7.4 Column Reinforcement

7.4.1 Reinforcing Bar Material

Steel reinforcing bars for all bridge substructure elements (precast and cast-in-place) shall be in accordance with Section 5.1.2.

7.4.2 Longitudinal Reinforcement Ratio

The reinforcement ratio is the steel area divided by the gross area of the section (A_s/A_g). The maximum reinforcement ratio shall be 0.04 in SDCs A, B, C and D. The minimum reinforcement ratio shall be 0.007 for SDC A, B, and C and shall be 0.01 for SDC D.

For bridges in SDC A, if oversized columns are used for architectural reasons, the minimum reinforcement ratio of the gross section may be reduced to 0.005, provided all loads can be carried on a reduced section with similar shape and the reinforcement ratio of the reduced section is equal to or greater than 0.01 and $0.133f'_c/f_y$. The column dimensions are to be reduced by the same ratio to obtain the similar shape.

7.4.3 Longitudinal Splices

In general, no splices are allowed when the required length of longitudinal reinforcement is less than the standard mill length of (typically 60 ft). In general, sSplicing of column longitudinal reinforcement shall be outside the plastic hinge regions. But in SDC A, splices need only be located a minimum of 1.5 times the column diameter from the top and bottom of the column. The bridge plans shall clearly identify the "No Splice Zones". the limits of the permissible splice zone limits. Figure 7.4.3-1 shows standard the column reinforcement standard practice for staggered splice locationsdetails. No splice is allowed when the required length of longitudinal reinforcement is less than the standard mill length of reinforcement (typically 60 ft).

For bridges in SDC's A and B, no lap splices shall be used for #14 or #18 bars. Either lap or mechanical splices may be used for #11 bars and smaller. Lap splices shall be detailed as Class B splices. The smaller bars in the splice determine the length of lap splice required. When space is limited, #11 bars and smaller can use welded splices, an approved mechanical butt splice, or the upper bars can be bent inward (deformed by double bending) to lie inside and parallel to the lower bars. The spacing of the transverse reinforcement over the length of a lap splice shall not exceed 4.0 in. or one-quarter of the minimum member dimension.

For bridge in Splicing of longitudinal column reinforcement outside the No Splice Zones in SDC's C and D, bars shall be spliced shall usingbe mechanical splices meeting the requirements of *Standard Specifications* Section 6-02.3(24)F. Lap splices in longitudinal reinforcement may be used for bridges in SDCs A and B. The spacing of the transverse reinforcement over the length of lap splice shall not exceed 4.0 in. or one-quarter of the minimum member dimension. not be spliced at points of maximum moment, plastic hinge regions, or in columns less than 30 feet long between the top of footing, or shaft, and the bottom of crossbeam. Column longitudinal reinforcements could be spliced within the zone where flexural demand is less than column cracking moment capacity. The bridge plans must show lap splice location, length, and optional mechanical splice locations. *Standard Specifications* Section 6-02.3(24)F covers requirements for mechanical splices.

Column longitudinal reinforcement sSplices shall be staggered. Lap splices shall be detailed as Class B splices. For intermediate column construction joints, the The distance between lap splices of adjacent bars shortest staggered lap bar shall be greater than the maximum of project above the joint 60 bar diameters or minimum of 24″measured along the longitudinal axis of the column. For welded or mechanical splices, tThe distance between splices of adjacent bars shall be greater than the maximum of bar shall project above the joint 20 bar diameters or 24". Figure 7.4.3-1 shows the standard practice for staggered splice locations.

~~For bridges in SDCs A and Bthrough D, no lap spilces shall be used for bars Nos. 14 or 18. eEither lap or mechanical splices couldmay be used for splicing column longitudinal reinforcements . S, splices of #11 and smaller bars may use lap slices. When space is limited, #11 and smaller bars can use welded splices, an approved mechanical butt splice, or the top bar can be bent inward (deformed by double bending) to lie inside and parallel to the bars below. When the bar size exceeds #11, a welded splice or an approved mechanical butt splice is required. Lap splices shall be detailed as Class B splices. The smaller bars in the splice determine the type of splice required.The spacing of the transverse reinforcement over the length of lap splice shall not exceed 4.0 in. or one-quarter of the minimum member dimension.~~

Column Splice and Plastic Hinge Region Details

~~SDCs A and B (current Figure)~~

Figure 7.4.3-1

~~For bridges in SDCs C and D, mechanical splices could be used for splicing column longitudinal reinforcements.~~

~~Mechanical splices shall meet requirements of the *Standard Specifications* Section 6-02.3(24)F and "Ultimate Splice" strain requirements provided in AASHTO LRFD Table C5.10.11.41f-1. See the current Bridge Special Provision for "Ultimate Splice Couplers."~~

~~**New Figure** (hoops only)~~

~~**Column Splice and Plastic Hinge Region Details- SDCs C and D**~~
~~***Figure 7.4.3-12***~~

7.4.4 Longitudinal Development

A. **Crossbeams –** Development of longitudinal reinforcement shall be in accordance~~.~~ with the AASHTO Seismic ~~Article~~Section 8.8.4 and 8.8.8 requirements for SDCs C and D. Column longitudinal reinforcement shall be extended into crossbeams as close as practically possible to the opposite face of the crossbeam (below the bridge deck reinforcement).

~~with AASHTO Seismic 8.8.4. Longitudinal reinforcing shall be extended into the crossbeam as required for seismic joint design.~~

For precast prestressed concrete girder bridges in SDCs A and B with fixed diaphragms at intermediate piers, column longitudinal reinforcement may be terminated at top of lower crossbeam, provided that adequate transfer of column forces is provided.

For precast prestressed concrete girder bridges in SDCs C and D with two-stage fixed diaphragms at intermediate piers, all column longitudinal reinforcement should extend to the top of the cast-in-place concrete diaphragm (upper crossbeam) above the lower crossbeam. Careful attention should be given that column reinforcement does not interfere with extended strands projecting from the end of the prestressed concrete girders. In case of interference, column longitudinal reinforcement obstructing the extended strands may be terminated at top of the lower crossbeam, and shall be replaced with equivalent full-height stirrups extending from the lower to upper crossbeam within the effective width as shown in Figure 7.4.4-1. All stirrups within the effective zone, based on an approximate strut-and-tie

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model, may be used for this purpose. The effective zone shall be taken as column diameter plus depth of lower crossbeam provided that straight column bars are adequately developed into the lower crossbeam. The effective zone may be increased to the column diameter plus two times depth of lower crossbeam if headed bars are used for column longitudinal reinforcement.

If the depth of lower crossbeam is less than 1.25 times the tension development length required for column reinforcement, headed bars shall be used. Heads on column bars terminated in the lower crossbeam are preferable from a structural perspective. However, extra care in detailing during design and extra care in placement of the column reinforcement during construction is required. Typically the heads on the column bars will be placed below the lower crossbeam top mat of reinforcement. Headed reinforcement shall conform to the requirements of ASTM 970 Class HA.

Transverse column reinforcement only needs to extend to the top of the lower crossbeam just below the top longitudinal steel. However, when the joint shear principal tension is less than $0.11\sqrt{f'_c}$, minimum cross tie reinforcement shall be placed acting across the upper cross beam in accordance with the AASHTO Seismic 8.13.3. The minimum cross tie reinforcement shall provide at least as much confining pressure at yield as the column spiral can provide at yield. This pressure may be calculated assuming hydrostatic conditions. If the joint shear principal tension exceeds $0.11\sqrt{f'_c}$, then additional joint reinforcement as outlined by AASHTO Seismic 8.13.3 shall be provided. With the exception of J-bars, the additional reinforcement shall be placed in the upper and lower crossbeam. The cross tie reinforcement may be placed with a lap splice in the center of the joint.

Large columns or columns with high longitudinal reinforcement ratios may result in closely spaced stirrups with little clear space left for proper concrete consolidation outside the reinforcement. In such cases, either hanger reinforcement comprised of larger bars with headed anchors may be used in the effective zone shown in Figure 7.4.4-1or supplemental stirrups may be placed beyond the effective zone. Hanger reinforcement in the effective zone is preferred.

The designer is encouraged to include interference detail/plan views of the crossbeam reinforcement in relation to the column steel in the contract drawings. Suggested plans include the views at the lower stage crossbeam top reinforcement and the upper crossbeam top reinforcement.

B. **Footings –** Longitudinal reinforcement at the bottom of a column should extend into the footing and rest on the bottom mat of footing reinforcement with standard 90° hooks. In addition, development of longitudinal reinforcement shall be in accordance with AASHTO Seismic 8.8.4 and AASHTO LRFD 5.11.2.1. Headed bars may be used for longitudinal reinforcement at the bottom of columns. The head shall be placed at least 3 inches below the footing bottom mat reinforcement. This may require the footing to be locally thickened in the region of the column to provide ~~clearance to~~cover for the bottom of the headed bars.

Longitudinal Development Into Crossbeams

Figure 7.4.4-1

C. **Shafts –** Column longitudinal reinforcement in shafts is typically straight. Embedment shall be ~~Lap Splices~~a minimum length equal to $l_{ns} = l_s + s$ (per TRAC Report WA-RD 417.1 titled "Noncontact Lap

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Splices in Bridge Column-Shaft Connections”).

Where:

l_s =

l_{ac} =

l_d =

s =

The requirements of the AASHTO Seismic 8.8.10 for development length of column bars extended into oversized pile shafts for SDC C and D shall not be used.

All applicable modification factors for development length, except one, in AASHTO LRFD 5.11.2 may be used when calculating l_d. The modification factor in 5.11.2.1.3 that allows l_d to be decreased by the ratio of (A_s required)/(A_s provided), shall not be used. Using this modification factor would imply that the reinforcement does not need to yield to carry the ultimate design load. This may be true in other areas. However, ~~our~~ WSDOT shaft/column connections are designed to form a plastic hinge, and therefore the reinforcement shall have adequate development length to allow the bars to yield.

See Figure 7.4.4-2 for an example of longitudinal development into shafts. Section 7.8.2-K provides additional requirements for transverse shaft reinforcement to confine the non-contact lap splice.

Longitudinal Development Into Shafts
Figure 7.4.4-2

7.4.5 Transverse Reinforcement

A. **General –** All transverse reinforcement in columns shall be deformed. Although allowed in the AASHTO LRFD Specification, plain bars or plain wire may not be used for transverse reinforcement.

Columns in SDCs A and B may use spirals, circular hoops, or rectangular hoops and crossties. Spirals are the preferred confinement reinforcement and shall be used whenever a #6 spiral is sufficient to satisfy demands. When demands require reinforcement bars greater than #6, circular hoops of #7 through #9 may be used. Bundled spirals shall not be used for columns or shafts. Also, mixing of spirals and hoops within the same column is not permitted by the AASHTO Seismic Specification. Figure 7.4.5-1 and 7.4.5-2 show transverse reinforcement details for rectangular columns in high and low seismic zones, respectively.

Columns in SDCs ~~B,~~ C~~,~~ and D shall use ~~spiral or~~ circular hoop ~~transverse confinement~~ reinforcement where possible, although rectangular hoops with ties may be used when large, odd shaped column sections are required. Where the column diameter is 3 ft, or less, consult with the WSDOT Steel Specialist regarding the constructability of smaller diameter welded hoops.

~~Spirals are the preferred confinement reinforcement and shall be used whenever a #6 spiral is sufficient to satisfy demands. When demands require reinforcement bars greater than #6, circular hoops of #7 through #9 may be used. Bundled spirals shall not be used for columns or shafts. Also, mixing of spirals and hoops within the same column is not permitted by the AASHTO Seismic Specification. Figure 7.4.5-1 and 7.4.5-2 show transverse reinforcement details for rectangular columns in high and low~~

~~seismic zones, respectively.~~

When rectangular hoops with ties are used, consideration shall be given to column constructability. Such considerations can include, but are not limited to a minimum of 2′-6″ by 3′-0″ open rectangle to allow access for the tremie tube and construction workers for concrete placement, in-form access hatches, and/or external vibrating.

A larger gap between transverse reinforcement should be provided at the top of columns to allow space for the crossbeam longitudinal reinforcement to pass. In SDC's C & D, the gap shall not exceed the maximum spacing for lateral reinforcement in plastic hinge regions specified in AASHTO Seismic 8.8.9. This can be of particular concern in bridges with large super elevations.

Constant and Tapered Rectangular Column Section SDCs C and D
Figure 7.4.5-1

Constant and Tapered Rectangular Column Section SDCs A and B
Figure 7.4.5-2

B. **Spiral Splices and Hoops –** Welded laps shall be used for splicing and terminating spirals and shall conform to the details shown in Figure 7.4.5-3. Only single sided welds shall be used, which is the preferred method in construction. Spirals or butt-welded hoops are required for plastic hinge zones of columns. Lap spliced hoops are not permitted in columns in any region.

Although hooked lap splices are structurally acceptable, and permissible by AASHTO LRFD Specification for spirals or circular hoops, they shall not be allowed due to construction challenges. While placing concrete, tremies can get caught in the protruding hooks, making accessibility to all areas and its withdrawal cumbersome. It is also extremely difficult to bend the hooks through the column cage into the core of the column.

When welded hoops ~~or mechanical couplers~~ are used, the plans shall show a staggered pattern around the perimeter of the column so that no two adjacent welded splices ~~or couplers~~ are located at the same location. Also, where interlocking hoops are used in rectangular or non-circular columns, the splices shall be located in the column interior.

Circular hoops for columns shall be shop fabricated using a manual direct butt weld ~~,~~or resistance butt weld~~, or mechanical coupler~~. Currently, a Bridge Special Provision has been developed to cover the fabrication requirements of hoops for columns and shafts, which may eventually be included in the *Standard Specifications*. Manual direct butt welded hoops require radiographic nondestructive examination (RT), which may result in this option being cost prohibitive at large quantities. ~~Resistance butt welded hoops are currently available from Caltrans approved fabricators in California and have costs that are comparable to welded lap splices. Fabricators in Washington State are currently evaluating resistance butt welding equipment. When mechanical couplers are used, cover and clearance requirements shall be accounted for in the column details.~~

Columns with circular hoop reinforcement shall have a minimum 2" concrete cover to the hoops to accommodate resistance butt weld "weld flash" that can extend up to ½" from the bar surface.

Field welded lap splices and termination welds of spirals of any size bar are not permitted in the plastic

hinge region including a zone extending 2'-0" into the connected member and should be clearly designated on the contract plans. If spirals are welded while in place around longitudinal steel reinforcement, there is a chance that an arc can occur between the spiral and longitudinal bar. The arc can create a notch that can act as a stress riser and may cause premature failure of the longitudinal bar when stressed beyond yield. Because high strains in the longitudinal reinforcement can penetrate into the connected member, welding is restricted in the first 2'-0" of the connected member as well. ~~***Note:***~~ It would acceptable to field weld lap splices of spirals off to the side of the column and then slide into place over the longitudinal reinforcement.

Welded Spiral Splice and Butt Splice Details

Figure 7.4.5-3