Development of Earthquake-Resistant Precast Pier Systems for Accelerated Bridge Construction in Nevada

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Summary:

Accelerated bridge construction (ABC) technique uses innovation, new techniques, and materials in a safe and cost effective manner to accelerate the bridge construction. Use of prefabricated structural elements is an integral part of many ABC efforts. What matters most in ABC is how to connect the prefabricated elements to the rest of the structure to behave satisfactory under the service loads and extreme events like earthquake.

This study focuses on the seismic performance of two types on novel connections to be utilized in earthquake-resistant precast pier systems for ABC in Nevada: (1) pocket details for moment and pin connections and (2) one-piece pipe pin connections.

Pocket connections are constructed by making a pocket in the footing or cap beam. The connection is formed either by extending a precast column into the pocket and grouting the gap between the column and the pocket (which is called EPC-PC), or by extending the longitudinal bars of a precast column into the pocket and filling the pocket with concrete (which is called ELB-PC). These types of connections are indented to behave as a monolithic connection in hinging the columns outside the connection region. The pockets are formed using corrugated metal pipes (CMPs) to enhance the shear transfer between the pipe and adjoining member. The focus of this study is on EPC-PC.

Pipe pin connections were first developed by Caltrans engineers to eliminate moment transfer between the column and superstructure, and hence reduce the moment and shear demands in adjoining members. These connections are composed of a steel pipe embedded in the column and a can embedded in the cap beam. The shear force is transferred between the two components through pipe-can contact and friction force at the interface while no moment is transferred between the two components. Rebar hinges are the most commonly used type of the bridge column hinges in the U.S. Previous earthquakes revealed that this connection type suffers severe damage due to shear failure and sliding. As an alternative for rebar hinges, a new generation of pipe pin connections, called one piece pipe pin was proposed and developed in this study to improve the seismic performance of hinges. This connection is constructed using an grout-field steel pipe embedded at both ends in the column and adjoining member (either cap beam or footing). A hinge gap is provided at interface to improve the rotational capacity of the connection. The tensile forces are transferred between the elements using welded studs on the surface of the pipe and the compressive force are transferred through bearing of the pipe top and bottom ends and welded studs.

This study is aimed at investigating (1) the seismic performance, response, and behavior of pocket connections, one-piece pipe pin connections, and rebar hinge connections to be utilized in precast construction (2) to compare the overall performance and response of one-piece pipe pin connections with those of the rebar hinges, and (3) the seismic behavior of a precast two-column bent utilizing one-piece pipe pins and rebar hinges combined with pocket details at the top joints and moment pocket connections at the base. To meet these objectives, shake table test of a one-third scale precast two-column bent model constructed using precast elements and connections is going to be conducted at the University of Nevada, Reno Earthquake Engineering Laboratory until failure.

The two-column bent is of four elements: two precast columns, one precast strip footing, and a precast cap beam. Columns are connected to the footing using EPC-PC with embedment length of 1.2 times the column diameter to simulate monolithic moment connections at the base. The connectivity at the column-cap beam joints is provided using the rebar hinge and one-piece
pipe pin connections, which are combined with pocket details to provide the feasibility for use in precast fabrication.

The cab beam, footing, and the top and bottom pocket connections were designed to satisfy the code (AASHTO 2014) requirements for capacity protected members. These elements are intended to remain essentially elastic during the seismic event. The column dimensions and span were determined so that the ultimate base shear and overturning moment demand of the bent remain within the limits of the shake table. The rebar hinge connection was detailed based on the design guidelines proposed by Cheng and Saiidi (2010). The one-piece connection was designed to replicate the flexural capacity of the rebar hinge. To enhance the shear capacity of the pipe, it was filled with high-strength grout. The shear capacity and required embedment length of the pipe in the column and cap beam pocket was determined based on the design guideline proposed by Zaghi and Saiidi (2010) for top pipe pin connections.

The 142-degree lateral component of Sylmar convertor station ground motion record obtained during the 1994 Northridge, California earthquake was selected as the input ground motion of shake table. Results of the analytical studies showed that the selected ground motion results in a relatively symmetric response of the bent and is strong enough to induce failure. The bent is subjected to increasing amplitudes of the ground motion to capture the response, behavior, and performance of the bent under low-to-high amplitude seismic excitations. Moreover, the time axis of the ground motion record is compressed by a factor of $\sqrt{1/3}$ to account for the scaling factor. To determine the natural frequency and damping ratio of the bent, response of the bent to a random white noises is measured prior to each run.

Results of the preliminary pushover analyses, input ground motion record and loading protocol, results of the preliminary dynamic analysis, drawings of the test model, components, and reinforcement details, and instrumentation layouts are presented in this document.

References:


Results of Pushover Analyses:

Push Loading:

Shear Force Variation

Axial Force Variation
Pull Loading:

Shear Force Variation

Axial Force Variation
Input Ground Motion Record and Loading Protocol:

Input Acceleration History

Reponse vs. Design Spectrum

Design Spectrum:
Location: Reno downtown
Coordinates:
  Latitude: 39.530895
  Longitude: -119.814972
PGA: 0.473g
$V_{S30} = 364$ m/sec
$V_{S100} = 488$ m/sec
Site Class: C
<table>
<thead>
<tr>
<th>Run No.</th>
<th>Loading Protocol</th>
<th>Dynamic Analysis Results</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
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<td>Scale Factor</td>
<td>PGA (g)</td>
<td>D_{\text{max}} (in.)</td>
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<tr>
<td>WN1</td>
<td>R1</td>
<td>0.1 0.0923</td>
<td>17.2</td>
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<tr>
<td></td>
<td>R2</td>
<td>0.2 0.185</td>
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<tr>
<td></td>
<td>R3</td>
<td>0.4 0.369</td>
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<tr>
<td>WN4</td>
<td>R4</td>
<td>0.6 0.554</td>
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<td></td>
<td>R5</td>
<td>0.8 0.738</td>
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<td>R6</td>
<td>1.0 0.923</td>
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<tr>
<td>WN7</td>
<td>R7</td>
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</tbody>
</table>

Note: D_{max}=maximum absolute displacement at each run; %DE: fraction of design motion; V|D_{max}=base shear corresponding to absolute maximum displacement at each run; WN: white noise.
Results of Dynamic Analysis:

Spliced Base Acceleration History

Spliced Displacement History

Spliced Base Shear History
Two-column Bent Drawings
Corrugated Metal Pipe
2\(\frac{2}{3}\)"x0.5" [68x13]-16 Gauge
I.D.=18" [457 ]

High-Strength
Grout

Precast
Column

#3 [Ø=10] Spiral
(C-3)

RC
Footing

1.44
[425]

1.0
[25]

3.125
[83]

4.0
[100]
#3 Cross Tie (F-11)

#5 Hooked Bar (F-4)

#3 [Ø=10] Spiral (C-3)

#5 Continuous Bar (F-1)

#5 Hooked Bar (F-3)

#5 Hooked Bar (F-5)

#5 Hooked Bar (F-8)

#5 Crisscross Bar

Top Reinforcements

Swift Lift Anchor 8 Ton, 1-3/32''x10'' [28x254]

Project: Precast Two-column Bent Shake Table Test

Title: Footing Details - 1

Designed and Drawn by: A. Mehrsprouse

App. by: M. Saidi Saidi, Prof.

University of Nevada, Reno

Nevada Department of Transportation

Scale: 1:20

Sheet No.: S-08

Date: Nov. 17, 2015
W12x87 Transverse Beam
20 Split-lock Washer
W8x67 Longitudinal Beam
20 Nut
Grade 8-3/4 [20]-10
L=10" [254]
20.2"x2" [25x25] Square Washer
1/4 [6]-thick Hydrostone Pad

Precast Cap Beam

Hydrostone Pad

Precast Cap Beam

Stiffener Plate

2'-3" [686]

[62/3]
[163]

2'-3" [686]

[4-1/2]
[166]

2'-3" [686]

[62/3]
[163]

2'-3" [686]

3/4" [89]

2'-9" [838]

[711]
Instrumentation Layouts
Longitudinal Bars