



## 20-9 SPLICES IN BAR REINFORCING STEEL

### Introduction

Structural components in bridges often require splicing of the bar reinforcing steel (rebar). Any rebar longer than the standard 60 ft length (some rebars may be available in 80 ft lengths) will need to be spliced either by lap splicing or butt splicing. Butt splicing is achieved either through the use of mechanical couplers or through welding, and such splicing shall conform to the requirements of either Ultimate Butt Splice or Service Splice.

In Seismic Critical Elements (as defined in the next section), the Design Engineer must specify locations where rebar splicing is permitted and require these splices to conform to either Ultimate Butt Splice specifications or Spiral Termination Detail Type 1 as described in this *Memo to Designers* (MTD). In order to achieve this, the Design Engineer shall first identify Seismic Critical Elements in a bridge structure.

In general, rebar splices in bridge components that are not Seismic Critical shall meet the requirements of either a Service Splice or a Lap Splice.

The purpose of this Memo is to provide analysis methods, design procedures, and contract plan detailing examples for the engineering of rebar splices.

### Classification of Bridge Components

Seismic Critical Bridge Elements undergo significant post-elastic deformation, dissipate seismic energy, and function through a seismic event. These components shall be designed and detailed as ductile members (see Caltrans *Seismic Design Criteria* (SDC) Section 3.1.1), which can sustain seismic damage without leading to structural collapse or loss of structural integrity. Seismic Critical Elements include, but are not limited to columns, shafts, and piles in soft or liquefiable soils.

Other structural elements such as outrigger bent cap beams, dropped bent cap beams, bent cap beams in C-bents, and abutment diaphragm walls shall be designed and categorized as Capacity Protected Members. Under certain circumstances these cast-in-place elements can be categorized as Seismic Critical if they are likely to experience seismic damage, and in such cases a design exception is required.

Components not designated as Seismic Critical are designed to remain elastic in a seismic event in accordance with Caltrans SDC. Such elements include the superstructure, footings, pile caps, seat-type abutment walls, and piles in granular soils. At times, it may be necessary to make an exception and design a Non-Seismic Critical Element as a Seismic Critical Element to meet a nonstandard design requirement (see MTD 20-11 for details).



In Seismic Critical Elements, the Design Engineer shall clearly identify the locations where splices in longitudinal (main) rebars are not allowed. These locations shall be designated on the plans as “No-Splice” Zones. Engineered Ultimate Butt Splices in main rebars are permitted outside the “No-Splice” Zones in Seismic Critical Elements. See Table 1 for Reinforcement Splice Requirements and designated “No-Splice” Zones for different structural components and Attachment ‘A’ for examples of typical column/pile shaft details for Seismic Critical Elements. In general, where the length of the rebar cage is less than 60 ft, splices in longitudinal rebars shall not be allowed.

**Table 1: Reinforcement Splice Requirements**

Component	Seismic Classification	Location <sup>7</sup>	Longitudinal Reinforcement	Transverse Reinforcement	
				Hoops	Spirals
Bridge Column	Ductile member	Inside PHR	No Splice	Ultimate <sup>1</sup>	Not Allowed
		Outside PHR	Ultimate <sup>1</sup>	Ultimate <sup>1</sup>	Not Allowed
Pile Extension/ Type I Shaft Cage Dia. < 14"	Ductile member	Inside PHR	No Splice	Not Allowed	Spiral Splice Type I <sup>2</sup>
		Outside PHR	Ultimate <sup>1</sup>		
Pile Extension/ Type I Shaft 14" ≤ Cage Dia. < 30"	Ductile member	Inside PHR	No Splice	Ultimate <sup>1</sup>	Spiral Splice Type I <sup>2</sup>
		Outside PHR	Ultimate <sup>1</sup>		
Pile Extension/ Type I Shaft Cage Dia. ≥ 30"	Ductile member	Inside PHR	No Splice	Ultimate <sup>1</sup>	Not Allowed
		Outside PHR	Ultimate <sup>1</sup>		
Type II Shaft	Capacity Protected	Top 20 feet	No Splice	Ultimate <sup>1</sup>	Not Allowed
		Everywhere Else	Service <sup>1</sup>		
Pile Group in Competent Soil <sup>6</sup>	Capacity Protected	Everywhere	Lap Splice	Service <sup>1</sup>	Spiral Splice <sup>3,8</sup>
Pile Group in Soft/ Liquefiable Soil	Ductile member	Inside PHR	No Splice	Ultimate <sup>1</sup>	Spiral Splice Type I <sup>2,8</sup>
		Outside PHR	Ultimate <sup>1</sup>		
Pier Walls (Vertical Reinf.) <sup>4</sup>	Ductile member	Inside PHR	No Splice	N/A	N/A
		Outside PHR	Ultimate <sup>1</sup>		
Bent Caps and Pile Caps	Capacity Protected	Inside Critical Zones <sup>9</sup>	No Splices	N/A <sup>5</sup>	N/A <sup>5</sup>
		Outside Critical Zones <sup>9</sup>	Service <sup>1</sup>		
Superstructures	Capacity Protected	Inside Critical Zones <sup>9</sup>	No Splices	N/A <sup>5</sup>	N/A <sup>5</sup>
		Outside Critical Zones <sup>9</sup>	Service <sup>1</sup> or Lap Splices as allowed by SDC		

### Notes for Table 1:

- 1) See Standard Specifications requirements for Ultimate Butt Splice and Service Splices.
- 2) This splice requires an extra turn at spiral pitch  $S/2$  and a 90 degree hook, see Attachment 'B', Splice Termination Detail Type 1.
- 3) Spiral Splice Detail, see Attachment 'B' for acceptable Alternatives, Splice Termination Details Type 2 and 3.
- 4) 90°-135° cross ties are to be used as shown in other Caltrans documents.
- 5) Hoops/ spirals extending from Column/Piles into the Bent Caps or Footings are covered elsewhere in the table. All other reinforcement within these components shall be Service Spliced.
- 6) Does not include Standard or 'class piles', for 'class piles' see Standard Plans.
- 7) See the "Seismic Design Criteria" for definition of the Plastic Hinge Region (PHR) and Seismic Classifications listed in the table.
- 8) The use of spirals for piles with cage diameter  $\geq 30$  in shall not be allowed. Hoops shall be used for transverse reinforcement.
- 9) Critical Zones are locations where the moment demand is greater than 75% of the maximum moment.

## Classification of Splices in Bar Reinforcing Steel

Splices are classified into three functional categories, "Ultimate", "Service", and "Lap" splices, as shown in Table 1. This identification is based on expected strain demands in the rebar and splice assemblies.

The Design Engineer shall specify Ultimate Butt Splices in longitudinal rebars outside the "No-Splice Zone" in Seismic Critical elements. In addition, either Ultimate Butt Splices or Spiral Termination Detail Type 1 shall be specified in all the transverse reinforcement (such as hoops) for Seismic Critical Elements. This classification ensures the rebar splice will conform to the Ultimate Butt Splice requirements in the Standard Specifications.

The Design Engineer shall specify Service Splice in main reinforcement of capacity protected bridge components (away from point of maximum moment) such as footings, bent caps, and girders (see SDC 3.4 and 8.1.3). In addition, rebars provided to resist seismic forces from vertical acceleration shall also incorporate "Service Splice" where required (SDC 7.2.2). For transverse flare reinforcement details and splice criteria in flared columns see MTD 6-1 'Column Analysis Considerations.'

Where a pier wall forms a part of a bridge substructure system, the vertical rebar of the pier wall shall incorporate Ultimate Butt Splices where splicing is allowed. Service splices are adequate for splicing noncritical horizontal rebar where required.

If a project includes the use of Ultimate Butt Splice and/or Service Splices, then the Design Engineer shall convey this information to the Specifications Engineer through a "Memorandum to Specifications Engineer". The following sections address splice design and detailing requirements for several specific structure types.

## Guidance on the Design of Substructure Elements

### Case 1: Single-Column Bent on Pile Footing

This structural system shall be designed to force plastic hinging at the bottom of the column where it may be inspected following a seismic event.

To identify the “No Splice” Zone for a single-column bent with bending in the transverse direction, the Design Engineer may refer to SDC Section 3.1 and to the following steps:

- 1) Establish the moment diagram (demand) associated with the transverse push of this system.
- 2) Compute the moment capacities from a moment-curvature analysis of the cross-section:  
 $M_n$  = Moment capacity of the cross-section corresponding to a concrete strain of 0.003 at the extreme compression fiber.  
 $M_y$  = Moment capacity of the cross-section corresponding to first yield of a rebar  
 $M_p$  = Plastic moment capacity as defined in SDC 3.3.
- 3) Identify the extent of the “Plastic Hinge Region” as defined in Section 7.6.3 of the SDC. For a column under transverse bending, this zone typically extends into the column the greater of:
  - a. 0.25 x Column Length from the top of the footing
  - b. the region of column where moment demand exceeds  $0.75M_p$
  - c. 1.5 times the column dimension in the direction of bending
- 4) The “No Splice” Zone that is identified on Structure Plans shall be the larger of the zones obtained from step 3 above.

Note: The Design Engineer shall also establish a “No-Splice Zone” based on a moment diagram obtained from the longitudinal push of the bridge. Since a plastic hinge may potentially form at the top of column due to longitudinal movement of the bridge, the allowable splice zone cannot extend to the top of column. Therefore, the allowable splice zone shall be determined based on longitudinal as well as transverse deformation cases.



## Case 2: Single-Column Bent on an Enlarged (Type II) Shaft

This structural system shall be designed and detailed to force the plastic hinge to form at the interface of the shaft and the column where it may be inspected immediately following a seismic event.

The Design Engineer shall ensure that a plastic hinge forms in the column, but not in the shaft. To achieve this, the Design Engineer shall provide a factor of safety, as stated in SDC, between the moment demand and moment capacity in the shaft.

Reinforcement detailing shall be based on the following guidelines:

- 1) The main bars assembled in the column cage shall be extended into the shaft in a staggered formation with embedment lengths as recommended by the SDC section 7.7.3.2. This practice ensures adequate column bar anchorage in case the plastic hinge damage penetrates into the shaft.
- 2) At least fifty (50) percent of the column confinement steel, as placed in the plastic hinge region, shall be extended into the shaft for the embedded portion of the column cage as required by the SDC (spacing of hoops may be doubled).
- 3) The confinement steel provided for the top portion of the shaft shall be as required by the SDC. In addition the clear spacing between transverse rebars in shafts shall not be less than 5 inches to meet the minimum 5 by 5 inch clear window required for proper concrete flow. Rebars may be bundled if required.
- 4) Spacing of the confinement steel provided in the shaft below the termination of the column rebar cage may be twice that provided in the top portion of the shaft; however, the shear requirements in the shaft shall be satisfied. Note that the maximum moment and maximum shear in the shaft likely do not occur at the same section.
- 5) Hoops shall be used in Type II shafts and shall meet the Ultimate Butt Splice specifications.

### Case 3: Single-Column Bent on Prismatic (Type I) Shaft

In this case the plastic hinge will form below ground typically at depths of two to five times the diameter of the shaft. This depth will increase significantly for shafts in soft or liquefiable soils. There will be a considerable cost increase if an attempt is made to force the plastic hinge to form closer to the ground level. The following recommendations are made regarding detailing requirements for reinforcing steel in prismatic shafts:

- 1) The potential plastic hinge region shall be identified based on a moment diagram for the column-shaft combination including the soil “p-y” data. Where appropriate, a 50 ft zone (based on a 60 ft long rebar), centered on the potential plastic hinge location shall be designated as the “No-Splice Zone”. Splices outside this zone shall meet the Ultimate Butt Splice requirements.
- 2) Hoops in prismatic Type I shafts shall meet the Ultimate Butt Splice specifications. Spirals shall use the Spiral Splice Termination Detail Type I shown in Attachment ‘B’ for the entire length of shaft. Hoops shall be used in Type I shafts, unless the cage diameter is less than 30 inches where a spiral may be used as allowed in Table 1.

### Case 4: Multi-Column Bent on Pinned Footings

In multi-column bents with pinned footings, plastic hinges form at the tops of columns. The cap beams shall be stronger than the columns as required by Caltrans SDC.

Multi-column bents that are pinned at bases of columns are treated as an inverted cantilever with the top portion of column defined as the plastic hinge region. A “No-Splice Zone” shall be designated on the plans as explained in Case 1.

Hoops and main column bars shall meet the Ultimate Butt Splice specifications. In columns where spirals are allowed (see Table 1), spirals shall use the Spiral Splice Termination Detail Type 1 as shown in Attachment ‘B’ for the entire length of the column.

### Case 5: Multi-Column Bent on Enlarged (Type II) Shafts

Columns in multi-column bents on enlarged shafts may be pinned or fixed to the shafts. In either case, the Design Engineer shall provide a factor of safety between the moment demand and moment capacity in the shaft as stated in the SDC. The top 20 ft segment of the shaft shall be designated as a “No-Splice Zone.” For other requirements, refer to Case 2 above.

Hoops shall be used in enlarged shafts as shown in Table 1 and shall meet the Ultimate Butt Splice specifications.



### Case 6: Multi-Column Bent on Prismatic Pile Shafts

The design procedures and the rebar splice requirements for this case are similar to those of a single-column bent on prismatic pile shaft.

The Design Engineer may seek a waiver from the Strategy or Type Selection committees for very tall columns for all cases listed above where the 0.25L rule specified in the SDC for defining the plastic hinge region cannot be met. Where appropriate, a 50 ft zone starting at the top of the column cage may be designated as the “No- Splice Zone.”

### Guidelines on the use of Hoops and Spirals

To assure good seismic performance as well as to facilitate ease of construction, hoops shall be used in place of spirals in seismic critical elements except as allowed by Table 1. The discrete nature of hoops provides an advantage in seismic critical elements since the failure of one hoop does not lead to a premature plastic hinge failure. When a plastic hinge forms, the confinement steel is exposed as a result of a loss of cover concrete. With additional deformation, the strains in the transverse reinforcement increase. Any break at a single location in spiral reinforcement may cause a considerable length of the spiral to become ineffective, and lead to premature plastic hinge failure.

The following table lists minimum rebar hoop diameters that are readily available.

**Table 2: Minimum Hoop Diameters.**

Rebar Designation (U.S.)	Minimum Hoop Diameter (inches)
#4	Cannot be used for hoops
#5, # 6	14
# 7	22
# 8	30

The following guidelines shall be followed with regard to hoops and spirals:

- a) Hoops with Ultimate Butt Splices shall be used over the entire length of columns, shafts and piles (Seismic Critical Elements) having a rebar cage diameter of 30 inches or larger. In addition, in rebar cages having a smaller diameter, use hoops with Ultimate Butt Splices for their entire length as specified in Table 1.

- b) In Seismic Critical Elements having a diameter smaller than 30 inches, when it may not be practical to provide hoops as allowed by Table 1, spiral reinforcement may be used with the following restrictions:
  - i) The “Plastic Hinge Region” shall be designated as the “No-Splice Zone” for the spirals.
  - ii) Terminations in spirals as allowed in Table 1 shall conform to the requirements in Attachment ‘B’ of this MTD.

The Designer should detail Seismic Critical Elements without spirals if allowed in Table 1.

- c) Combination of spiral reinforcement with hoops shall not be used, with the exception of the superstructure where hoops may have to be used to accommodate rebar congestion.

## Special Hook Detail in Spiral Reinforcement

The spiral reinforcement is generally discontinued at the column-soffit interface to facilitate placement of main rebars in the cap beam, and is restarted just above the soffit rebars. Similarly, the spiral reinforcement may be discontinued at the column-footing interface. Since the reinforcement is subjected to high strains at these locations of a Seismic Critical Element, the spiral reinforcement shall terminate in, and begin with a special hook.

The special hook is obtained through an extra turn in the spiral coil together with the tail, equal in length to the diameter of the rebar cage, passing through the core of column (see “Splice Termination Detail Type 1” in Attachment ‘B’). The pitch of the spiral reinforcement at these locations shall be no more than half of the pitch of the spiral at a typical section. This hook shall be shown on the structure plans.

## Special Terminating Details for Spiral Reinforcement

Special terminating details are required at the extremities of the column rebar cage and at locations allowed by Table 1 when spirals are used (see Attachment B). The spiral rebar at these locations is subjected to relatively lower levels of straining. The details in Attachment ‘B’ show two alternatives, Spiral Splice Termination Details Type 2 and 3, which should be used at these locations and should be shown on the structure plans. In-lieu of these details, the “Splice Termination Detail Type 1”, the special hook described in the preceding section may be used.

## Illustrative Examples

Attachment ‘A’ (Sheets 1 & 2) shows column and shaft details to help the Design Engineer in specifying details such as the “No Splice” Zone and for specifying regions where an Ultimate Butt Splice is required. Attachment ‘B’ shows acceptable spiral splice details. Additional rebar detailing guidelines can be found in Section 13 of the *Bridge Design Details* (Caltrans, 1992).





## References:

Caltrans, (2013). *Seismic Design Criteria, Version 1.7*, California Department of Transportation, Sacramento, CA

Caltrans, (2001) *Memo To Designers 20-6: Seismic Strength of Concrete Bridge Superstructures*, California Department of Transportation, Sacramento, CA

Caltrans, (1999) *Memo To Designers 20-11: Establishing Bridge Seismic Design Criteria*, California Department of Transportation, Sacramento, CA

Caltrans (2009) *Memo To Designers 6-1: Column Analysis Considerations*, California Department of Transportation, Sacramento, CA

Caltrans (1992) *Bridge Design Details*, Section 1 3: Reinforcement, California Department of Transportation, Sacramento, CA

Caltrans (2010) *Standard Specifications*, Section 52.6 Splicing, California Department of Transportation, Sacramento, CA

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