the integral abutment guidelines in Table 3.2.7.2, the designer should consider stub abutments. For many bridge and bridge site conditions stub abutments as detailed on standard sheets will be feasible. However, the designer will need to consider modifications to standard abutments and alternate abutment types for highly unusual bridges and bridge sites.

To estimate the bottom footing elevations for continuous concrete slab bridges, the designer should review the applicable standard sheets. To estimate the bottom footing elevation for beam bridges, the designer should first determine the deck elevation at the low side exterior beam centerline. From the top of deck subtract superstructure depth (deck/haunch/beam), estimated bearing height (3 inches integral/6 inches stub), and low step to bottom footing height (3.5 feet integral/4'-1 stub). The estimated bottom footing elevation will be level, except as noted below.

For integral abutments it is desirable to slope the abutment footing and top of berm when the difference in elevation from the centerline of exterior beams is greater than 1.5 feet.

For stub abutments it is typically desirable to keep the bottom of footing level and adjust the beam seats.

For the usual bridge deck profile or a moderately superelevated deck profile the bottom of the stub abutment footing should be horizontal but, if the difference in bearing seat elevations is greater than 2.5 feet, the designer should consider sloping the bottom of the footing.

3.2.7.3 Berms

3.2.7.3.1 Slope

A bridge berm slope is generally normal to the bridge abutment, but also may be normal to a roadway or railroad under the bridge. Under normal situations the designer may make the following initial assumptions for berm slopes:

- For fill heights less than 30 feet from grade to toe of berm, the steepest berm slope may be taken as 2.5:1, horizontal to vertical.
- For fill heights from 30-40 feet, the steepest berm slope may be taken as 3:1.
- For fill heights greater than 40 feet, contact the Soils Design Section for an initial berm slope estimate.

However, the designer shall also consider the following special situations:

- For bridges located over streams and rivers in the western Iowa Loess Hills counties (Woodbury, Monona, Harrison, Pottawattamie, Mills, and Fremont), and for bridges situated in meandered stream and river alluvial sites/environments statewide (See list in C3.2.10.1.), the designer should use a 3:1 berm slope with fill heights less than 30 feet unless a steeper slope has previously been reviewed by the Soils Design Section. Note that bridges located over roads in upland Loess Hills areas are exempt from this shallower slope.
- For fill heights greater than 30 feet on either Iowa Loess Hills stream and river sites or meandered stream and river alluvial sites statewide (See list in C3.2.10.1.), the designer shall contact the Soils Design Section for an initial slope estimate.
- For bridges statewide located in areas with special, unusual, extremely variable, and/or questionable soil conditions, the designer shall contact the Soils Design Section for an initial slope estimate.

If steeper slopes are required, they may be accommodated by reinforced steepened slope (RSS) techniques, by lightweight fill techniques, and/or by soil remediation techniques such as intermediate foundation improvements (IFIs) or core-outs, but steeper slopes require full coordination with and design by the Soils Design Section.

The initial assumptions for berm slopes discussed above are used to develop a preliminary Type, Size, and Location (TS&L) plan for a bridge. When final soils analysis shows that an alternate berm slope is required, either shallower or steeper, revisions to the TS&L may be required at that time.

The designer shall check the berm slope at all potential critical points along the berm. This will ensure that the required berm slope is provided anywhere on the berm.

Objects such as bridge piers and bridge berms can create a sight obstruction on the inside curve of a highway. Minimum sight distance is required based on curve radius, design speed, etc., measured along the centerline of the inside lane around the curve [OD DM 6D-1]. Bridge piers located at clear zones typically do not cause an obstruction. Bridge berms located at the edge of the shoulder and within or close to a horizontal curve need to be checked by the Office of Design to verify that the berm is not causing an obstruction. These bridges may need to be lengthened to accommodate sight distance.

3.2.7.3.2 Toe offset

To improve snow removal operations and storage and reduce maintenance costs for roadway grade-separation structures with no side piers, it is desirable to design the finished grade of the berm toe 5 feet from the edge of shoulder. A minimum of 4 feet offset is acceptable for PPCB bridges if sufficient beam length remains to obtain the 4-foot minimum from the edge of shoulder to the toe. Use the next beam increment for that span if the minimum offset cannot be obtained. For CWPG bridges, set the toe of berm at the 5-foot offset location. For standard design bridges, ensure that minimum toe offsets are obtained.

3.2.7.3.3 Berm slope location table

The berm slope location table (BSLT) provides key points on the bridge berm to define the grading surface. This information is used by the Office of Design to calculate earthwork quantities and by the road contractor to assist in constructing the bridge berms. A BSLT shall be placed on the TS&L for all new bridges, or when a bridge is replaced or widened. Older versions of the BSLT on completed TS&L sheets will be grandfathered.

See the Office of Design's Standard Road Plans for earthwork [OD SRP EW 201-204] as these standards work with the BSLT. The grading surface represents the top of slope protection for grade separation structures. For river crossings, riprap may be placed on top of the grading surface or embedded below when needed to increase the bridge opening area. A typical section riprap detail identifying the grading surface must be included on the TSL sheet to clearly show the intent. Refer to the commentary for additional guidance related to typical berm situations and example design details.

Points A, B, D and W are the key points used to describe the grading surface. All points are defined by their elevation, station and offset (as referenced from the centerline of construction survey or survey baseline). The points are located a distance of 3 feet from the outside edge of the bridge. W is defined as the grading surface at the end of wing. To determine the elevation at W, drop 0.15 feet from the edge of shoulder elevation. B is at the top of berm and A at the toe of berm. The Point B, top of berm elevation, should be set at an elevation 2' above the estimated bottom abutment footing elevation. Sometimes additional A or B points are needed to better define the berm, especially for bridges with skews greater than 15 degrees.

For dual bridges with complex or non-uniform berms, the addition of D points may be desired. The intent of the D points is to define a single grading control line for both bridges at a constant elevation. See commentary for examples.

The letters A, B, C, D and W are reserved for the bridge berm grading. If additional points are desired to better define the grading needed, use a different lettering scheme.

For roadway grade separation structures with no side piers, A points are defined where the finished grade of the berm meets the edge of the shoulder plus offset [OD SRP EW-203 and EW-204, BDM 3.2.7.3.2]. For roadway grade separation structures with side piers, A points are usually defined at the clear zone [OD SRP EW-211]. The designer can determine the elevations of A points from existing or proposed grade information for the roadway under the bridge and cross slopes of the pavement and shoulder. For a bridge over a stream, railroad, or urban roadway A points are defined where the toe of the berm meets the existing ground or proposed ground surface.

3.2.7.3.4 Recoverable berm location table

A recoverable berm location table (RBLT) provides bridge baseline station/offset and elevations for the various points to provide sufficient information for the contractor to construct the recoverable berm [OD SRP EW 203 & EW-204]. A recoverable berm is constructed for bridge berms with no outside piers and provides a flattened slope for errant vehicles. When the toe of the bridge berm is not located within the clear zone, an RBLT is not required.

The recoverable berm is represented by points B, C1, C2, and C3, as shown on the standard construction details sheet [OD SRP EW 203 & EW-204]. Point B is located 3 feet from the outside edge of the bridge deck at the top of the bridge berm. In order to create the flattened area for the recoverable berm, a line must be established that is 15 degrees or less from the edge of the lane (traveled way) to point B. This will establish the line segment BC from point B to point C2, which should be at a 6:1 horizontal to vertical or flatter slope. If the slope is greater than 6:1, the angle from the lane to point B must be lowered to graphically determine the limits of the recoverable berm.

The line segment BC intersects the edge of the shoulder at point C3. The elevation of point C3 is the edge of the shoulder elevation at that location. Point C2 is on line BC and is located a distance equal to twice the shoulder width from the edge of the traveled way. Continuation of the shoulder slope to point C2 determines the elevation.

The station distance between point C2 and C3 is defined as “X”. A station distance “X” toward the bridge should be applied to determine the location of point C1. Point C1 should be 5 feet from the edge of the shoulder unless otherwise noted on the TS&L, minimum of 4 feet. See the standard road plan for bridge berms with no outside piers for more information [OD SRP EW 203 & EW-204, BDM 3.2.7.3.2]. The elevation of point C1 is based on a continuation of the shoulder slope to that location. Point C1 is established to provide a transition from the recoverable berm back to the normal toe of the bridge berm. See the example RBLT in the commentary for this article.

3.2.7.3.5 Slope protection

This article covers slope protection guidelines for all except railroad bridges [BDM 3.2.4.1.4, 3.2.4.2.4].

- **Bridges over roadway**

  For bridges over a roadway, macadam slope protection is typically used. Concrete slope protection should be shown on berms adjacent to path or sidewalk facilities. Exceptions to this include proposing slope protection to conform to project aesthetic guidelines.

- **Bridges over waterway**

  For bridges over a waterway it is recommended that riprap be placed on the bridge berms due to limited maintenance resources and the potential for significant abutment scour. See also the article for riprap at abutments [BDM 3.2.2.6.5.1, to be added in the future].

  In most cases, specify riprap to a minimum 50 year flood elevation with erosion stone extending from the riprap to the front face of the abutment. When the top of berm is significantly higher than the 50 year flood elevation, it is recommended that erosion stone be placed from the top of riprap to the top of berm to protect the berm slope from deck drains and local erosion/scour.
  The exception is when designing riprap for a bridge with a pressure flow condition. A pressure flow condition for the purpose of determining type of slope protection is defined below. For the pressure flow condition, extend riprap placement to the front face of the abutment.

  1. The 100 year water surface exceeds the low beam at the abutment creating a pressure flow situation.
  2. Bridges behind levee systems, where levee failure could create a pressure flow condition.

  For projects that require a sovereign lands permit, a broken concrete substitute for riprap will not be allowed. The prelim designer should place a note on the TSL directing the final designer to include this restriction in the revetment bid item reference notes.

3.2.7.3.6 Grading control points

If channel shaping or special grading is required, the designer shall provide grading control on the TSL or Site Plan Sheet. The grading linework should match what is shown in the STRUCTURES model of the .str file and may be supplemented with stations, offsets and elevations labeled as “G” points. A typical stream crossing example is shown in the commentary. The purpose of the grading control is to communicate channel or special grading needs to Design, which will assist them in the preparation of the grading plans.

Generally, channel grading control would be shown in one of two ways:

- By centerline stream – provide the alignment, profile, typical cross section and begin/end locations
- By toe of channel – provide a series of grading control points along each side of channel at the toe of slope

3.2.7.3.7 Mechanically Stabilized Earth (MSE) Walls adjacent to abutments

The Office discourages the use of MSE walls in lieu of sloped berms to shorten a bridge. However, the Office accepts the use of MSE walls in lieu of sloped berms as part of a solution to avoid ROW impacts or to address unique site conditions. If an MSE wall solution is proposed, the preliminary designer shall coordinate with the Office of Design (OD) and the Bridge Office aesthetics coordinator relative to structure geometry, MSE wall alignment and aesthetic accommodations.

MSE walls may be proposed for the approach roadway and terminate at the back face of abutment footing/diaphragm or at the end of a bridge wing extension/wing. MSE walls may also continue past the abutment and along the edge of bridge foreslope to terminate at the toe of the berm, or they may wrap around the bridge abutment from the front to the sides. The “W” points in the BSLT table are not required for corners of the bridge with proposed roadway approach MSE walls.

Considerations for Integral Abutments:

For MSE walls along the front face of an integral abutment, the centerline abutment bearing shall be placed at least 4.5 feet from the front face of an MSE wall.

Considerations for Stub Abutments:

The centerline of the piling shall be a minimum of three feet from the face of the MSE wall at the bottom of the MSE wall. The front row of piles shall be battered unless the batter increases the bridge length by more than five feet due to the interference with the MSE wall. The preliminary designer should consult final design before proposing a stub abutment with 6:1 or vertical piling.

3.2.7.4 Piers and pier footings [AASHTO-LRFD 3.6.5]

For typical bridges the office selects among four pier types: frame pier, T-pier (hammerhead pier), pile bent, and diaphragm pier. Pier selection criteria include the following:

- **Waterway conditions:** For stream or river crossings, the most significant consideration in choice of pier type is the potential for ice or driftwood flow. If the drainage area is small, 50 square miles or less, pile bents usually are acceptable for spans up to 100 feet. Consideration shall be given to the unbraced length of pile bent piers with respect to scour.

  Superstructure spans exceeding 100 feet could require excessive number of piles and pile bent piers may not be economical. For longer spans the designer should consider T-piers [6.6.1.1.2], and in certain situations a frame pier may be considered. Regardless of drainage area, however, if significant ice or driftwood flow is expected, the pile bent shall be fully encased [BDM 6.6.1.1.3].

  If the drainage area is large, more than 50 square miles, or there is potential for significant ice or driftwood flow, the office strongly recommends T-piers.

  For pier foundations in stream or river channels the office requires the designer to set the bottom of the footing about 6 feet below the streambed elevation, regardless of the calculated scour elevations.

  If piles are not feasible because sound rock is close to the waterway surface, the designer should consider diaphragm piers [BDM 6.6.1.1.4].

- **Roadway conditions:** For grade separations the most economical choice usually is frame piers. The preferred clear zone width should be provided for the location of piers [OD DM 8A-2]. If the clear zone allows a pier to be within 30 feet of a roadway, design for Vehicular Collision force or redirection/absorption of the collision load may be needed pending investigation of an exemption [BDM 6.6.2.6].

  In order to exempt a design from vehicle collision force, the bridge must be classified as critical/essential or typical. Consult the section supervisor and AASHTO LRFD Specifications Commentary [AASHTO-LRFD C3.6.5.1] (see commentary). The exemptions are based on the annual probability of a pier being hit by a heavy vehicle.

  Investigations in the office have indicated that providing structural resistance in the pier usually will be a better and more economical option than providing an embankment or barrier, except where a median barrier will be provided as part of the highway design. In urban areas where a median barrier is necessary, the preferred approach at the median pier is to increase the barrier height to 54 inches (TL-5) and route the barrier around the pier so that the vehicular collision force need not be applied [AASHTO-LRFD C3.6.5.1] (see commentary).

  Typical options for a pier which resists collision forces is a frame pier with a crash strut [BDM 6.6.4.1], a T-pier or wall pier.

- Bridge locations where ROW, environmental or other economic impacts could occur, the clear zone may be designed to meet the acceptable clear zone width with approval from the supervising Section Leader. If a frame pier is within the acceptable horizontal clear zone [BDM 6.6.2.6] and not sufficiently protected it will require a crash strut [BDM 6.6.4.1]. In that situation a T-pier is an alternative.

  Dual bridges placed edge to edge with a 2-inch gap generally should have separate piers for each bridge.

  Unless pier footings will bear on rock, the preliminary designer should set the preliminary bottom of pier footings 5 feet below finished grade. The final bridge designer shall verify that the final bottom footing elevation allows for a minimum one foot cover thickness over the top of footing.

- **Railway conditions:** For railroad crossings, pier and footing guidelines are given in previous articles [BDM 3.2.4.1.3 and BDM 3.2.4.2.3]

- **Subsurface conditions:** The majority of Iowa pier foundations are supported on steel H-piles. If rock is close to the surface, spread foundations for piers may be notched into the rock layer.

  Drilled shafts socketed into rock may be an option on some sites [BDM 6.3.1.1].

- **Aesthetics:** If aesthetics are a consideration, the designer will need to follow the pier type and style established for the bridge.

3.2.7.5 Wing walls

The preliminary designer shall verify that abutment wing walls provide an acceptable slope from the end wing to the berm. For typical PPCB or CWPG bridges, there should be no need to change standard wing wall lengths. However, if any of the following conditions apply, the designer shall check the need to increase wing wall lengths per criteria defined by BDM 6.5.4.3.1:

- Skew greater than 30 degrees
- Superelevation
- Beam depth greater than 63 inches, the BTE beam depth.

Refer to the commentary for details on the wing length check and design methods. Note that a 2.5:1 slope extended from the top of berm should be used for designing wings, even for situations with flatter berm slopes.

Any wing walls requiring more than 5 feet beyond the standard wing extension length may be steepened to a 2:1 slope pending approval by the section leader. Non-standard wing lengths should be noted as such on the TSL. Final design will determine how the additional wing length will be addressed.