Module 2 –
AASHTO ABC Guide
Specifications, Seismic
Design Requirements for
Connections

Lee Marsh, Ph.D., P.E
Deputy Director – America’s Technical Excellence Center

Greg Banks, P.E., S.E
Project Manager and Senior Bridge Engineer
AASHTO LRFD Guide Specifications for ABC

NCHRP
Web-Only Document 242:
Recommended AASHTO Guide Specifications for ABC Design and Construction

Michael P. Culmo
CME Associates, Inc.
East Hartford, CT

Lee Marsh
BergerABAM

John Stanton
University of Washington

Dennis Mertz

AASHTO Guide Specifications for ABC

NCHRP 12-102 Final Report provides additional commentary and background
Outline

I. Overview of AASHTO LRFD Guide Specifications for ABC - Seismic

II. Seismic Design for ABC (3.4)

III. Seismic Connection Design and Detailing (3.6.4-7 & 3.4.12)
I. Overview of *Guide Specifications for ABC- Seismic*

- Aims to ensure minimal damage of the structure under moderate earthquake and collapse prevention under rare earthquakes.

- Adopts a **Type I design strategy** exclusively (inelastic behavior under ductile limit state should occur only in the substructure).

- Written to **supplement** (not to replace) the current specifications.

- Future editions of *Guide Specifications for ABC* are expected to incorporate ongoing ABC seismic research.
II. Seismic Design for ABC (3.4)

• Force-Based Design (AASHTO LRFD, 2017)

OR

• Displacement-Based Design (AASHTO SGS, 2011)

Regardless of the seismic analysis/design method the Earthquake Resisting Systems (ERS) and Elements (ERE) shall be identified.
II. Seismic Design for ABC

<table>
<thead>
<tr>
<th>Force, $F$</th>
<th>Brittle Links</th>
<th>Ductile Link</th>
<th>Brittle Links</th>
</tr>
</thead>
</table>

- Ductile Behavior, $F_d < \text{All } F_{ib}$
- Brittle Behavior, Any $F_{ib} < F_d$

Displacement, $\Delta$
The Designer should evaluate the implications of using prefabricated elements and/or connections in or near the plastic hinge zones.
II. *Seismic Design for ABC (3.4)*

All members of the ERS must have sufficient strength and ductility to form the intended structural plastic mechanism.
II. Seismic Design for ABC (3.4)

• Ensure **continuity of load path** under load reversals.
• Ensure **development of cyclic inelastic deformations**.
• Realize that **maximum demands typically occur at connections** of prefabricated elements.
• **Limit** the occurrence of conditions leading to **rapid loss of resistance** (local buckling, stress concentrations, etc.)

DETAILING IS IMPORTANT!
II. Seismic Design for ABC

All connections and Earthquake Resisting Elements (EREs) in the GS for ABC only permitted with the Owner’s approval.
Other details are permitted provided that:

1. They are approved by the Owner,

AND

2. The designer demonstrates adequate load transfer with consideration for compatibility of deformations and constitutive relations of materials.
III. Seismic Connection Design and Detailing (3.6)

- Mechanical bar connectors (3.6.4)
- Grouted duct connections (3.6.5)
- Pocket connections (3.6.6)
- Socket connections (3.6.7)
- Two-stage integral pier cap (3.6.12)
3.6.4 Mechanical Bar Connectors

Note: No more than one connector per bar in plastic hinge zone is allowed (3.6.4.4) so this detail does not meet the GS for ABC.
3.6.4 Mechanical Bar Connectors

- Connector Types as defined in ACI 318-14

- **Type 1**: Capacity $\geq (1.25 f_y)A_b$

- **Type 2**: Capacity $\geq (f_u)A_b$

  (Limited to bars with $f_y \leq 60$ ksi)
3.6.4 Mechanical Bar Connectors

Type 1 connector: not allowed
3.6.4 Mechanical Bar Connectors

Type 2: Allowed

- For SDC A/Seismic Zone 1.
- Seismic SDC B/Zone 2 with Owner’s approval.
- Seismic SDCs C&D/Zones 3&4 w/ add’l requirements (3.6.4.4).
Type 2 Connectors in Plastic Hinge Zone for SDCs C&D Seismic Zones 3&4 (3.6.4.4)

Only grouted sleeve coupler (GC) or headed reinforcement coupler (HC) allowed.
**Type 2 Connectors in Plastic Hinge Zone for Seismic Zones 3&4 (Force-based Design)**

- Reduced modification factor $R_r$

$$R_r = \gamma R$$  \[\text{[AASHTO ABC EQ. 3.6.4.4.1-1]}\]

- 0.8 for $L_{sp} \leq 4 \, d_b$
- 0.5 for $L_{sp} > 4 \, d_b$
Type 2 Connectors in Plastic Hinge Zone for Seismic Zones 3&4 (Displacement-based Design)

• Use plastic moment capacity based on moment-curvature analysis of the column section with no mechanical connector.

• Calculate displacement capacity based on a reduced plastic hinge length, $L_{p}^{sp}$. 
Type 2 Connectors in Plastic Hinge Zone for Seismic Zones 3&4 (*Displacement-based Design*)

\[ \beta = 0.65 \text{ for GC} \]
\[ \beta = 0.75 \text{ for HC} \]

\[ L_{sp}^p = L_p - \left( 1 - \frac{H_{sp}}{L_p} \right) \beta L_{sp} \leq L_p \]

[AASHTO ABC Eq. 3.6.4.4.2-1]
Type 2 Connectors in Plastic Hinge Zone for Seismic Zones 3&4 (Displacement-based Design)

If $L > 4d_b$ AND $H_{sp} < 0.5D_c$

$$V = \frac{M_{po}}{(L - z)}$$

$V$ represents the shear force, $M_{po}$ represents the plastic moment, $L$ is the length, $z$ is the distance from the point of contraflexure, $H_{sp}$ is the height of the plastic hinge, $L_{sp}$ is the length of the plastic hinge, and $d_b$ and $D_c$ are dimensions related to the structural components.

Mechanical connectors include Grouted duct, Pocket, Socket, and Two-stage integral.
Debonding of Longitudinal Reinforcement for Mechanical Connectors in PHZ (3.6.4.5)

\[ l_{deb} \geq \max \left\{ 0.4 \, D_c, \frac{5000 \, \varepsilon_{ye} \, d_{bl}}{5000} \right\} \]

[AASHTO ABC EQ. 3.6.4.5-1]
3.6.5 GROUTED DUCT CONNECTIONS

\[ 3 \text{ to } 6d_{bl} \]

\[ \text{[EQ. 3.6.5.1-1]} \]

\[ \frac{0.67d_{bl}f_{ye}}{\sqrt{f'_{g}}} \geq f''_{g} \]

(grade 60 bars)

\( f'_{g} \) to be taken \( \leq 8.0 \text{ ksi} \)

Source: Brenes (2006)
3.6.5 GROUTED DUCT CONNECTIONS

**UHPC Grouted Duct**

- Debonding: $\geq 4d_b$
- Mechanical connectors: Grouted duct Pocket Socket Two-stage integral
- $d_b$ (#8-#11) $f_y \leq 75$ ksi
- Column: $\geq 8d_b$
- PC Pier Cap: $\geq 4d_b$
3.6.6 POCKET CONNECTIONS

A A
PC Cap Beam
CIP Fill (PC Pocket)

[EQ.3.6.6.3-1]

(grade 60 bars)

\[ \leq \frac{d_{bf'y}}{f'_{cp}} \]

\( \geq 1.5 \text{ max agg.} \)
\( \leq 4 \text{ in.} \)

Steel Pipe

ASTM A 760
(only)

Source: Restrepo et al. (2011)

SECTION A-A

Mechanical connectors
Grouted duct
Pocket
Socket
Two-stage integral
3.6.6 POCKET CONNECTIONS

Steel Pipe Thickness

Set: \( F_H = F_p \cos(\alpha) \)

Solve: [AASHTO ABC EQ. 3.6.6.4-2]

\[
 t_{pipe} = \max\left( \frac{\rho_s D'_{cp} f_{yh}}{4f_{yp} \cos \alpha} , 0.060 \text{ in} \right)
\]

\[
 \rho_s = \begin{cases} 
 0.11 \sqrt{\frac{f'_{cp}}{f_{yh}}} & \text{for SDCs B and Zone 2} \\
 \max \left( \frac{0.11 \sqrt{f'_{cp}}}{f_{yh}} , 0.40 \frac{A_{st}}{(l_{ac})^2} \right) & \text{For Zones 3 & 4} \\
 \end{cases}
\]

- Calculated min. joint shear reinf. for SDCs C & D
3.6.7 SOCKET CONNECTIONS

**Wet (cast-in-place)**

- CIP Footing
- Embedded PC Column

**Formed (precast)**

- PC Cap
- Grout or Concrete Pour
- Embedded PC Column
3.6.7 SOCKET CONNECTIONS

PC Column in Socket

\[
P \quad \text{if } L_e \leq 1.5D_c \quad \text{Roughening (0.25” )required}
\]

\[
L_e \geq D_c
\]

\[
c, K_1, K_2, \mu
\]

(concrete placed against a clean concrete surface)

\[
\mu \text{ limited to 0.5 when } L_e < 1.1 D_c
\]
3.6.7 SOCKET CONNECTIONS
PC Column in Socket

- Mechanical connectors
- Grouted duct
- Pocket
- Socket
- Two-stage integral
3.6.7 SOCKET CONNECTIONS

Socket in Shaft

Spiral/Hoops Requirement

\[
\frac{A_{sh}}{s_{max}} \geq \frac{k f_{ul} A_l}{2\pi f_{ytr} l_s}
\]

Location

- A: \(k = 0.5\)
- B: \(k = 1.0\)
- C: \(k = 2.0\)

Intentional roughening required for \(L_e \leq 1.5D_c\)

\[l_e \geq l_s + e + \text{cover}\]

[Socket in Shaft]

Mechanical Heads, if used

[AASHTO ABC EQ. 3.6.7.3.2-1]

Mechanical connectors, Grouted duct, Pocket, Socket, Two-stage integral
3.6.12 TWO-STAGE INTEGRAL PIER CAP

1) LOWER PIER CAP
2) GIRDERS ERECTED
3) UPPER-STAGE CAP CAST
3.6.12 TWO-STAGE INTEGRAL PIER CAP
Joint Proportioning for SDC C&D or Seismic Zones 3 & 4
Thank you!

wsp.com