20.34 PRECAST BRIDGE COMPONENT CONNECTIONS

20.34.1 GENERAL

This BDM provides guidelines for the design and construction of precast concrete (PC) bridge component connections to achieve seismic performance emulating that achieved by conventional cast-in-place concrete design and construction. Accordingly, the Caltrans seismic design methods and performance requirements for conventional cast-in-place concrete construction, as required by the latest edition of the *Caltrans Seismic Design Criteria* (SDC) are applicable to the design of systems using the precast concrete connections addressed in this BDM. This BDM addresses bridge connections in which at least one of the members meeting at the joint is a precast concrete member. Reinforcing bars for seismic critical members are limited to ASTM A706 Grade 60 until additional experimental data and design recommendations for seismic performance of higher grade bars are approved by the Office of Earthquake Engineering, Analysis, and Research (OEEAR).

20.34.2 DEFINITIONS

Emulation – Achievement of the same minimum overall seismic performance of a bridge using precast concrete components as that expected for conventional cast-in-place concrete bridge systems. The overall seismic performance of bridges with precast concrete connections should be based on the system displacement ductility capacity requirements of the SDC, with associated hysteretic response similar to that achieved by cast-in-place bridge systems, as demonstrated by physical testing formally documented in the published literature.

Grouted Duct Connection – A moment connection formed between a column (precast or cast-in-place concrete) and a precast concrete bent cap or footing by extending the column longitudinal bars into matching corrugated steel ducts embedded within the bent cap or footing that are subsequently filled with a cement-based, flowable, small-aggregate material such as high-strength, non-shrink grout or Ultra-High Performance Concrete (UHPC).

Integral Connection – A connection between bridge components that provides continuity with moment transfer.

Pocket Connection – A moment connection formed between a column (precast or cast-in-place concrete) and a precast concrete bent cap or footing by extending the column longitudinal bars into a single void formed within the bent cap or footing using a corrugated steel pipe that is subsequently filled with concrete or other cementitious material.

Socket Connection – A moment connection formed between a concrete column or pile and a precast concrete bent cap or foundation member by extending the column or pile a specified distance into a single void formed within the bent cap or foundation member using a corrugated steel pipe. The gap between the pipe and the column/pile is subsequently filled with concrete or other cementitious materials.

20.34.3 NOTATION

PC = Precast concrete

PGA = Peak ground acceleration

SDC = Caltrans Seismic Design Criteria

UHPC = Ultra-High Performance Concrete

A_{st} = total area of column longitudinal reinforcement developed into the joint (in.^{2})

A_s^{jv} = area of vertical joint shear reinforcement (in.^{2})

A_s^{jh} = area of horizontal joint shear reinforcement (in.^{2})

A_{cap}^{bot} = area of bent cap bottom flexural steel (in.^{2})

A_{cap}^{top} = area of bent cap top flexural steel (in.^{2})

B_{cap} = bent cap width (in.)

b = bent cap width minus clear cover (in.)

D = diameter of pipe-pin (in.)

d_{bl} = nominal diameter of column longitudinal bar (in.)

$d_{bl\text{-}eq}$ = equivalent bar diameter of bundled bars, based on the sum of the cross-sectional areas of the bundled bars.

D'_{cp} = average diameter of confined pocket fill between corrugated steel pipe walls (in.)

D_c = maximum column cross-sectional dimension (in.)

D_h = diameter of the opening above the bent cap socket (in.)

D_s = depth of superstructure (in.)

D_{sk} = depth of socket (in.)

d_d = inside diameter of grouted duct (in.)

f'_c = specified compressive strength of unconfined concrete (psi)

f'_{ce} = expected compressive strength of concrete surrounding grouted duct (psi)

f_{ye} = expected yield strength of column longitudinal reinforcement (ksi)

f_{yh} = specified minimum yield strength of transverse reinforcement for equivalent hoop = 60 ksi

f_{yp} = specified minimum yield strength of corrugated steel pipe (ksi)

l_{ac} = minimum length of column longitudinal reinforcement embedded into the bent cap or footing (in.)

$l_{ac,UHPC}$ = minimum length of column longitudinal reinforcement embedded in UHPC-filled duct (in.)

p_t = principal tension stress in the joint (ksi)

s = hoop spacing (in.)

t_{pipe} = thickness of corrugated steel pipe (in.)

20.34.4 PRECAST CONNECTION CATEGORIES AND TYPES

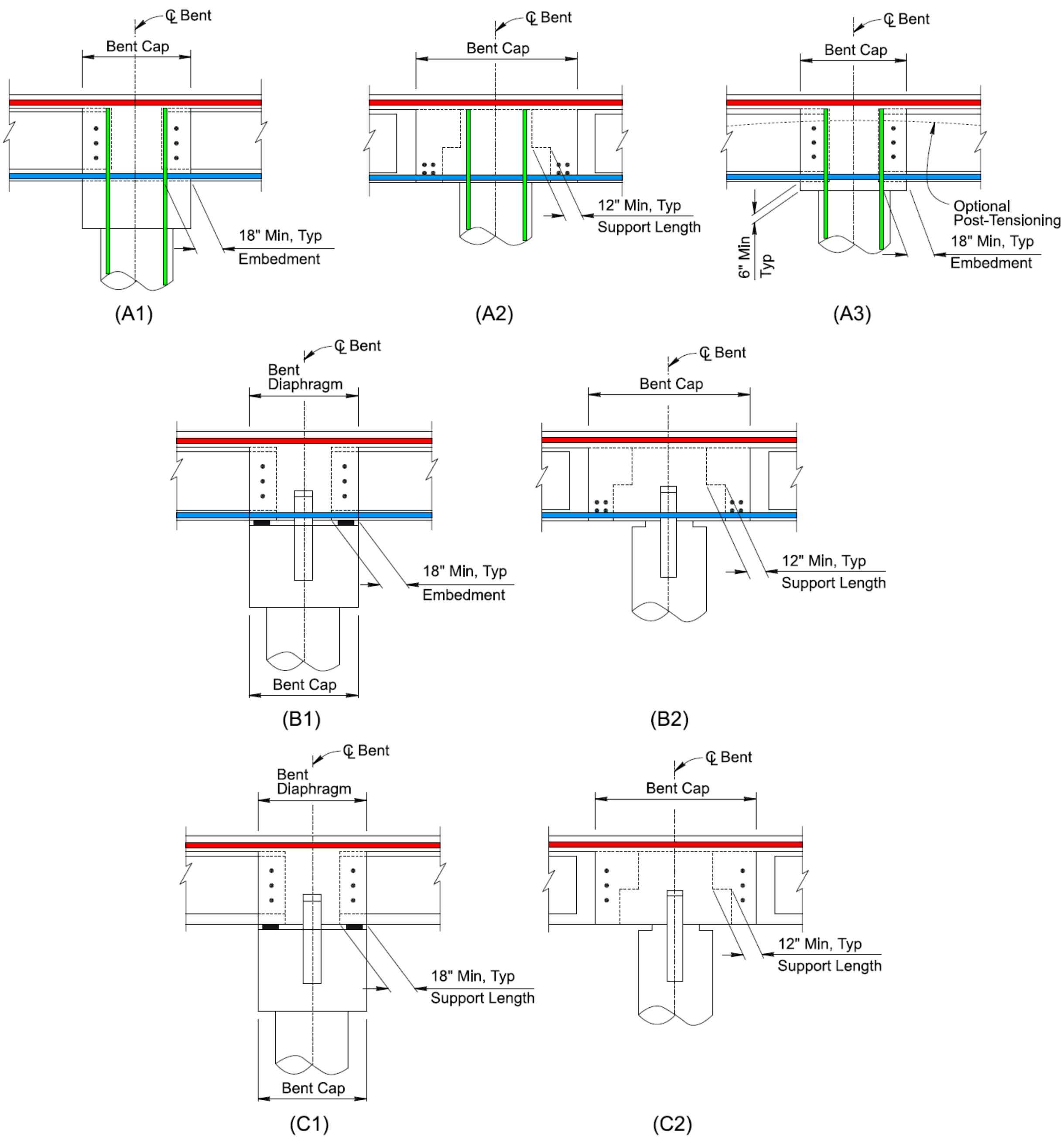
In general, PC connections for bridge applications may be classified as: 1) PC girder-to-bent cap connections; 2) moment connections between columns and bent caps or footings, or between piles and PC foundations; and 3) pinned connections between columns and bent caps or foundations.

Allowable PC girder-to-bent cap connections should be as specified in the SDC. Moment connections between columns and PC bent caps and footings are formed by using grouted duct~~s~~, pocket, or socket connections. Socket connections should only be used where the column, pile, or pile extension diameter is less than or equal to 3 ft.

All PC connection types should provide a continuous load path and force transfer without failure between the connected members to ensure adequate strength, stiffness, and ductility of the overall structural system in a seismic event. Moment connections should have the capacity to resist column overstrength demands.

20.34.5 PC GIRDER-TO-BENT CAP CONNECTIONS

Caltrans SDC Section 7.2.1.2 provides the requirements for precast girder-to-bent cap connections. The allowable PC girder-to-bent cap connections are illustrated in Figure 20.34.5-1, with required positive and negative moment reinforcement highlighted schematically in blue and red, respectively. Additionally, column reinforcement extending into the bent cap for integral connections is shown in green. Types A and B are the preferred connection types; however, Type C connections, when used for lower seismic demand applications (PGA<0.6*g*), are designed to act as a pin with negligible moment transfer.



Legend:

- Negative moment reinforcement
- Positive moment reinforcement
- Column longitudinal reinforcement

NOTES:

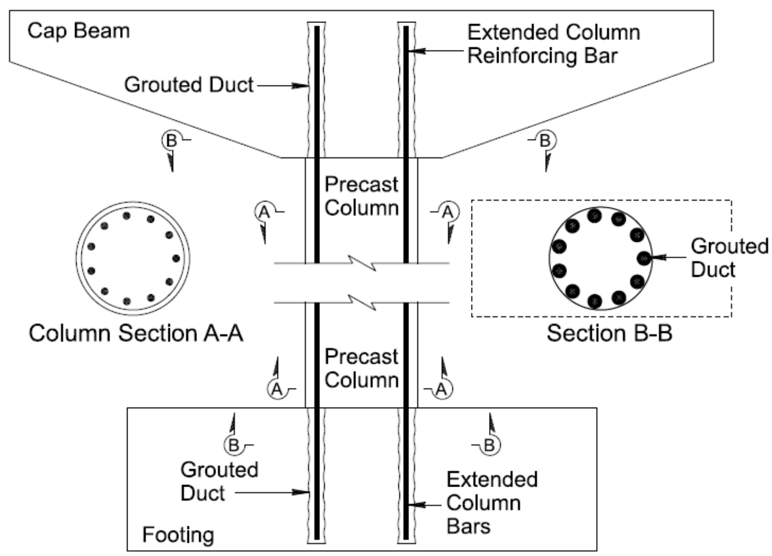
Figures are schematics and do not show all reinforcement and connection details.
The drop bent cap width may be different from the bent diaphragm width.

Figure 20.34.5-1 Allowable PC Girder-to-Bent Cap Connections (SDC, Section 7.2.1.2)

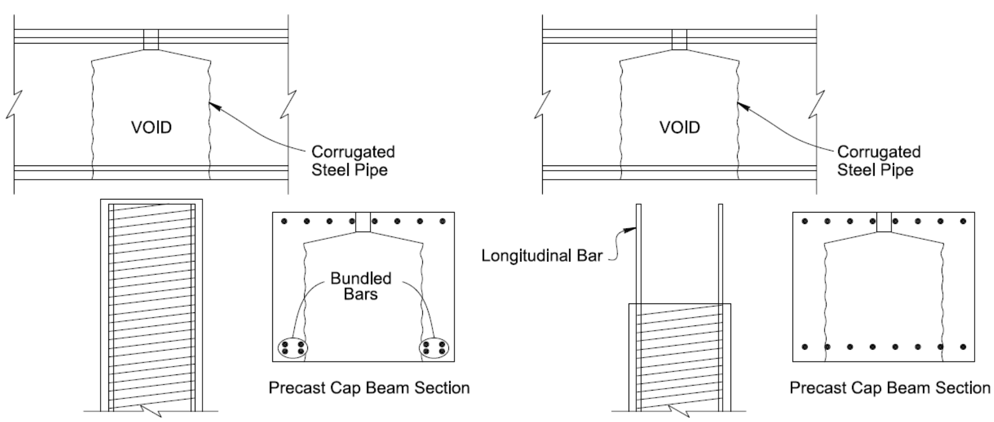
20.34.6 MOMENT CONNECTIONS: COLUMN-TO-BENT CAP OR FOOTING

Figure 20.34.6-1 shows schematic diagrams for three types of moment connections (grouted duct, pocket, and socket) that may be used to join a column/pile (precast or cast-in-place) to a PC or cast-in-place bent cap or footing.

The joint shear design provisions of Sections 7.4.2 to 7.4.5 of the SDC are applicable to all connection types, subject to the changes stated herein. Joint shear requirements for bridge framing types should be satisfied as shown in Table 20.34.6-1.



(a) Grouted Duct Connections in PC Cap and PC Footing
(Tazarv and Saiidi, 2014)

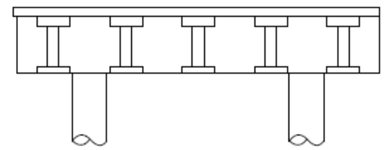
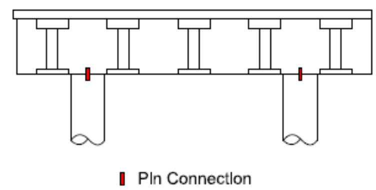
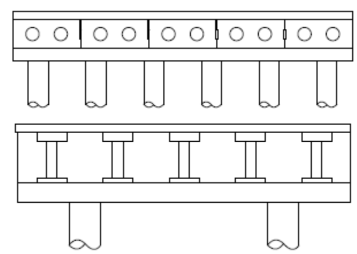
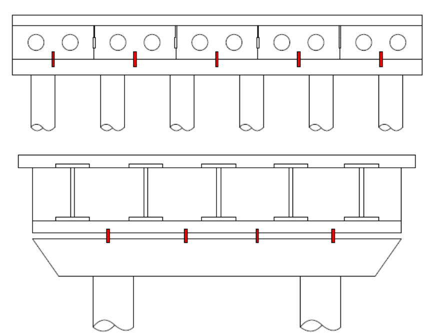
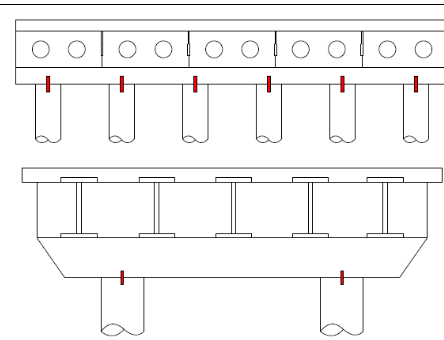


(b) Socket Connection (c) Pocket Connection

Socket and Pocket Connections (Mehrsoroush et al., 2017; Saiidi et al., 2019)

Figure 20.34.6-1 Schematics for Grouted Duct, Socket, and Pocket Connections

Table 20.34.6-1 Bridge Framing and Joint Shear Requirements

Joint	Joint Shear Requirement	Schematic Example
Column connected integrally to bent cap and girders fixed to bent cap (bent cap is within the superstructure)	Joint shear reinforcement required longitudinally and transversely for multi-column bents	
Column pin-connected to bent cap (bent cap is within the superstructure)	No joint shear reinforcement	
Column connected integrally to drop bent cap, and drop bent cap connected integrally to superstructure	Joint shear reinforcement required longitudinally and transversely for multi-column bents	
Column connected integrally to drop bent cap and drop bent cap pin-connected to superstructure	Joint shear reinforcement required only transversely for multi-column bents	
Column pin-connected to drop bent cap and drop bent cap integrally connected to the superstructure	No joint shear reinforcement	

20.34.6.1 Grouted Duct Connection

A grouted duct connection provides continuity for all column bars and is permitted where a moment connection is required between a column and a bent cap or footing. Column longitudinal bars are placed in matching corrugated steel ducts within the PC bent cap or footing and subsequently filled with a non-shrink, high-strength grout or UHPC to complete the connection. A representative grouted duct connection used for joining a column to a PC bent cap is illustrated in Figure 20.34.6.1-1. Refer to Restrepo et al. (2011) for additional information on grouted duct connections.

20.34.6.1.1 Materials and Details for Grouted Duct Connection

Ducts used in a grouted duct connection should satisfy the following:

- Be formed with semi-rigid steel ducts, which are cast into the concrete.
- Consist of galvanized ferrous metal per ASTM A653 and be fabricated with either welded or interlocked seams.
- Be corrugated with a minimum wall thickness of 26 gage for ducts less than or equal to 4-inch diameter and 24 gage for ducts greater than 4-inch diameter.
- Use a corrugation rib height of at least 0.12 inch.
- Incorporate a minimum clear distance between ducts of at least 2 inches and 1.33 times the maximum coarse aggregate size.
- No more than two column bars should be bundled in a duct. However, it is preferable to avoid column bar bundling.
- Use a minimum inner duct diameter of $2.75d_{bl}$ for a single column bar in a duct and a duct diameter of $2.5d_{bl\text{-}eq}$ for two-bar bundles.

Grout used in grouted duct connections should satisfy the following:

- Consist of either a cementitious, non-shrink grout in accordance with ASTM C1107 or UHPC.
- Have a specified 28-day compressive strength of at least 500 psi greater than that specified for the concrete in the bent cap or footing, to help ensure the PC connection does not become a weak link in the system.
- Concrete used for the PC bent cap or footing should consist of a Portland cement-based concrete conforming to Standard Specifications and/or Special Provisions for normal-weight concrete. Lightweight concrete is not permitted.

20.34.6.1.2 Column Bar Size and Embedment Length

The column’s longitudinal bar size used in a grouted duct connection should not exceed #14. Regardless of the calculated minimum embedment length, column longitudinal bars within grouted ducts and the ducts themselves should extend as close as practically possible to the top surface of the PC bent cap or bottom surface of the footing.

Minimum Embedment Length with Grout

The minimum embedment length of column longitudinal reinforcement bonded in a duct using specified grout within a PC bent cap or footing, l_{ac}, should be taken as:

$$l_{ac} = 24d_{bl} \qquad \text{(Eq. 20.34.6.1.2-1)}$$

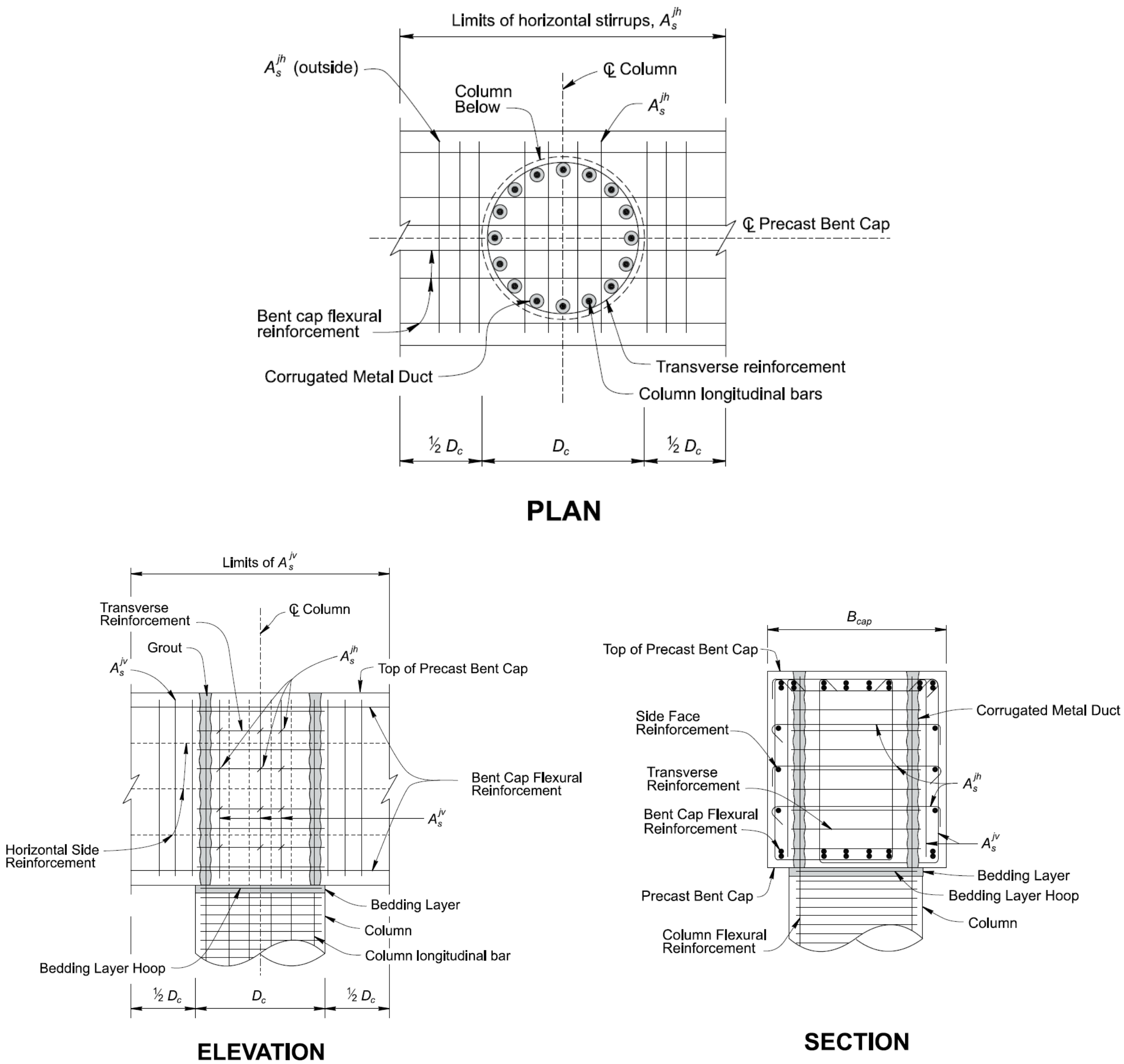


Figure 20.34.6.1-1. Grouted Duct Connection between Column and PC Bent Cap

Minimum Embedment Length with UHPC

The minimum embedment length of column longitudinal reinforcement bonded in a duct using specified UHPC within a PC bent cap or footing, $l_{ac,UHPC}$, should be taken as:

$$l_{ac,UHPC} = \text{maximum of } \left(3500 \frac{d_{bl}^2}{d_d \sqrt{f'_{ce}}}, 24 d_{bl} \right) \qquad \text{(Eq. 20.34.6.1.2-2)}$$

Column longitudinal bars bonded with UHPC in the duct should be debonded from the UHPC for a length of $4d_{bl}$ starting at the interface of the adjoining member containing the duct.

Embedment Length Factor for Epoxy-Coated Reinforcement

For epoxy-coated column longitudinal reinforcement, the minimum embedment length of Equations 20.34.6.1.2-1 and 20.34.6.1.2-2 should be multiplied by a factor of 1.2.

20.34.6.1.3 Reinforced Bedding Layer

A reinforced bedding layer should be placed to accommodate any placement tolerance between the end of the column and the bent cap soffit. The bedding layer should consist of the same grout used for a grouted duct connection and should satisfy the following:

- Be reinforced with transverse reinforcement around the column bars within the bedding layer.
- The minimum height at any edge of a bedding layer should be 3 inches.
- Bedding layer transverse reinforcement should match the size and type of transverse reinforcement used for the column plastic hinge region or other transverse reinforcement at the adjacent column top (or bottom) such as a small diameter rebar cage pinned connection.
- Bedding layer transverse reinforcement should be spaced evenly through the depth of the bedding layer with a spacing that is less than or equal to that used at the adjacent column top or bottom – see Figure 20.34.6.1.3-1.
- For a sloped bedding layer, one or more extra hoops parallel to the bent cap should be added to ensure that the unsupported length of column bars in the bedding layer adjacent to the column does not exceed that used at the end of the column.
- The vertical concrete cover over the first hoop in the column adjacent to the PC bent cap or foundation member is permitted to be less than that specified in Article 5.10.1 of AASHTO-CA LRFD Bridge Design Specifications (Caltrans, 2019).

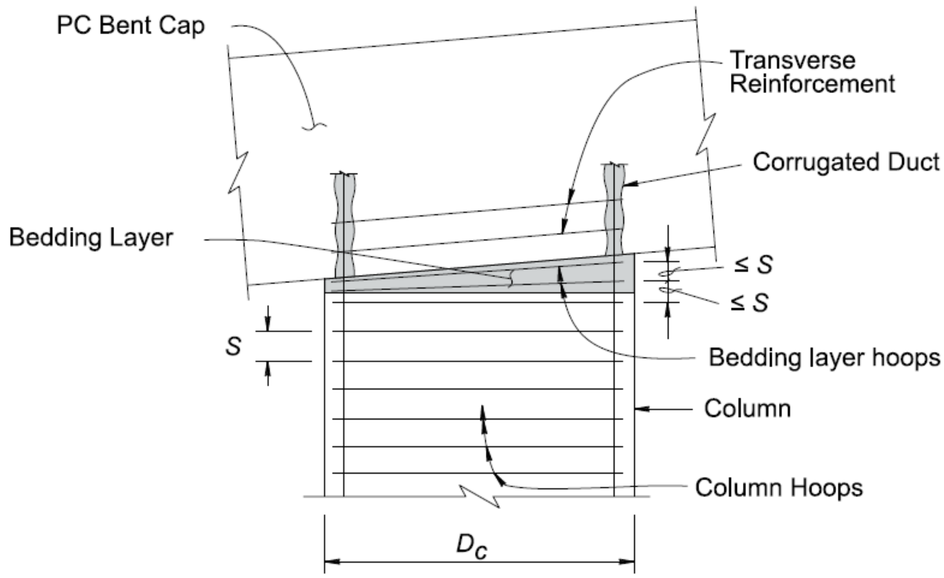
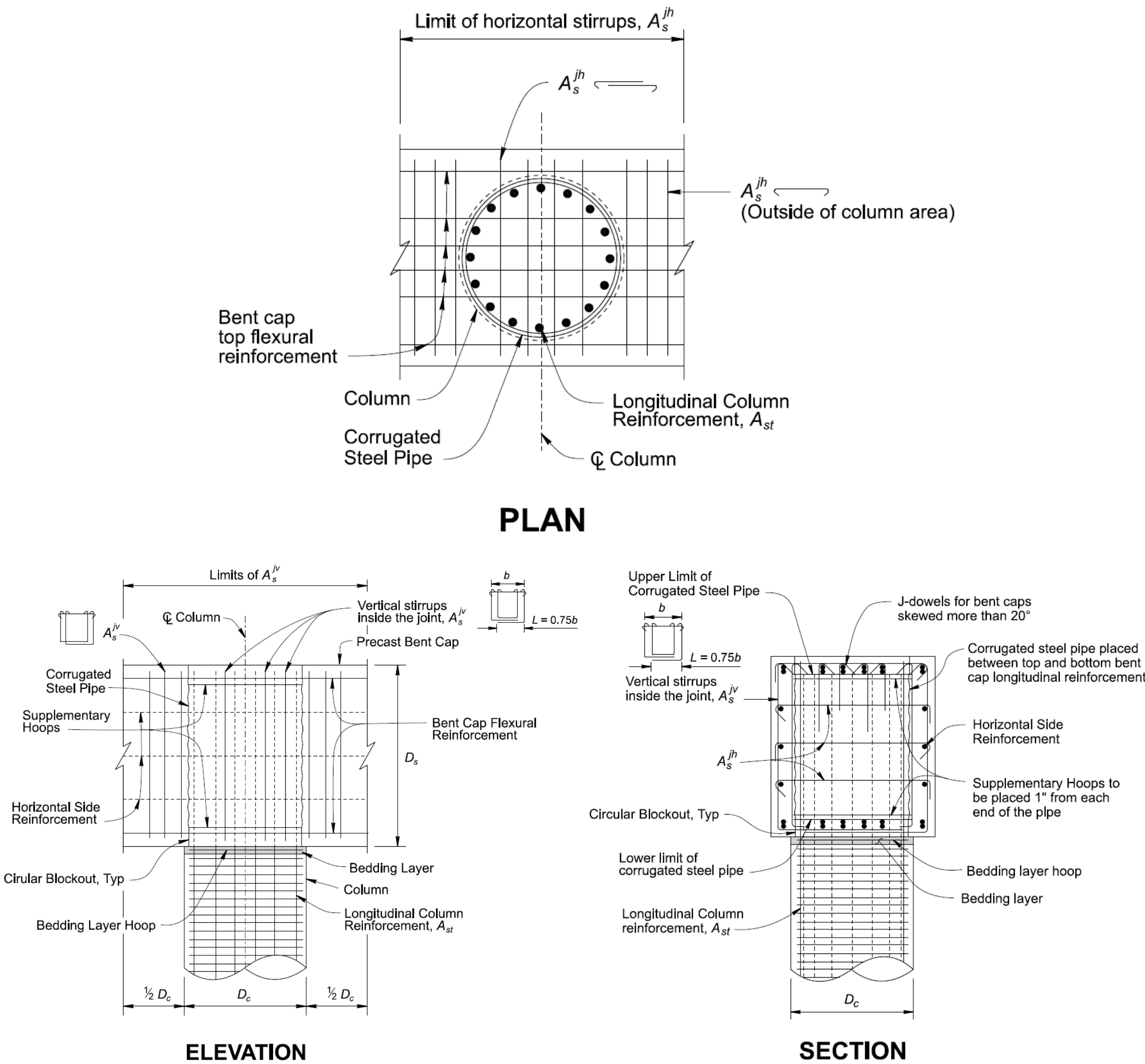


Figure 20.34.6.1.3-1 Schematic of Reinforcement in Bedding Layer at Column-to-Bent cap Interface

20.34.6.2 Pocket Connection

A pocket connection provides continuity for all column bars and is permitted where a moment connection is required between a column and a bent cap or footing. Column longitudinal bars are extended into a single void formed within the bent cap or footing using a stay-in-place corrugated steel pipe that is subsequently filled with a specified concrete to complete the connection. A representative pocket connection used for joining a column to a PC bent cap is illustrated in Figure 20.34.6.2-1.

In a pocket connection, the steel pipe is configured to permit continuous top and bottom longitudinal bent cap (or footing) reinforcement through the joint. Additionally, the steel pipe may be penetrated to enable the horizontal joint shear reinforcement, A_s^{jh} to be placed.



NOTE: To minimize conflict with column bars, do not place horizontal stirrups near the inside edge of the duct

Figure 20.34.6.2-1 Pocket Connection between Column and PC Bent Cap

20.34.6.2.1 Joint Shear

Principal Tension Stress Not Exceeding $3.5\sqrt{f'_c}$

Where the principal tension stress, p_t, in the joint is less than or equal to $3.5\sqrt{f'_c}$, the minimum joint shear reinforcement is satisfied by providing a minimum thickness of the corrugated steel pipe, t_{pipe}, determined from Equation 20.34.6.2.1-1.

$$t_{pipe} \geq \text{maximum of} \left(0.05 \frac{D'_{cp}\sqrt{f'_c}}{f_{yp}}, 0.06 \text{ in.} \right) \quad (20.34.6.2.1\text{-}1)$$

Principal Tension Stress Exceeding $3.5\sqrt{f'_c}$

Where the principal tension stress, p_t, in the joint is greater than $3.5\sqrt{f'_c}$, confining joint shear reinforcement is provided by using a minimum thickness of the corrugated steel pipe, t_{pipe}, determined from the larger value from Equations 20.34.6.2.1-1 and 20.34.6.2.1-2.

$$t_{pipe} \geq 0.16 \frac{A_{st} D'_{cp} f_{yh}}{l_{ac}^2 f_{yp}} \quad (20.34.6.2.1\text{-}2)$$

The additional joint shear reinforcement satisfying the requirements of Sections 7.4.4 and 7.4.5 of the SDC should be provided. The horizontal joint shear reinforcement, A_s^{jh} is provided by penetrating the steel pipe.

Additionally, a supplementary hoop is placed around the steel pipe, 1 inch from each end of the pipe, as shown in Figure 20.34.6.2-1. These hoops should match the size of the bedding layer reinforcement and use a hoop diameter not more than the steel pipe diameter (including corrugation) plus 4 inches.

20.34.6.2.2 Materials for Pocket Connection

The corrugated steel pipe used to form a void in a PC bent cap or footing should:

- Consist of a helical, lock-seam, corrugated steel pipe conforming to ASTM A760, Standard Specification for Corrugated Steel Pipe, Metallic-Coated for Sewers and Drains.
- Satisfy the thickness requirements of Section 20.34.6.2.1.
- Use a helical lock seam conforming to the requirements of AASHTO T249, Standard Method of Test for Helical Lock Seam Corrugated Pipe.
- Use a pipe diameter based on fabrication and placement tolerances established for the project.
- Concrete fill used in the corrugated steel pipe should satisfy the following:
- Consist of a Portland cement-based normal-weight concrete. Lightweight concrete is not allowed.
- Use a concrete mix designed to achieve a specified concrete compressive strength at least 500 psi greater than the specified concrete strength of the PC bent cap or footing.
- Use a concrete mix, including maximum coarse aggregate size, designed to ensure the pocket and bedding layer are filled without voids.

Concrete used for the PC bent cap or footing for a pocket connection should consist of a

Portland cement-based concrete conforming to Standard Provisions for normal-weight concrete. Lightweight concrete is not permitted.

20.34.6.2.3 Column Bar Size and Embedment Length

The column's longitudinal bar size used in a pocket connection should not exceed #14. Regardless of the calculated minimum embedment length, column longitudinal bars within corrugated steel pipes should extend as close as practically possible to the top surface of the PC bent cap or bottom surface of the footing.

Minimum Embedment Length

The minimum embedment length of column longitudinal reinforcement bonded in a corrugated steel pipe using the specified concrete within a PC bent cap or footing, l_{ac}, should be taken as:

$$l_{ac} = 24\, d_{bl} \qquad \text{(Eq. 20.34.6.2.3-1)}$$

Embedment Length Factor for Epoxy-Coated Reinforcement

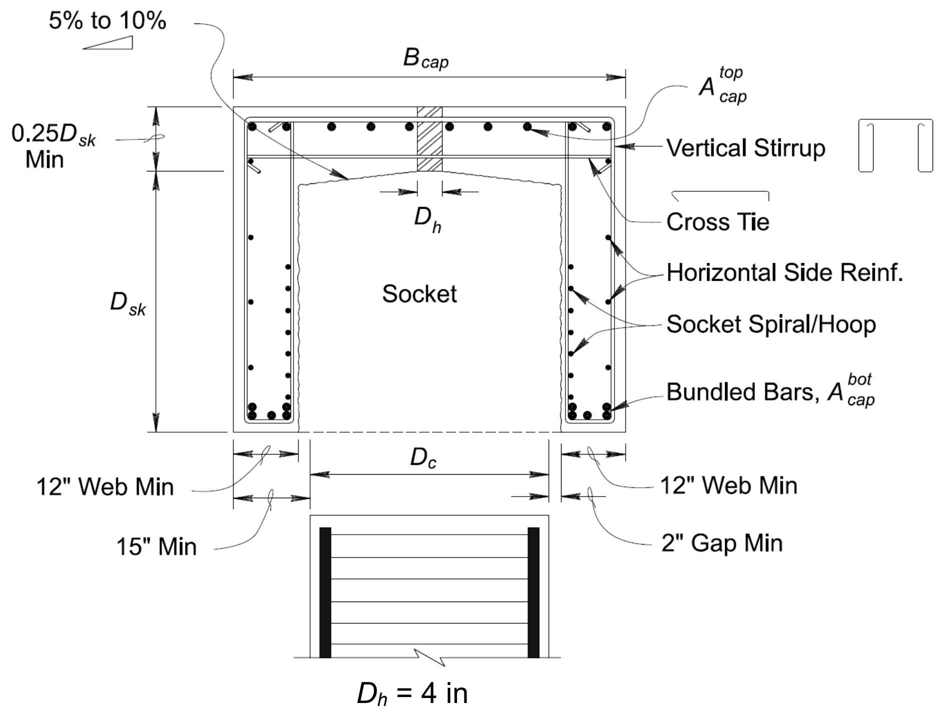
For epoxy-coated column longitudinal reinforcement, the minimum embedment length of Equation 20.34.6.2.3-1 is multiplied by a factor of 1.2.

20.34.6.2.4 Reinforced Bedding Layer

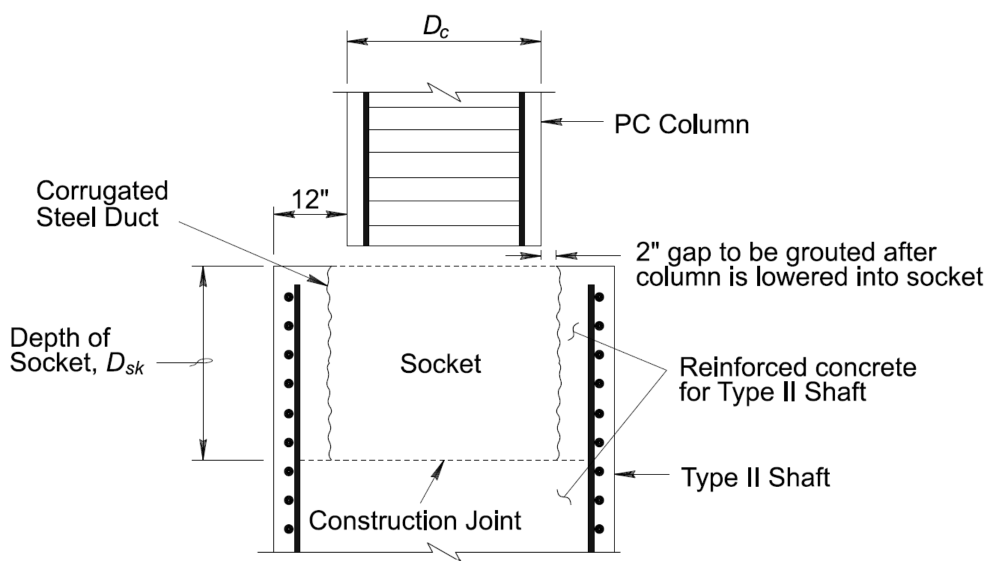
Where a bedding layer between the bent cap soffit/top of footing and column end is required to accommodate placement tolerances, the provisions of Section 20.34.6.1.3 are applicable, except that the specified concrete fill for a pocket connection is used in place of grout.

20.34.6.3 Socket Connections

Socket connections are only to be used for columns/piles with diameters less than or equal to 3 ft. For a socket connection, the top or bottom portion of the finished PC column is extended into a corrugated steel pipe in the cap beam or footing, and the gap between the column and the pipe is grouted (see Figure 20.34.6.3-1). Refer to Saiidi et al. (2019) for additional information on socket (and pocket) connections. The cap beam or footing can be cast-in-place if the void dimensions make it impractical to be precast concrete.



(a) PC Column-to-Bent Cap Section



(b) PC Column-to-Type II Shaft Section

Figure 20.34.6.3-1 Details of Socket Connections

20.34.6.3.1 Joint Shear

Socket connections are not to be used where the principal tension stress in the joint is greater than $3.5\sqrt{f_c^{'}}$.

The minimum joint shear reinforcement should be satisfied by providing a minimum thickness of the corrugated steel pipe, t_{pipe}, determined from Equation 20.34.6.2.1-1.

20.34.6.3.2 Materials for Socket Connection

The corrugated steel pipe used to form a void in a PC bent cap or footing should satisfy the requirements stated in Section 20.34.6.2.2.

Grout used in socket connections should satisfy the requirements stated in Section 20.34.6.1.1.

20.34.6.3.3 Depth of the Socket and Embedment Length

The ends of the column should extend as close as practically possible to the top surface of the PC bent cap or the bottom surface of the footing.

The minimum depth of the socket, D_{sk}, should be:

$$D_{sk} \geq \text{ maximum of}\left(24d_{bl}, 0.79d_{bl}\frac{f_{ye}}{\sqrt{f_c^{'}}}, D_c\right) \qquad (20.34.6.3.3\text{-}1)$$

In Equation 20.34.6.3.3-1, f_{ye} and f'_c are in ksi.

20.34.7 PINNED CONNECTIONS FOR COLUMN-TO-BENT CAP OR FOUNDATION

A zero-moment or a reduced-moment connection may be used to connect a column (precast or cast-in-place) to a precast or cast-in-place concrete bent cap or foundation. These connections eliminate or reduce moment transfer and may simplify the construction where a fixed connection is not required. The column and bent cap or foundation are designed to resist the shear and axial forces transmitted through the pin.

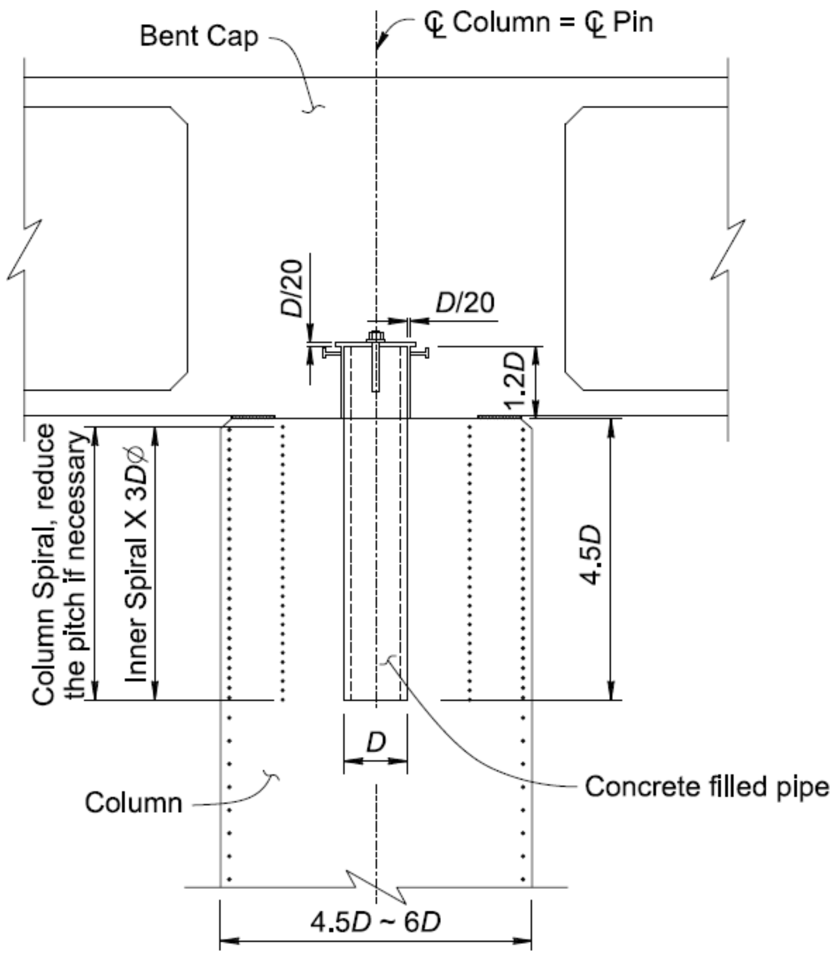
20.34.7.1 Zero-Moment Pinned Connection

A zero-moment pinned connection does not transmit moment between a column and a PC bent cap or footing. A telescopic pipe-pin for two-way hinges, illustrated in Figure 20.34.7.1-1, is one approach that satisfies the performance requirements of a zero-moment connection. The minimum height of the concrete filled pipe above the top of the column, indicated as 1.2*D*, should be 9 inches.

20.34.7.2 Reduced-Moment Pinned Connection

A pinned connection between a column and a bent cap or foundation member that provides partial moment transfer is considered a reduced-moment connection. This connection may be used between PC or cast-in-place columns and bent caps or foundations, including drilled shafts, especially where columns may be subjected to uplift due to seismic loading. A partial moment transfer may be achieved by using a pipe-pin with a central tension member, as illustrated in Figure 20.34.7.2-1. In Figure 20.34.7.2-1, the minimum height of the pipe-pin in the column and in the Type II shaft should be 12 inches.

A reduced moment connection may also be achieved by using a small diameter rebar cage.



Pipe-pin vertical dimension in bent cap $1.2D \geq 9$ inches

Figure 20.34.7.1-1 Column-to-Superstructure Zero-Moment Connection Using Telescopic Pipe-Pin, Elevation View (Zaghi and Saiidi, 2010)

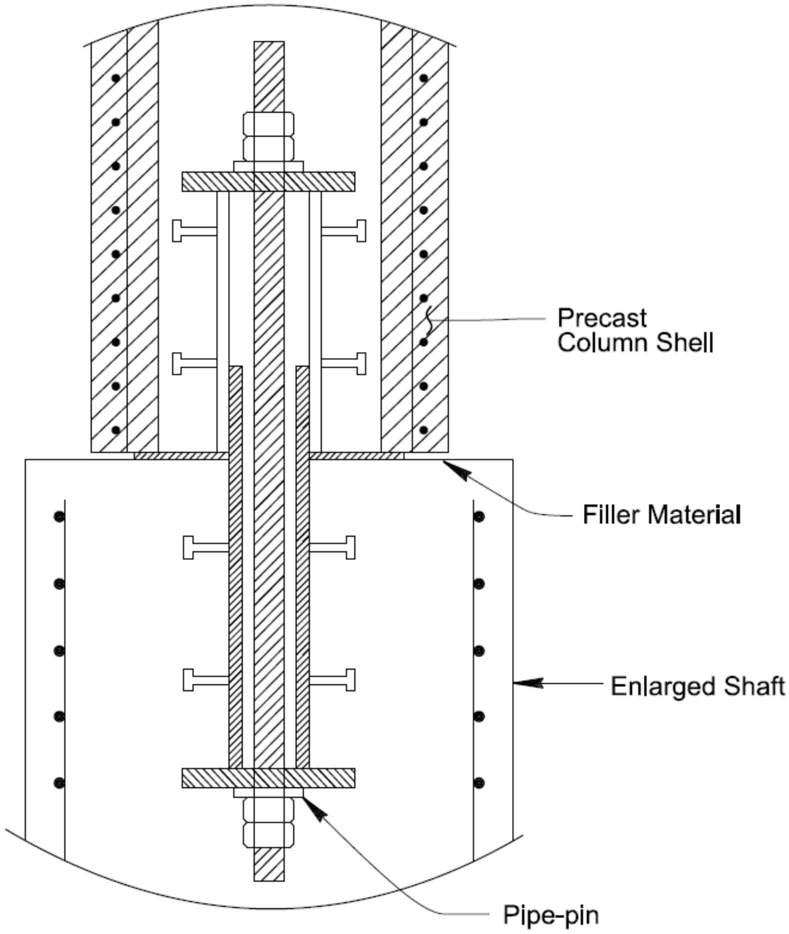


Figure 20.34.7.2-1 PC Column-to-Drilled Shaft Reduced-Moment Connection Using a Pipe-Pin, Elevation View (Mehraein and Saiidi, 2016; Mehrsoroush and Saiidi, 2014)

20.34.8 CONSTRUCTION TOLERANCES AND MOCK-UPS

Tolerances for structure member dimensions to ensure efficient production and fit-up during construction should be as recommended in the Caltrans Accelerated Bridge Construction (ABC) Manual (Caltrans, 2021). Also, mock-ups to ensure that the structural members can be assembled in the field with the appropriate properties should be as recommended in the Caltrans ABC Manual.

20.34. 9 REFERENCES

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2. Caltrans. (2021). *Caltrans Accelerated Bridge Construction Manual, Edition 1*, California Department of Transportation, Sacramento, CA.
3. Caltrans. (2019). *California Amendments to AASHTO LRFD Bridge Design Specifications, 8th Edition*, California Department of Transportation, Sacramento, CA.
4. Mehrsoroush, M., and Saiidi, M.S. (2014). Experimental and Analytical Seismic Studies of Bridge Piers with Innovative Pipe-Pin Column-Footing Connections and Precast Cap Beams. Report No. UNR/CA 14-2281, Department of Civil and Environmental Engineering, University of Nevada, Reno.
5. Mehrsoroush, M., Saiidi, M.S., and Ryan, K. (2017). Development of Earthquake-resistant Precast Pier Systems for Accelerated Bridge Construction Report No. CCEER-17-03, Department of Civil and Environmental Engineering, University of Nevada, Reno.
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9. Tazarv, M, and Saiidi, M.S. (2014). Next Generation of Bridge Columns for Accelerated Bridge Construction in High Seismic Zones. Report No. CA14-2176, Department of Civil and Environmental Engineering, University of Nevada, Reno.
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