ACIES

Asociación Colombiana de Ingeniería Estructural

Presentación Técnica

"Coupler Connections in the Proposed AASHTO Seismic Specifications for Accelerated Bridge Construction"

Dr. M. Saiid Saiidi

Distinguished Research Faculty, UCLA (University of California, Los Angeles)

Professor Emeritus, UNR (University of Nevada, Reno)

Coupler Connections in the Proposed AASHTO Seismic Specifications for ABC (NCHRP 12-105)

M. Saiid Saiidi, Distinguished Researcher, UCLA

Professor Emeritus, UNR

M. Tazarv, A. Itani, D. Sanders

T. Murphy, M. Reno, M. Pelton

NCHRP

University of Nevada, Reno

South Dakota State University

QUINCY ENGINEERING

MODJESKI and MASTERS

1


NCHRP
RESEARCH REPORT 935
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Proposed AASHTO Seismic Specifications for ABC Column Connections

Published April 2020

2

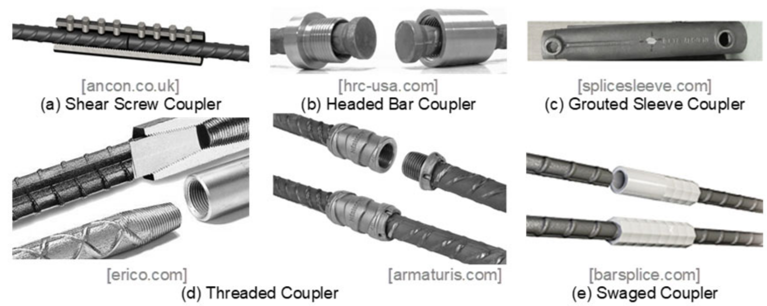
Objectives of NCHRP 12-105

- ➢ **Develop proposed AASHTO displacement-based design and construction specifications for ABC column connections in moderate and high seismic regions.**
- ➢ **Include mechanical bar couplers, grouted ducts, pocket, and socket connections.**

Include analytical and experimental studies

3

Mechanical Bar Splices (Couplers)

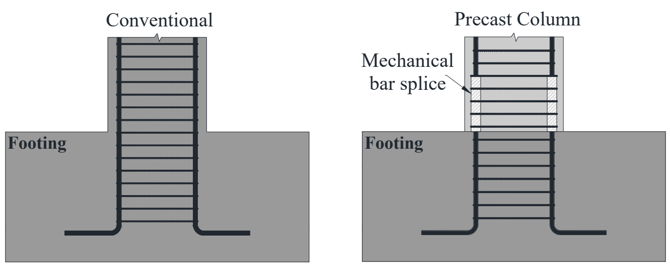


4

Mechanically-Spliced Bars in Plastic Hinges

- Similar Detailing
- Similar Design Methods
- Similar Seismic Performance

→ **Emulation**



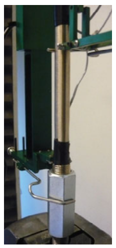
PROHIBITED **in Plastic Hinge Zones (AASHTO and Caltrans)**

5

Shake Table Test of 4-Span Bridge Model w/ Shear Screw Couplers

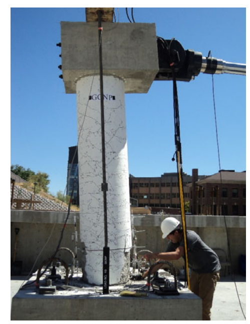
6

Shake Table Test of Column Model w/ Threaded Bar Couplers



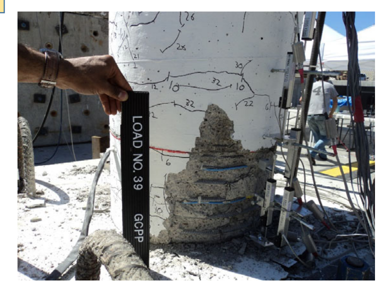
7

Cyclic Test of Column Models



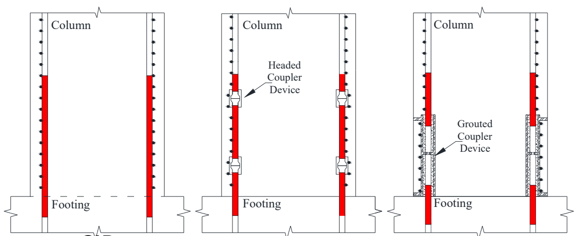
Headed Bar Coupler

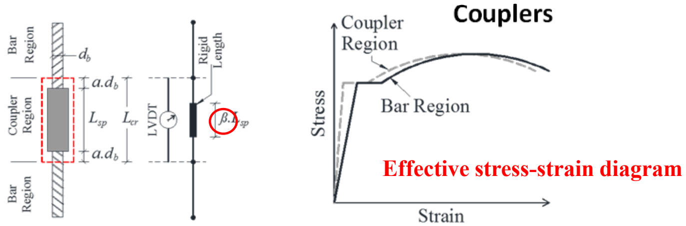
Grouted Sleeve Coupler



8

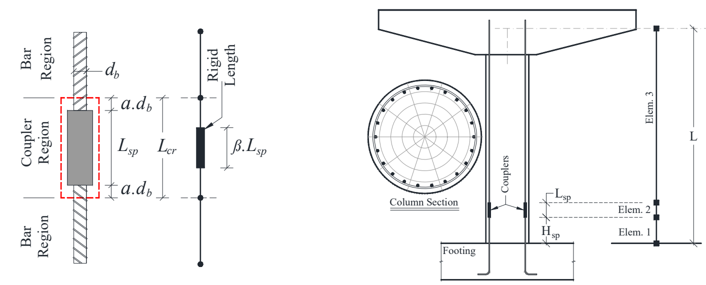
Effect of Couplers on Spread of Yielding





9

Proposed Ductility Equation



$$\frac{\mu_{sp}}{\mu_{CIP}} = (1 - 0.18\beta)\left(\frac{H_{sp}}{L_{sp}}\right)^{0.1\beta}$$

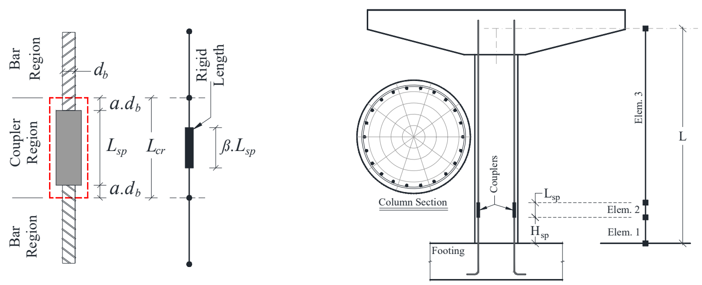
Use H_{sp} = 0.1 *in*. when coupler is at the interface

Couplers can reduce the displacement ductility by up to 40%.

10

10

Proposed Modified Plastic Hinge Length



$$L_p^{sp} = L_p - (1 - \frac{H_{sp}}{L_p})\beta L_{sp} \leq L_p$$

L_p is the AASHTO plastic hinge length:

$$L_p = 0.08L + 0.15 f_{ye} d_b \geq 0.3 f_{ye} d_b$$

11

11

Task 8.1 – Coupler Testing

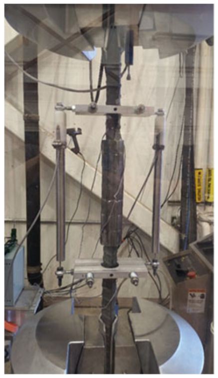
Evaluate Proposed Test Methods and Acceptance Criteria

12

Test Setup

Grouted Coupler

Headed Coupler



Swaged Coupler

For each coupler type, 10 specimens tested:
3 Monotonic, 3 Cyclic, 4 Dynamic

13

GSM1 - f_u = 97.0 ksi - ε_u = 31,363 microstrain

a) Fracture under static monotonic loading

GSC1 - f_u = 100.9 ksi - ε_u = 24,035 microstrain

b) Fracture under cyclic loading

GSD1 - f_u = 107.8 ksi - ε_u = 64,477 microstrain

c) Fracture under dynamic monotonic loading

HBM1 - f_u = 97.31 ksi - ε_u = 112,563 microstrain

a) Fracture under static monotonic loading

HBC1 - f_u = 96.22 ksi - ε_u = 69,391 microstrain

b) Fracture under cyclic loading

HBD1 - f_u = 101.1 ksi - ε_u = 120,319 microstrain

c) Fracture under dynamic monotonic loading

SWM1 - f_u = 102.0 ksi - ε_u = 54,396 microstrain

a) Fracture under static monotonic loading

SWC1 - f_u = 101.2 ksi - ε_u = 50,386 microstrain

b) Fracture under cyclic loading

SWD1 - f_u = 105.0 ksi - ε_u = 52,311 microstrain

c) Fracture under dynamic monotonic loading

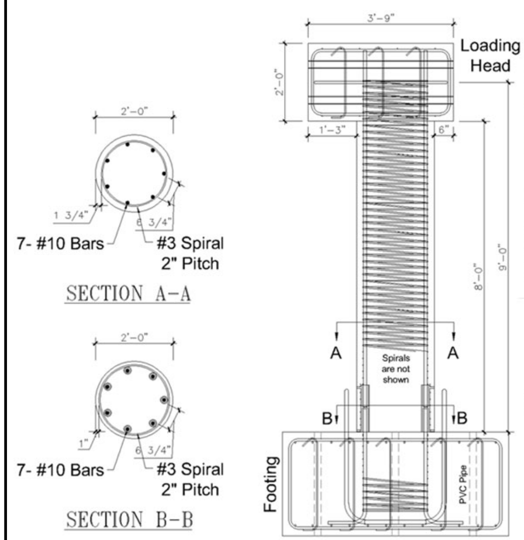
14

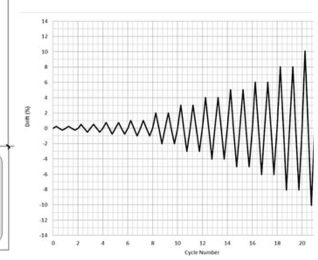
Task 8.2 – Column Tests

Half-Scale Column with Grouted Couplers at Base

15

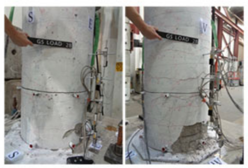
Cyclic Testing of Half-Scale Column (GC10)





16

Observed Damage of GC10



(a) South-east face (b) North-west face

4.0% drift

(a) South-east face (b) North-west face

5.0% drift

8.0% drift

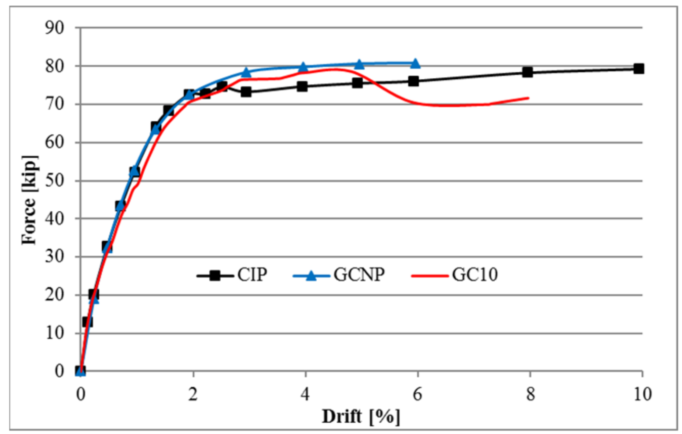
Fractured coupler as seen under 8% drift ratio (fracture occurred under 5% drift)

17

Force-Displacement Envelopes

CIP: Conventional column; No splices; No. 8

GCNP: Spliced w/ GS; No. 8 (25 mm); GC10: Spliced w/ GS; No. 10 (32 mm)



18

TASK 9

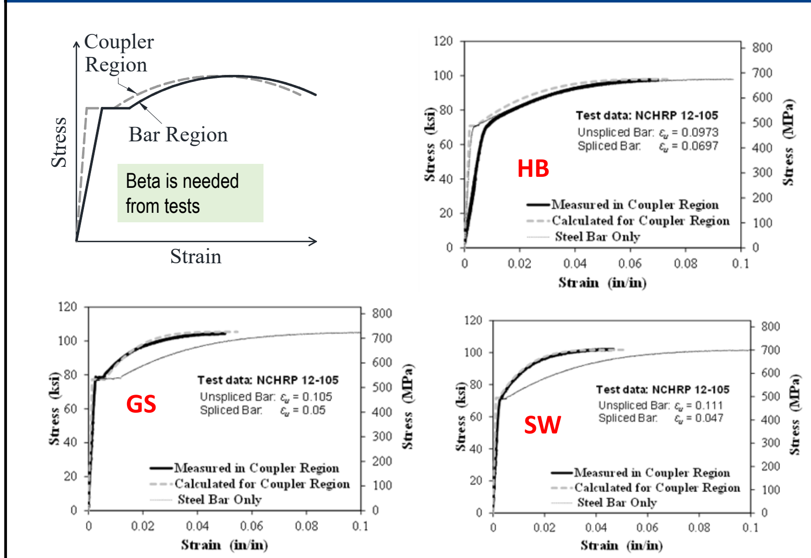
Validate the analytical program based on the test results.

OBJECTIVES:

(1) Determine feasibility of the acceptance criteria and testing methods for mechanical bar splices and refine as needed,
(2) Determine accuracy of the proposed material model for mechanical bar splices and refine as needed,
(3) Verify proposed methods for displacement-based design of mechanically spliced columns,
(4) Determine feasibility of testing methods for mechanically spliced columns and refine as needed, and

19

Comparison w/ Data



20

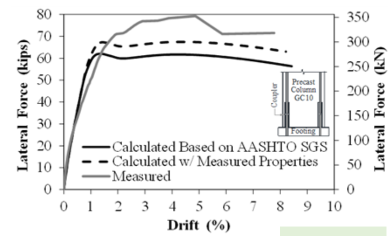
Verify methods for displacement-based design of mechanically spliced columns

Design Method	Analysis Type	Column Element in Pushover Analysis	Analysis Requirements
Cast-in-place (CIP) columns	Moment-Curvature or Pushover	Usually conducted using a lumped plasticity model, which requires an analytical plastic hinge length. However, distributed plasticity model can also be utilized	AASHTO Guide Specifications for LRFD Seismic Bridge Design
Method 1. Spliced columns using proposed displacement ductility equation	Use CIP analysis results	Use CIP analysis results	$\frac{\mu_{sp}}{\mu_{CIP}} = (1-0.18\beta)(\frac{H_{sp}}{L_{sp}})^{0.1\beta}$
Method 2. Spliced columns using proposed plastic hinge length equation	Moment-Curvature or Pushover	Lumped plasticity model only	Similar to CIP but with $L_p^{sp} = L_p - (1-\frac{H_{sp}}{L_p})\beta L_{sp} \le L_p$
Method 3. Spliced columns using proposed stress-strain model for couplers	Pushover only	Distributed plasticity model only	Coupler stress-strain model (Table T9.3-1)

21

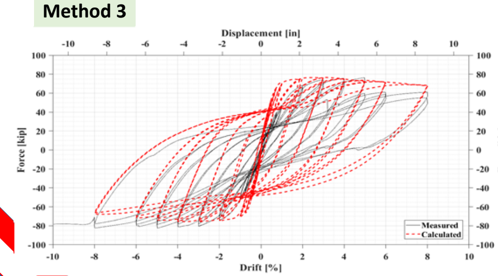
Comparison w/ Test Data

- Method 1--- Difference 2% or less
- Method 2 --- Difference 8% or less
- Method 3:



Method 2

Method 3



22

TASK 13

Update proposed specifications after consideration of review comments and prepare ballot items for AASHTO Highway Subcommittee on Bridges and Structures consideration.

23

Task 13.1 – Proposed Guidelines

Seismic Design of Columns with ABC Connections

24

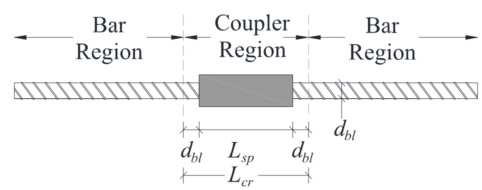
Guidelines as Appendix to SGS
(Seismic Guide Specifications)

- Additional requirements for seismic connections using ABC details
- Does not supplant the requirements of the Seismic Guide Specifications – adds to them
- Three main sets of provisions
  - Bar couplers
  - Grouted duct connections
  - Pocket/socket connection details

Coupler Provisions

- Section C3 of the Appendix
- Coupler length definition:

$$L_{cr} = L_{sp} + 2d_{bl}$$



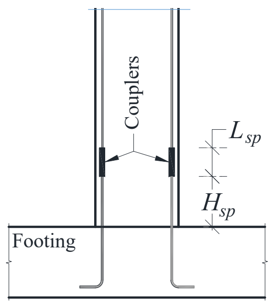
- Ductility modification:

$$\alpha_{sp} = (1 - 0.18\beta)\left(\frac{H_{sp}}{L_{sp}}\right)^{0.1\beta}$$

Plastic Hinge Length

- Presence of couplers accounted for by using altered plastic hinge length with existing strain limits

$$L_p^{sp} = L_p - \left(1 - \frac{H_{sp}}{L_p}\right)\beta L_{sp} \le L_p$$



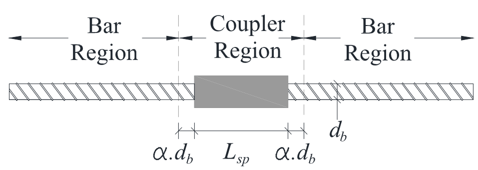
- Strain adjustment for section analysis:

$$\frac{\varepsilon_{sp}}{\varepsilon_s} = \frac{L_{cr} - \beta L_{sp}}{L_{cr}}$$

27

Proposed Qualification Requirements for Seismic Couplers

- Mechanical Properties of Spliced A615 and A706 Grade 60 bars used in plastic hinge regions
- Monotonic, Cyclic, and Dynamic testing procedures
- Seismic Splices: Couplers that are not longer than $15d_b$ and exhibit bar fracture outside the coupler region with a strength that is at least 95% of the tensile strength of a corresponding "un-spliced specimen"



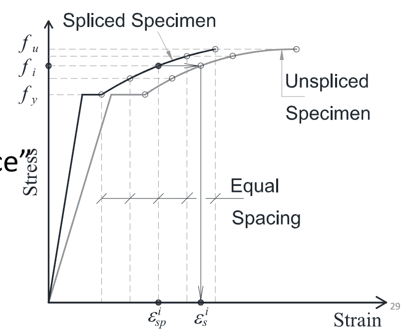
28

Monotonic Test

- Test Unspliced and Spliced Specimens
- Obtain full stress-strain curve for both types of specimens
- Curves are superimposed and a coupler rigid length ratio, β, is found:

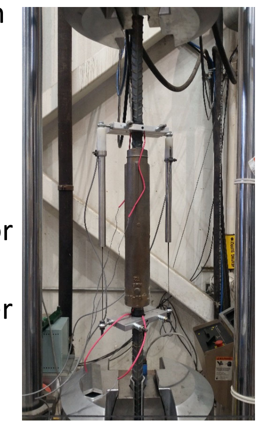
$$0.5 \leq \beta \leq 1.0$$

- Report mode of failure and if basic "seismic splice" requirements are met



Cyclic Test

- Cyclically load the spliced specimen at 10%, 30%, 50%, 70%, 80%, 90%, and 100% of the ultimate tensile strength (f_u) of the spliced bar. Repeat each cycle of loading four times.
- Report cyclic stress-strain graphs for the spliced specimens.
- Report mode of failure and whether the coupler meets basic "seismic splice" requirements.



Dynamic Test

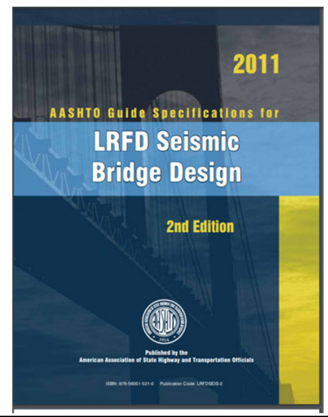
- Minimum 4 samples per lot
- Load the spliced specimen with a strain rate of 30,000 micro-strain/sec (3.0%/sec) to fracture.
- Report stress-strain graphs for the spliced specimens.
- Report mode of failure and whether the coupler meets basic “seismic splice” requirements.

31

31

Proposed ABC Seismic Specification

Add as Appendix C to AASHTO Seismic Guide Specifications



32

Two-Column Format

Specifications   Commentary

C3.0—MECHANICALLY SPLICED CONNECTIONS IN PLASTIC HINGE ZONES

C3.1—GENERAL

For some types of ABC connections, in particular those with mechanically spliced reinforcement in the plastic hinge region, there is a reduction in deformation capacity that must be accounted for. For bridge columns, this usually results in a decrease in displacement capacity when these connection types are used; however, when properly designed and constructed, seismic performance of columns with these connections will be satisfactorily.

C3.2—SPLICED REINFORCEMENT BAR

The length of the coupler region of a mechanically spliced connection shall be defined as:

$$L_{cr} = L_{sp} + 2d_{bl} \qquad \text{(C3.2-1)}$$

where:

L_{sp} = physical length of mechanical coupler (in.)

d_{bl} = diameter of the larger bar being spliced (in.)

Only couplers which have demonstrated through testing to consistently fail outside of the coupler region shall be used in plastic hinge zones of columns in SDC's C and D.

The length of the coupler, L_{sp}, shall not exceed 15 times the diameter of the smaller bar spliced.

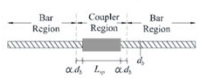


Figure C3.2-1—Coupler Region Definition

CC3.2

The limitation on the length of the coupler is needed to minimize adverse effects on the rotation capacity of the member due to a reduction in plastic hinge length, as well as the fact that test data for longer couplers is not available.

33

34

Sample Page

C3.0—MECHANICALLY SPLICED CONNECTIONS IN PLASTIC HINGE ZONES

C3.1—GENERAL

For some types of ABC connections, in particular those with mechanically spliced reinforcement in the plastic hinge region, there is a reduction in deformation capacity that must be accounted for. For bridge columns, this usually results in a decrease in displacement capacity when these connection types are used; however, when properly designed and constructed, seismic performance of columns with these connections will be satisfactorily.

C3.2—SPLICED REINFORCEMENT BAR

The length of the coupler region of a mechanically spliced connection shall be defined as:

$$L_{cr} = L_{sp} + 2d_{bl} \qquad \text{(C3.2-1)}$$

where:

L_{sp} = physical length of mechanical coupler (in.)

d_{bl} = diameter of the larger bar being spliced (in.)

Only couplers which have demonstrated through testing to consistently fail outside of the coupler region shall be used in plastic hinge zones of columns in SDC's C and D.

The length of the coupler, L_{sp}, shall not exceed 15 times the diameter of the smaller bar spliced.

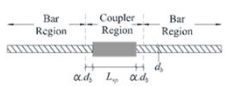


Figure C3.2-1—Coupler Region Definition

CC3.2

The limitation on the length of the coupler is needed to minimize adverse effects on the rotation capacity of the member due to a reduction in plastic hinge length, as well as the fact that test data for longer couplers is not available.

35

Task 13.3 – Examples

Column Design w/ Seismic ABC Connections

36

Purpose (paraphrased)

- C1.1—PURPOSE

- ABC methods and technology provides owners with a less invasive method of constructing bridges by minimizing the impact to users. …The connection details utilized in **ABC construction introduce uncertainty about sustaining inelastic seismic deformations**.
- The **purpose** of this appendix is to provide guidance to implement ABC connections in seismic regions to achieve **similar seismic performance as cast-in-place construction.**

37

Applicability

C1.2—APPLICABILITY

This appendix applies to precast columns utilizing mechanically spliced reinforcing steel in the plastic hinge regions, as well as those using pocket and grouted duct connections.

38

Applicability

C1.2—APPLICABILITY

This appendix applies to precast columns utilizing mechanically spliced reinforcing steel in the plastic hinge regions, as well as those using pocket and grouted duct connections.

39

Reduced Plastic Hinge Length

From Seismic Guide Specs

C3.4—ANALYTICAL PLASTIC HINGE LENGTH

The plastic hinge length, L_p, given in Article 4.11.6, shall be replaced with the spliced hinge length, L_p^{sp}, when using mechanically coupled bars in the plastic hinge region. The plastic hinge length for spliced bars shall be taken as:

$$L_p^{sp} = L_p - \left(1 - \frac{H_{sp}}{L_p}\right)\beta L_{sp} \leq L_p \qquad \text{(C3.4-1)}$$

where:

L_p = plastic hinge length for unspliced bars, given in Article 4.11.6 (in.)

L_{sp} = physical length of mechanical coupler (in)

40

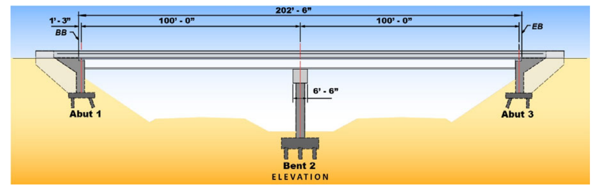
Design Examples

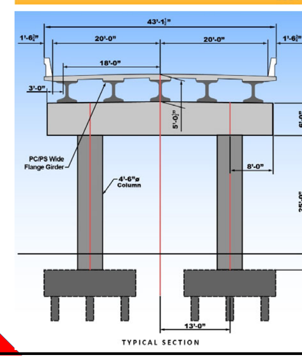
Table T11.4-1 NCHRP 12-105 Design Examples

Example No.	Column Connection Type: Top	Column Connection Type: Bottom	Design Method
1	Standard moment connection	Standard moment connection	Benchmark conventional bridge designed per AASHTO SGS
2	Grouted sleeve embedded in cap beam	Grouted sleeve embedded in columns	Designed based on specs developed in NCHRP 12-105
3	Swaged couplers embedded in columns	Swaged couplers embedded in columns	Designed based on specs developed in NCHRP 12-105
4	Grouted ducts in cap beam	Headed bar couplers; two on each longitudinal bar	Designed based on specs developed in NCHRP 12-105
5	Pocket	Pocket	Designed based on specs developed in NCHRP 12-105

41

Example 1
Conventional Construction





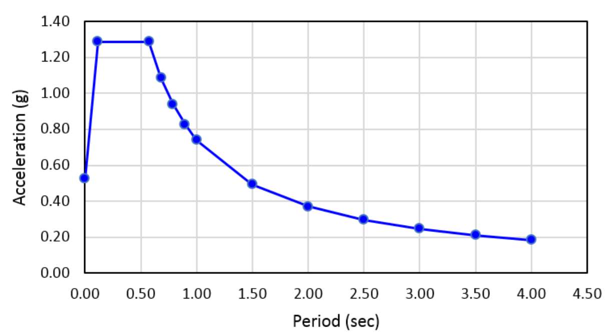
- Continuous PC/PS Girders
- Simply supported at Bent
- Columns fixed at base

42

Example 1
Design Earthquake

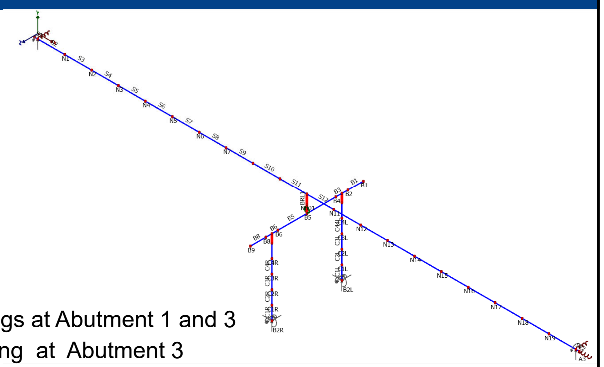
Site Class = D		
PGA = 0.526g	F_{PGA} = 1.00	A_S = 0.526g
S_S = 1.288g	F_A = 1.00	S_{DS} = 1.288g
S_1 = 0.490g	F_V = 1.510	S_{D1} = 0.740g

Design Response Spectrum



43

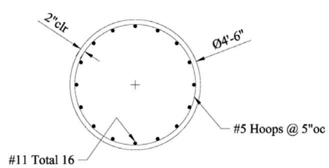
Example 1
Finite Element Model

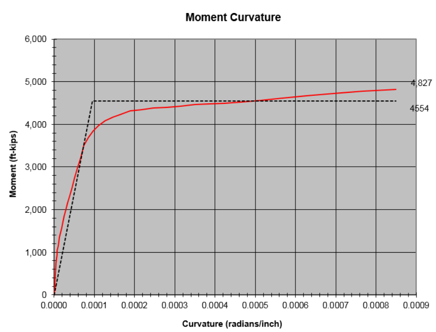


Transverse Springs at Abutment 1 and 3
Longitudinal Spring at Abutment 3 representing abutment passive pressure
Response Spectrum Analysis Applied in Longitudinal and Transverse Direction
Obtain Displacement Demands

44

Example 1
Moment Curvature Analysis

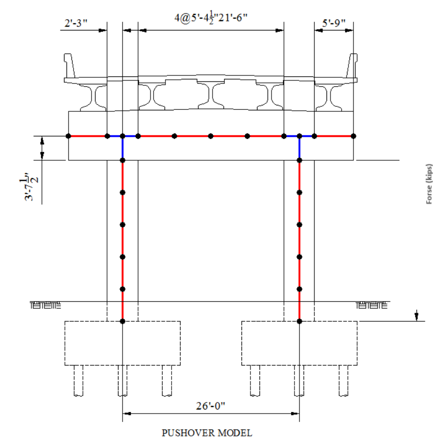


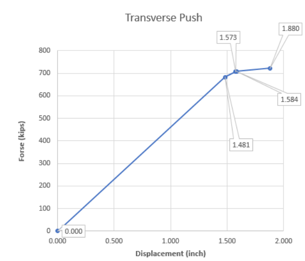


Basis of displacement capacity

45

Example 1
Pushover Analysis

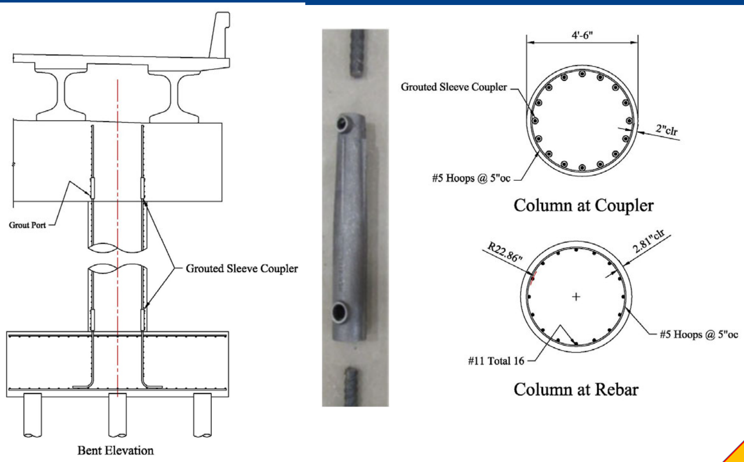




Use pushover model to determine yielding of plastic hinges in columns and for column shear

46

Example 2
Column w/ Grouted Sleeve Couplers



47

Plastic Hinge Length- Grouted Sleeve Couplers

Appendix C, Section C3.3

$$L_p^{sp} = L_p - \left(1 - \frac{H_{sp}}{L_p}\right)\beta L_{sp} \leq L_p \qquad \text{(C3.4-1)}$$

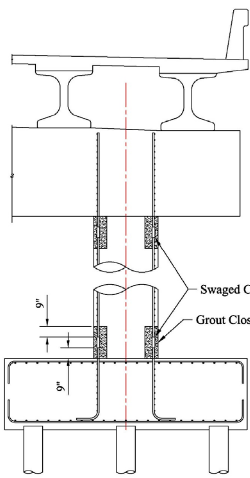
When using splices within connecting elements such as footings or cap beams, the column plastic hinge length adjacent to the connection shall be taken as 0.75 L_p but no less than L_p^{sp}.

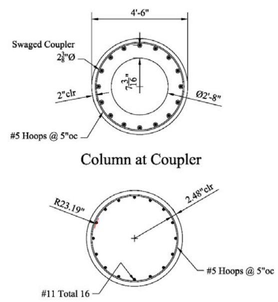
Column Displacement Capacity Analysis is similar to that used for conventional construction except that the plastic hinge length is adjusted as noted.

- The plastic hinge length is calculated per C3.4-1 at the bottom of the column
- The plastic hinge length of $0.75L_p$ is used at the top of the column

48

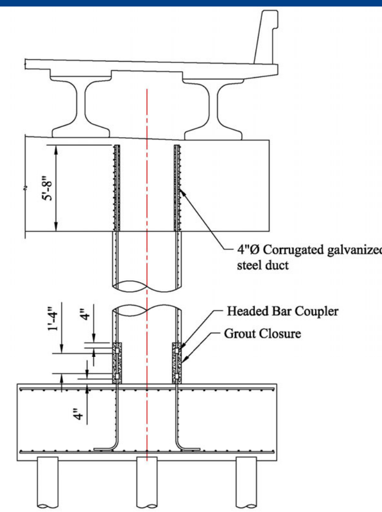
Example 3
Swaged Couplers





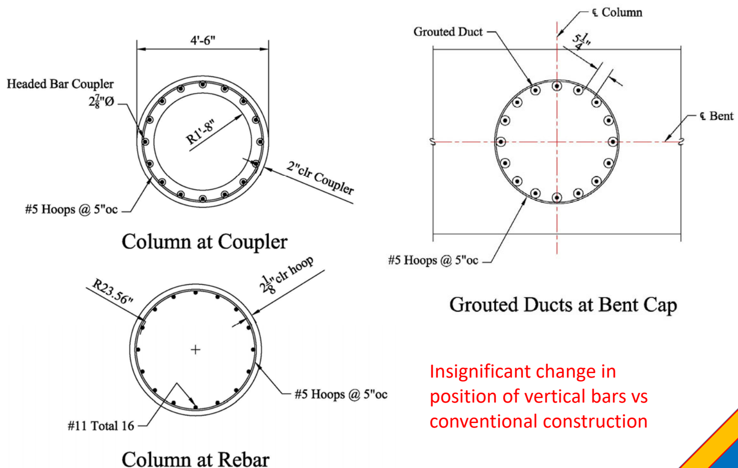
49

Example 4
Headed Bar Couplers/Grouted Duct



50

Example 4
Headed Bar Couplers/Grouted Duct



Insignificant change in position of vertical bars vs conventional construction

51

Message

- Much information has become recently available on the seismic performance of couplers that was reviewed, analyzed, and formed the basis of the proposed specifications.
- It is no longer necessary to prohibit the use of couplers in plastic hinges.
- Use the proposed specifications, realizing that the ductility capacity of columns with spliced bars can be lower than that of conventional construction.
- The proposed specifications provide proven methods and formulas to account for the reduced ductility capacity of columns with couplers.

52