A PRECAST, PRETENSIONED, ROCKING BRIDGE BENT FOR RAPID CONSTRUCTION AND HIGH SEISMIC PERFORMANCE

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Abstract

A new, rocking, pre-tensioned bridge bent system has been developed that 1) reduces construction time by precasting the beams and columns, 2) minimizes post-earthquake residual displacements by incorporating unbonded, pre-tensioned strands in the columns, and 3) reduces earthquake damage with rocking connections at the ends of the columns. Cyclic tests of subassemblies have demonstrated that the system can deform to drift ratios of around 6% with minimal damage and negligible residual displacements. Planned shaking table tests of a three-bent, two-span bridge at the University of Nevada, Reno will be used to evaluate the dynamic performance of the system.

Introduction

Within the United States, the design of reinforced concrete bridges in seismic regions has changed little since the mid-1970s, when ductile details were first introduced. Nearly all bridge bents (intermediate supports) in seismic regions are constructed of cast-in-place reinforced concrete. Many of these cast-in-place bridges have performed well in the past, but to meet modern design expectations for bridges, new structural systems and construction methods are needed to improve: 1) speed of construction, 2) seismic resilience and 3) durability.

A new concept has been developed that addresses each of these three concerns. This paper describes the concept, constructability and the results of subassembly testing of components of the new system. Two-span, three-bent shaking table tests are planned for 2014 at the University of Nevada, Reno Network for Earthquake Engineering Simulation (NEES) facility.

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Concept

The new system, shown schematically in Figure 1, has the following key features.

- The columns and beams are cast off-site and then assembled rapidly once they arrive on-site. Precasting not only accelerates construction, it also tends to improve worker safety and construction quality.

- Construction is further accelerated by using a “wet socket” connection between the column and the spread footing (Haraldsson et al. 2013). In this connection, the precast column is placed in the footing excavation, and the footing concrete is cast in place around it. To facilitate the transfer of forces into the surrounding concrete, the base of the column has a roughened exterior with a saw-tooth detail. No bars cross the interface between the precast column and cast-in-place footing. The column longitudinal bars are not bent out as they are in conventional construction, but instead, they are developed using mechanical anchors within the part of the column that is embedded in the footing. This design facilitates transportation, increases safety (no protruding bars), and improves performance (compared with bent-out bars).

- Post-earthquake residual displacements are reduced by pre-tensioning the precast bridge columns with unbonded tendons, which are designed to return the system to its original plumb position when the ground motion stops.

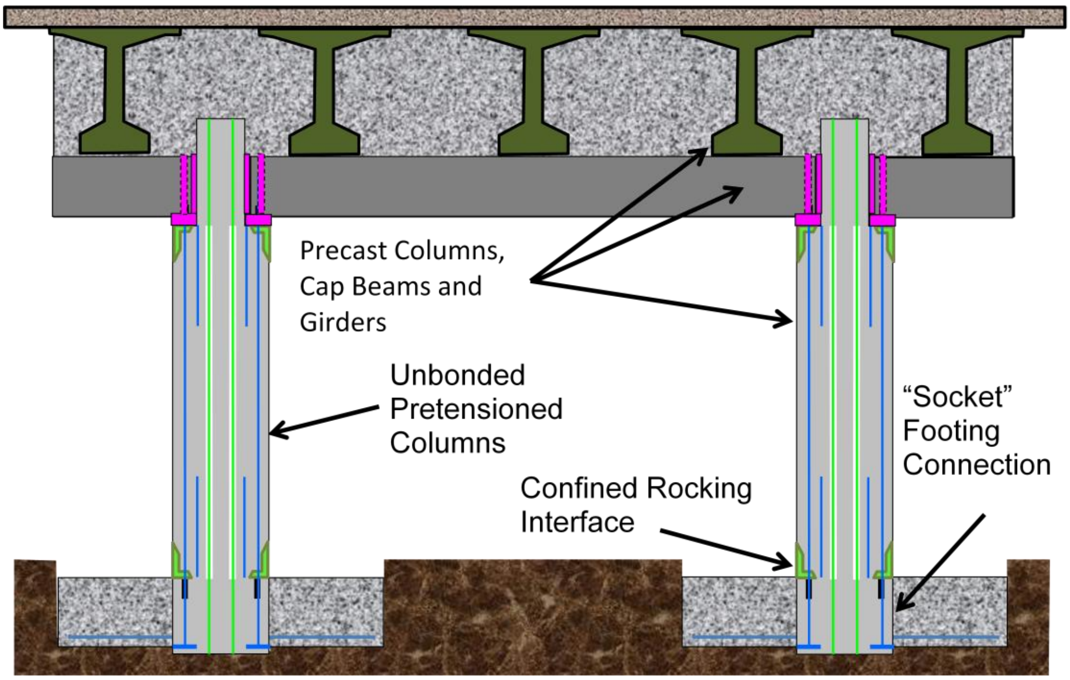


Figure 1. Precast, Pretensioned Rocking Column Bent Concept

- Damage to the system is minimized by incorporating a new rocking detail at the ends of the columns, as shown for the base of the column in Figure 2. The concrete at the interface is confined by a steel jacket (or "shoe"), which consists of circular steel pipe welded to an end plate, upon which the interface rocks. The longitudinal bars are debonded near the interface to distribute the bar elongation over a sufficient length to prevent bar failure at the design deformation. Discontinuous bars are also included in the system to help resist large compressive forces at the rocking interface, and to ensure that deformations are concentrated at this interface rather than above the shoe.

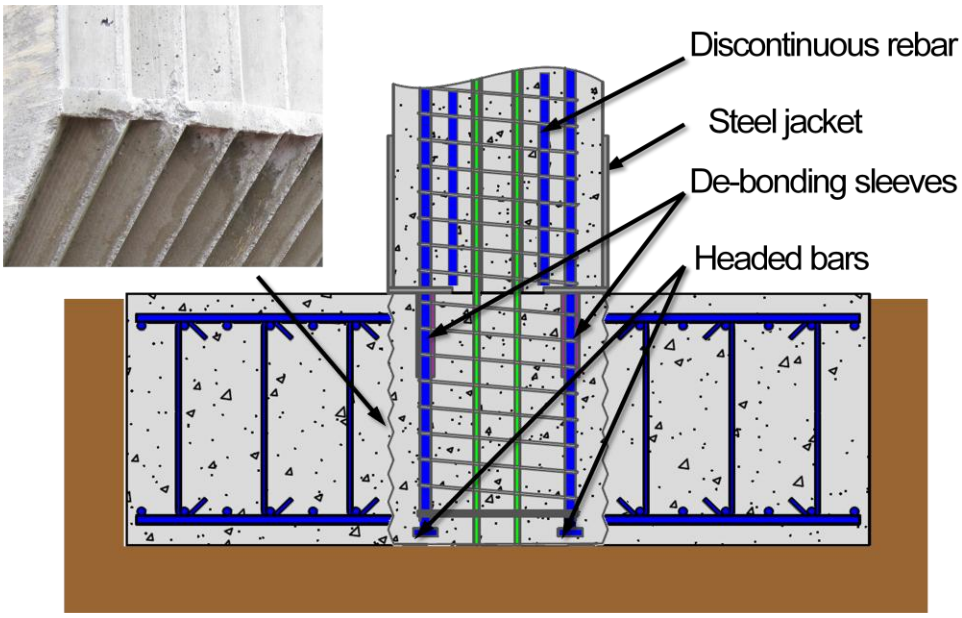


Figure 2. Base Detail for Precast, Pretensioned Rocking Column Bent

<u>Rapid Construction</u>

A non-prestressed version of the precast bent system was deployed in Washington State as part of the construction of a bridge over Interstate-5 (Khaleghi et al. 2012). The bridge had two spans, tall abutments on the ends and a center pier with four columns (Fig. 3).

The precast columns were connected to the cast-in-place spread footings using a wet socket connection (Haraldsson et al. 2013). The tops of the precast columns were connected to the precast cap-beam using a large-bar connection (Pang et al. 2010). The cap-beam was made in two segments because of weight constraints. No major problems were encountered during construction, and alignment was straightforward (Khaleghi et al. 2012). The placement of each cap-beam segment took less than 30 minutes. The precast, pre-tensioned rocking system has similar construction details as the non-prestressed system, so it could be assembled similarly, as illustrated in Figure 4

Figure 3. Construction of Precast Column Bent (without pretensioning)

Test of Sub-Assemblies

The resistance and damage progression of the top and bottom connections were evaluated with quasi-static tests of a column-to-spread-footing connection subassembly (PreT-SF-Rock) and a column-to-cap-beam connection subassembly (PreT-CB-Rock).

The columns were designed to have a strength similar (at 42% scale) to that of a typical reinforced concrete column. For both subassemblies, the octagonal columns had a diameter (flat-to-flat) of 20 in. (508 mm) and a cantilever length of 60 in. (1524 mm), resulting in a cantilever span-to-depth ratio of 3.0. The columns were subjected to a constant axial load while cyclic, lateral displacements were applied to the column. The loading setup is shown in Figure 5.

The cyclic performance of the subassemblies (Figure 6) greatly exceeded that of a comparable conventional reinforced concrete column connection (e.g., Pang et al. 2010).

- For peak drift ratios up to approximately 6%, the columns returned to their undeformed geometry upon unloading.

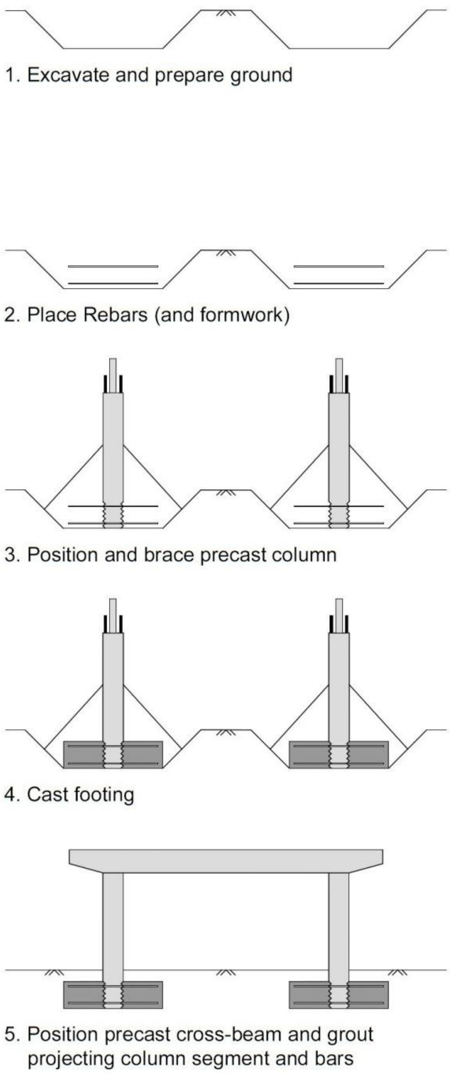


Figure 4. Construction Sequence

- The columns continued to resist nearly 100% of the peak lateral load after having been subjected to two cycles of deformation at a drift ratio of 10.4%.

- No spalling or bar buckling was observed during the tests, and the joint grout in the top connection suffered only cosmetic damage. The longitudinal bars for the column-to-spread-footing specimen fractured after being subjected to a drift ratio of 5.9%. The column-to-cap-beam bars, which had a longer debonded length, fractured after being subjected to a drift ratio of 7.0%.

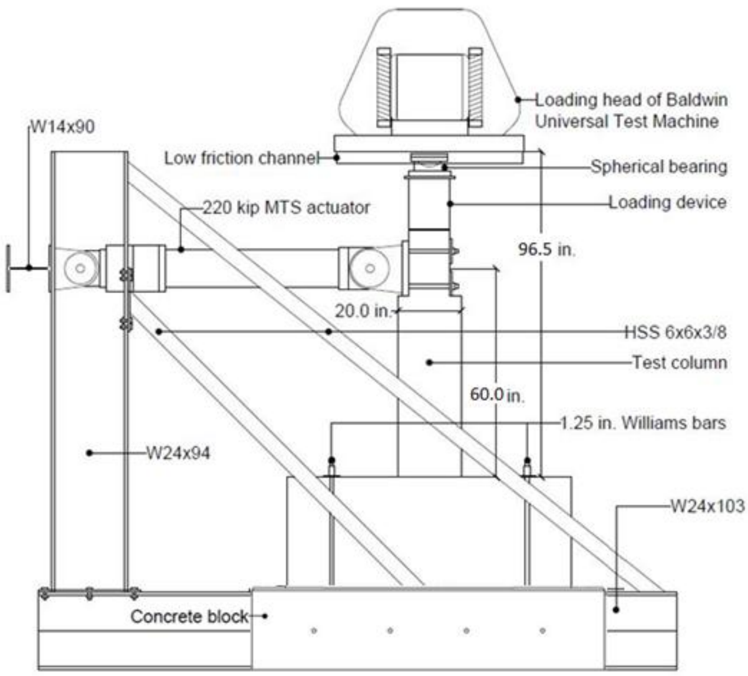
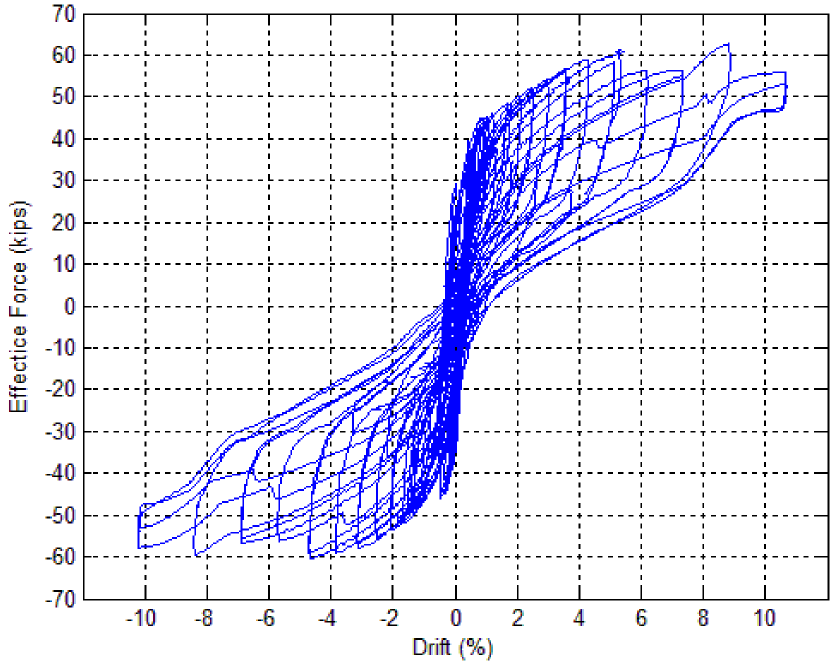


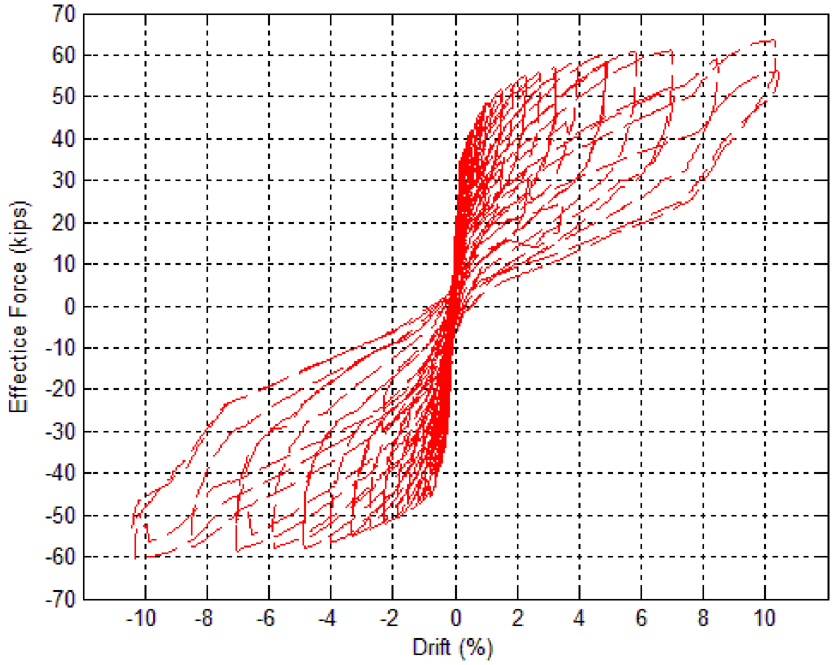
Figure 5. Loading Setup for Subassembly Tests

Planned Shaking Table Tests

The performance of the pretensioned, rocking bridge bent system will be evaluated with a three-bent, two-span shaking table tests at the NEES facility at the University of Nevada, Reno in 2014. The columns of the bents have been designed to perform (at 25% scale) similarly to those tested statically at the University of Washington. Figure 7 shows a schematic drawing of the shaking table specimen.



(a) Column Connection to Spread Footing (Pret-SF-Rock)



(b) Column Connection to Cap Beam (Pret-CB-Rock)

Figure 6. Measured Effective-Force vs. Drift Ratio Responses of Rocking Connection Sub-Assemblies

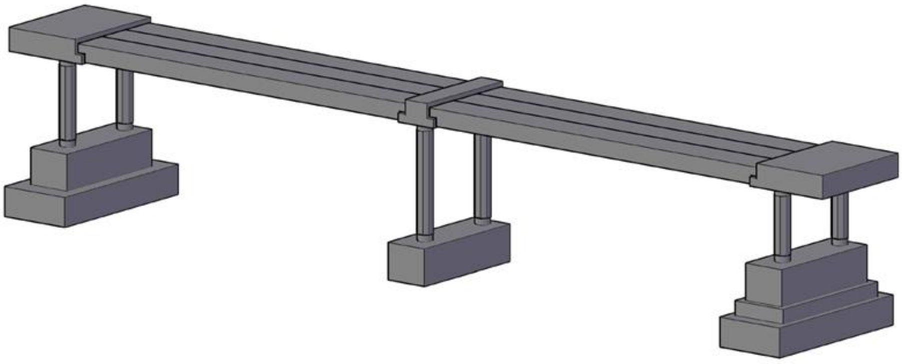


Figure 7. Schematic of Shaking Table Specimen

Conclusions

A new pretensioned, rocking column bridge bent system has been developed to accelerate bridge construction and improve seismic resilience.

- Field experience with a similar, non-prestressed system suggests that the new system could be constructed rapidly.
- Quasi-static tests of a column-to-spread-footing subassembly and a column-to-cap-beam subassembly indicate that the new system would perform better than a conventional reinforced concrete bridge. The lateral strength appears to degrade more slowly, the column re-centers at larger drift ratios, and the column suffers less damage.
- Upcoming shaking table tests of a three bent, two-span bridge will provide an evaluation of the dynamic performance of the system.

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