Precast Substructures
Comparison of Non-seismic and Seismic Connection Details

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Webinar
Outline

• “Non-seismic” vs “Seismic” definition

• Define Seismic Design Philosophy

• Explore the requirements for the lowest seismic design zone or category – with potential changes (SDC A and Zone 1)

• Examples of some connection types
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AASHTO Seismic Design “Response Spectrum”

Structure Vibration Period (seconds)

Structure “Spectral” Acceleration, $S_a$

$S_{DS} = S_s F_a$, Short-period Spectral Acceleration Coefficient

$S_{D1} = S_1 F_v$, One-second Spectral Acceleration Coefficient

Partitioning Parameter
For Seismic Zone or Category

As = PGA*F_{PGA}

Site-Adjusted Ground Acceleration Coefficient
## AASHTO Seismic Design Partitioning

<table>
<thead>
<tr>
<th>Acceleration Coefficient, $S_{D1}$</th>
<th>LRFD Specification, Seismic Zones</th>
<th>Seismic Guide Specification, Seismic Design Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{D1} &lt; 0.15$</td>
<td>1</td>
<td>A</td>
</tr>
<tr>
<td>$0.15 &lt; S_{D1} &lt; 0.30$</td>
<td>2</td>
<td>B</td>
</tr>
<tr>
<td>$0.30 &lt; S_{D1} &lt; 0.50$</td>
<td>3</td>
<td>C</td>
</tr>
<tr>
<td>$0.50 &lt; S_{D1}$</td>
<td>4</td>
<td>D</td>
</tr>
</tbody>
</table>
“Seismic” States – SDC B, C or D

Seismic Design Categories for Site Class E

34 states with SDC B/Zone 2 or Higher
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Chain Analogy - Capacity Design

Force, $F$

Brittle Links  Ductile Link  Brittle Links

Fib

Displacement, $\Delta$

Force

$F_d$  Ductile Behavior, Provided $F_d < \text{All } Fib$

Weakest $F_{ib}$

Brittle Behavior, If Any One $F_{ib} < F_d$

Adapted from Paulay and Priestley (1992)
Chain Analogy - Capacity Design

Weakest $F_{ib}$

Ductile Behavior, Provided $F_d < \text{All } F_{ib}$

Brittle Behavior, If Any One $F_{ib} < F_d$

Force, $F$

Brittle Links  Ductile Link  Brittle Links

Displacement, $\Delta$
Example Connection Locations in a Bridge

Note: In this Example:
Moment Continuity at Top and Bottom of Pier

CP Connections
ED Connections
Connection Interfaces
Plastic Hinge Zone

ED – Energy Dissipating (Ductile)
CP – Capacity Protected (Non-ductile)
Integral Piers – Continuity at Top

Two-Stage CIP Cap Beam with Precast Prestressed Girder Superstructure

Girders are made continuous over bents for live and lateral loads.

WSDOT
Damage from Cyclic Inelastic Loading

- Spalling Condition at 3.7% Drift
- Spalling Onset at 2.2% Drift
- Bar Buckling & Spiral Fracture at 5.6% Drift

Caltrans SDC A
Reduced-Scale ABC Column Tests

Columns After Testing
Design Successful For High Seismic Regions!
Definition of Connection

Development or Force Transfer Lengths Either Side of Interface

Connection Interface

Energy Dissipating or Deformation Accommodation Zone (Every other Location is a Capacity Protected Zone)
A Few Words on Continuity of Strength

• In high seismic areas inelastic ductility is required; thus clearly all members must have sufficient strength to form the intended plastic mechanism.
Where are the connections?

With ABC - Often Challenging to Keep the ED Connections Away from Connection Locations
What’s Special About Seismic Applications?

1. Continuity of load path under load reversals
2. Development of cyclic inelastic deformations
3. Maximum forces (moments) occur where we would like to connect prefabricated elements
4. Certain element/material behaviors may cause rapid loss of cyclic resistance
   – Local Buckling
   – Strain Concentrations
5. Detailing is important!
Displacement-Based Method - SGS

- Only Minimum Required Force, But No Unique Force Required
- Displacement Capacity Is Directly Checked, Based on Actual Provided Detailing. (Confinement)
- Elastic Response
- Plastic Hinge
- Yielding System
- Capacity
- Ensured

Fyclic Behavior

F_{Elastic}

F_{Yield}

F_{non-Seaismic}

Elastic
Example Pier Plastic Mechanisms

With Knowledge of System Lateral Behavior, Designer Can Control Locations of Plastic Hinges (and thus Damage)
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- Examples of connection types
Connection Forces and Support Lengths – SDC A

**Low A**
As to 0.05g
- Connection Force 0.15 of Permanent Weight
- Support Length 75% of Empirical Minimum, N

**High A**
As ≥ 0.05g
- Connection Force 0.25 of Permanent Weight
- Support Length 100% of Empirical Minimum, N

**SDC B**
- Forces by Demand Analysis
- Support Length 150% of Empirical Minimum, N
Site Adjusted Ground Acceleration, $A_s < 0.05g$  
$F_{Design} = 0.15 R_{PL}$

$A_s \geq 0.05g$  
$F_{Design} = 0.25 R_{PL}$

Restrained Superstructure/Substructure Connections

§ 3.10.9.2 LRFD / § 4.6 SGS
Minimum Detailing of Transverse Steel – SDC A

Low A
SD1 to 0.10g
• No Specific Requirements

High A
0.10g ≥ SD1 < 0.15g
• Use Same Minimum Transverse Steel as SDC B

SDC B
SD1 ≥ 0.15g
• Prescriptive Minimum Transverse Steel (Note LRFD and SGS Are Different – Full vs Limited Ductility)
A Few Words on Continuity of Strength

• In high seismic areas inelastic ductility is required; thus clearly all members must have sufficient strength to form the intended plastic mechanism.

• In low seismic (non-seismic) areas, continuity of strength is still required, just not the ductility (or deformation capacity).

• In low-seismic areas, there still needs to be lateral capacity commensurate with the minimum member strength requirements (e.g. 0.7 or 1 % minimum steel, etc)
Current Provisions LRFD & SGS

• LRFD Specification and Seismic Guide Specification (SGS) essentially the same

• “The horizontal design connection force shall be addressed from the point of application through the substructure and into the foundation elements”

• Added in 2010, and on the surface reasonable
Commentary Chapter 1 – Introduction

DESIGN PHILOSOPHY

“For bridges classified as SPC A, prevention of superstructure collapse is all that was deemed necessary for their level of seismic exposure. The requirements for these bridges is minimal and specify the support lengths for girders at abutments, columns and expansion joints, and that the design of connections of the superstructure to the substructure be for 0.20 times the dead load reaction forces”

ATC 6 (1981)
• There are ballot items to restore the original intent of the connection force requirement.

• Will be voted on in June.

• Clarification of the minimum intent will be provided. **Will not have to chase the minimum connection force into foundation.**

• Stay tuned!
• At a **sufficiently low seismic hazard** (ground acceleration, earlier / now spectral acceleration) structure has an **inherent ability to tolerate some minimal inelastic action**

• Provided connection force is adequate (thereby preventing unseating) **structure will survive consistent with acceptable performance** (i.e. some damage)
Thoughts on Detailing and Continuity

- High seismic areas inelastic ductility is required

- In “high SDC A” ($S_{D1} > 0.10$) minimum transverse steel reqd

- In SDC A, avoid unintentional weak links in lateral system, but explicit ductility capacity not required

MassDOT
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Precast Bent System for High Seismic Regions

- Member socket connection at base (ED)
- Few, but large, bars at precast cap connection (ED)
- Two-stage cap
- Upper stage CIP
- Girders integral with combined lower and upper stages of cap (CP)
Member Socket ED Connection

Precast Column with Cast-in-Place Footing
Summary

• Low seismic (SDC A) – Split into two categories

• Low seismic (SDC A) – Design pier connections for adjacent member forces. System does not need to be fully ductile. Also meet support length and limited detailing requirements

• High seismic (SDC B, C, D) – Design entire system to meet capacity design principles and to have inherent ductility capacity
TRB Committee on General Structures (AFF10)
Subcommittee on Accelerated Bridge Construction (AFF10-3)

Approximately one-fourth of the Nation's 600,000 bridges require rehabilitation, repair, or total replacement. The construction-related work used to address these needs can have significant impact to the surrounding area including mobility, safety, and other social-economic related impacts. Throughout the U.S., owner agencies are realizing that the results of using ABC strategies not only help address onsite related constraints, but can also improve how a bridge program is delivered when used in a more routine, programmatic manner.

Scope: The TRB Accelerated Bridge Construction (ABC) Subcommittee supports research, technology transfer, and implementation to advance ABC technologies related to policy, planning, procurement, design, materials, construction and contracting. The objective of the subcommittee is to expand the knowledge and expertise to foster the implementation of ABC related technologies.
Helpful Resources cont...

Research Tracking Spreadsheet

The National ABC Research project tracker provides an overview of approximately 80 ABC related research projects occurring throughout the U.S. It includes hyperlinks to completed deliverables, the status of on-going projects, and a list of ABC related Research Needs Statements (RNS) that are pending sponsorship.

Yellow highlighted projects are fairly new, red highlighted projects are pending additional information.

It is recommended that Users download the spreadsheet by selecting the following link: Project Tracker

https://sites.google.com/site/trbaff103/home
Example Resources – NCHRP
Precast Bridge Elements and Systems (PBES)

ABC – PBES is now widely deployed in lower seismic regions

A challenge for ABC is development of PBES for higher seismic regions
Example Resources – FHWA Highways for LIFE Project

• Full Descriptions of the Seismic ABC Challenge
• Main Report
• Appendices
  A. Design Specifications
  B. Design Example No. 1
  C. Design Example No. 2
• Testing Reports – Spread Footings, Drilled Shafts

http://www.fhwa.dot.gov/hfl/
Questions

Thank you!

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