

AN ALTERNATIVE PRECAST PIER SYSTEM FOR ACCELERATED BRIDGE CONSTRUCTION (ABC) IN SEISMIC REGIONS

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ABSTRACT

A new type of connection for precast piers in seismic regions is presented. The connection utilizes structural steel pipes to emulate the conventional cast-in-place seismic performance. Two large-scale cantilever piers are tested under quasi-static cyclic loading. One pier incorporates cast-in-place construction and is intended as the benchmark specimen to compare results. The other pier is precast with a structural steel pipe in the plastic hinge zone. Results from testing showed adequate strength and ductility of the precast pier. It performed better compared to cast-in-place benchmark. The precast pier achieved larger values of strength and ductility. It also suffered less cracking and damage during lower drift ratios compared to cast-in-place benchmark.

INTRODUCTION

Accelerated Bridge Construction (ABC) is gaining popularity in many states, including Idaho. For concrete bridges, the use of precast components can accelerate construction, reduce traffic disruption, improve quality, increase durability, and enhance site safety with reduced environmental impacts. One of the main concerns in application of precast concrete in regions with moderate-to-high seismicity is to ensure adequate performance of the connection between precast members. The traditional cast-in-place seismic design philosophy relies on formation of plastic hinges during an earthquake. These hinges form in the substructure system (e.g. columns) and are detailed to provide a ductile response during the earthquake. From the precast perspective, several types of connections have been proposed to emulate the traditional cast-in-place seismic performance. These include grouted ducts connection, splice-sleeve connection, member socket connection, pocket connection, and others as previously studied by Marsh et al. (1) and Mashal and Palermo (2) (3). Some of these connections have been used in actual bridges located in seismic zones.

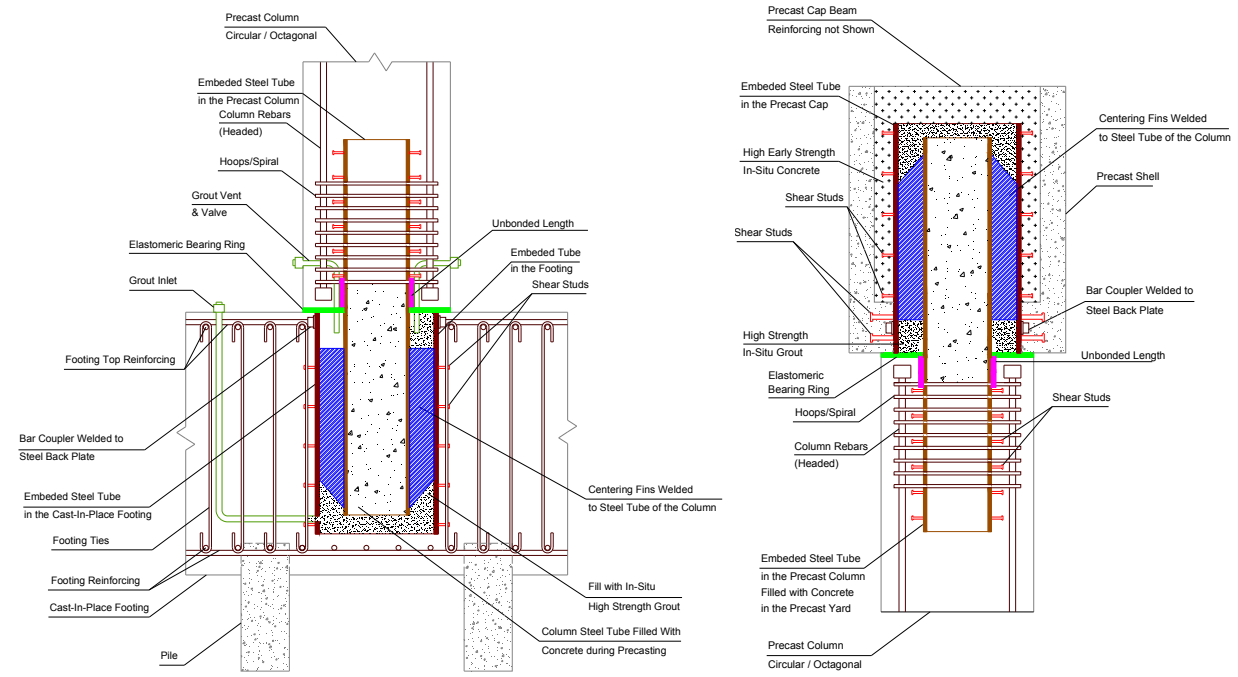
Each of the aforementioned connections has its pros and cons. For instance, grouted ducts connection has shown to provide adequate seismic performance, however it carries the risk of damage during transportation (e.g. protruding bars) and misalignment of the starter bars inside the ducts during assembly at the bridge site.

This research presents a new concept for a precast pier system in seismic zones. The concept uses embedded structural steel pipes in the potential plastic hinge zones. Compared to other precast connections such as grouted ducts, the proposed connection offers advantages such as: simple construction, greater installation tolerance, easier erection, the option for using a hollow cap beam to reduce weight of the precast element, use of non-proprietary materials, and improved serviceability (e.g. avoiding cracking to columns) during smaller earthquakes.

The proposed concept has been shown in Figure 1. The function of the pipe inside the precast column is to provide strength and ductility at the plastic hinge. The steel pipe provides shear and flexural resistance as well as confinement. It is similar to the concept for Concrete Filled Steel Tube (CFST); however in this instance the pipe is inside the precast column and does not run all height of it. The receiving pipe has a slightly larger diameter and is cast inside the footing and cap beam. There is an elastomeric pad at the column-to-footing and column-to-cap beam interface. This pad prevents crushing of concrete cover during

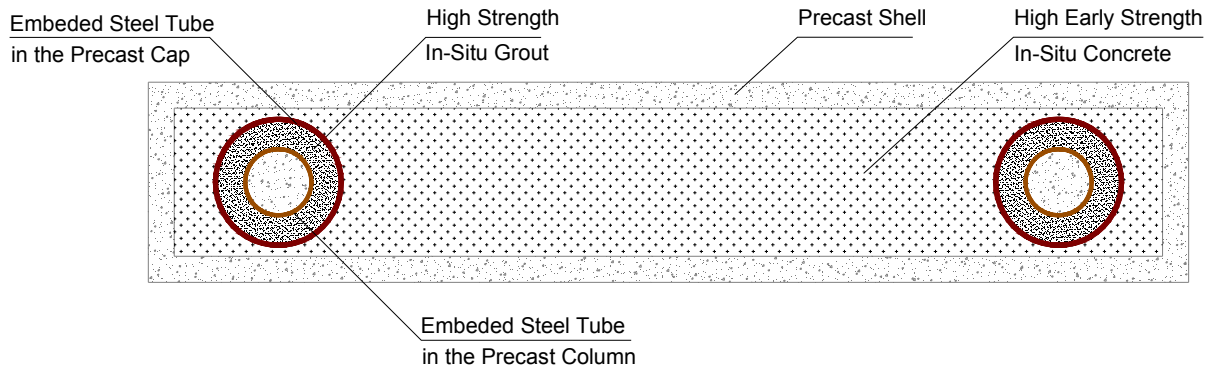
smaller earthquakes, which improves serviceability. As mentioned previously, the cap beam can be hollow or solid depending on the transportation constraints and weight limits.

The seismic design philosophy for the precast pier is that nonlinear deformation should be concentrated in the column pipe. In this instance, the cap beam, footings, and their components should remain elastic and are capacity protected elements.



(a) Column-to-footing connection

(b) Column-to-cap beam connection

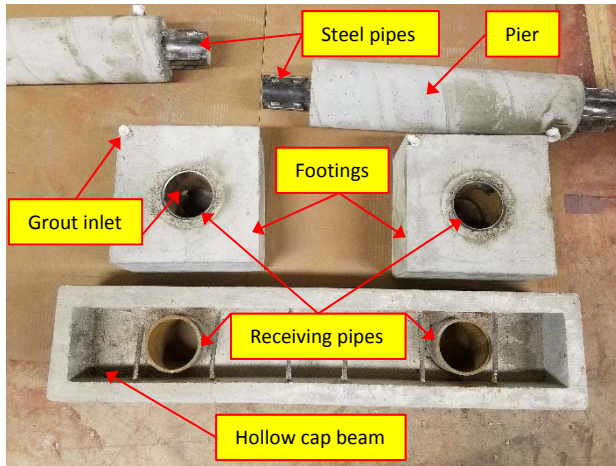


(c) Precast cap beam concept (hollow or solid)

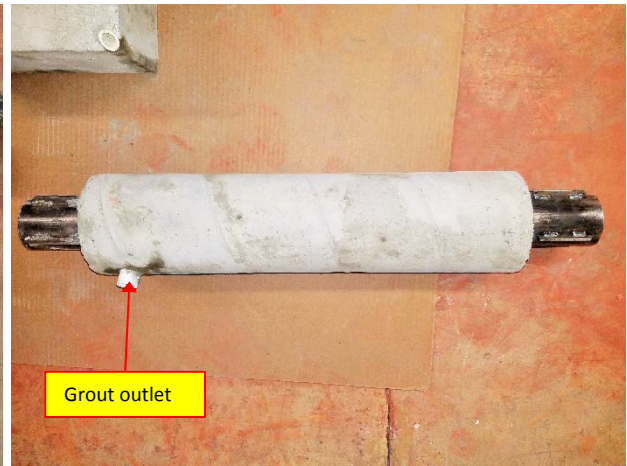
Figure 1. Concept for a precast pier system in seismic regions.

Figure 2 presents the assembly process for the proposed precast pier system. In this instance, the precast elements are assembled first before grouting the connections. The gap between the receiving and column pipes is filled with non-shrink, high-strength grout. For the column-to-footing connection, this gap is filled by pumping grout through the grout ducts cast in the footing and the column during precasting (Figure 2b). For the column-to-cap beam, the gap is filled by pouring grout from the top, using gravity. Once the grout

achieves a good strength (e.g. 3,000 psi), the hollow cap beam is then filled with in-situ high-early strength concrete.



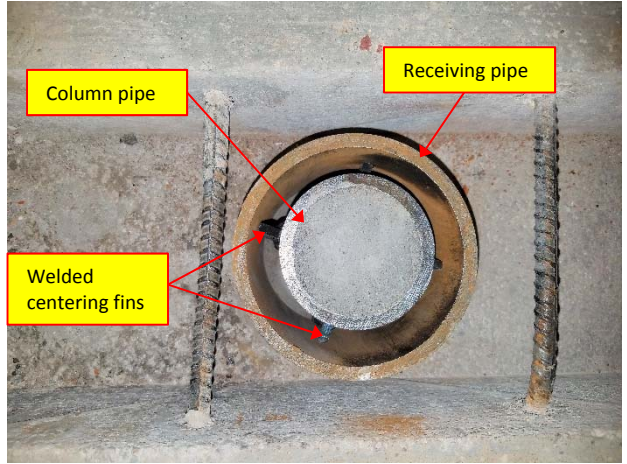
(a) Components of the precast bent



(b) Precast pier with steel pipes and welded fins



(c) Assembled precast pier



(d) Gap to be filled with high-strength grout



(e) Grout outlet in the column



(f) Grouted bent and concrete filled cap beam

Figure 2. Assembly sequence for the precast pier system.

EXPERIMENTAL PROGRAM

In the first phase, two large-scale cantilever specimens are tested under uni-directional quasi-static cyclic loading protocol as plotted in Figure 3. One specimen represents the conventional cast-in-place construction while the other is precast with pipe connection. The specimens represent 1/3rd scale piers in a typical highway bridge in Idaho. Both specimens were designed in accordance with AASHTO LRFD Bridge Design Specifications (4). Available literature from Wasserman and Walker (5) and Washington Department of Transportation Bridge Design Manual (6) are utilized to design the required embedment length of the column and receiving pipes to develop plastic capacity. The flexural capacity of the precast column with CFST at the interface is similar to that of the Cast-In-Place (CIP) with reinforcement bars. (Figure 4). Figures 5-6 present details of the cast-in-place and precast pier specimens, respectively. Testing arrangement is shown in Figure 7.

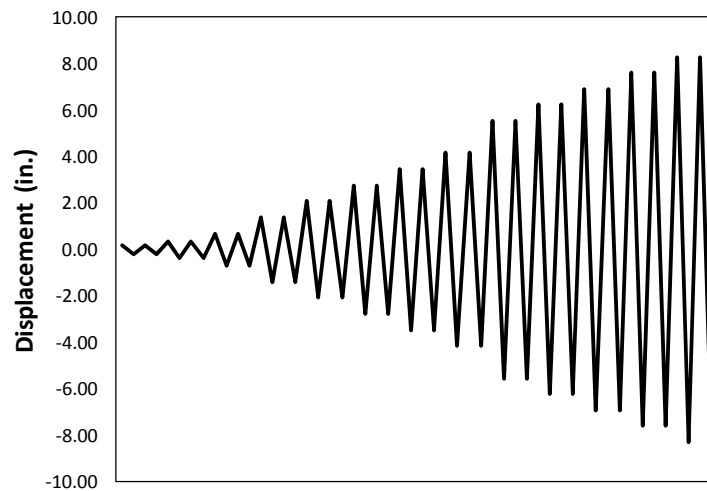


Figure 3. Quasi-static cyclic loading protocol.

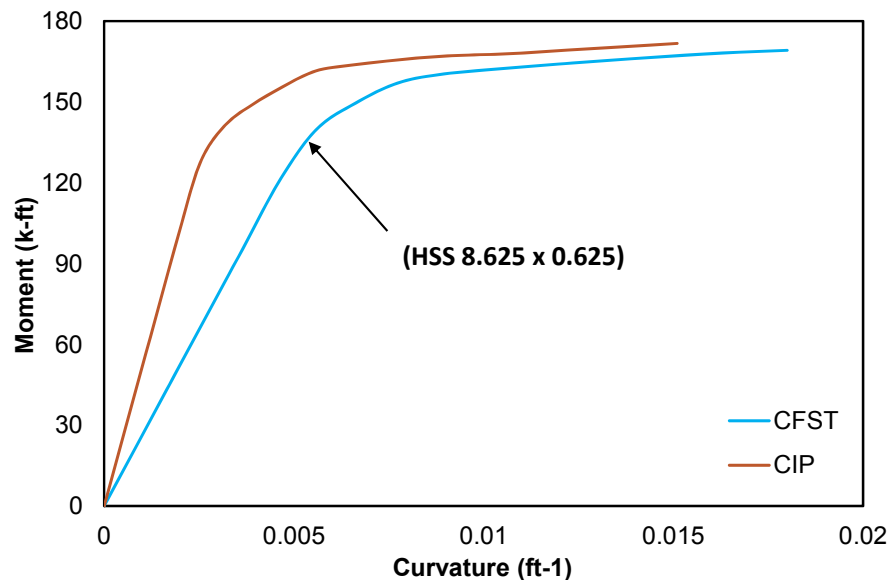


Figure 4. Theoretical moment-curvature plots for the specimens.

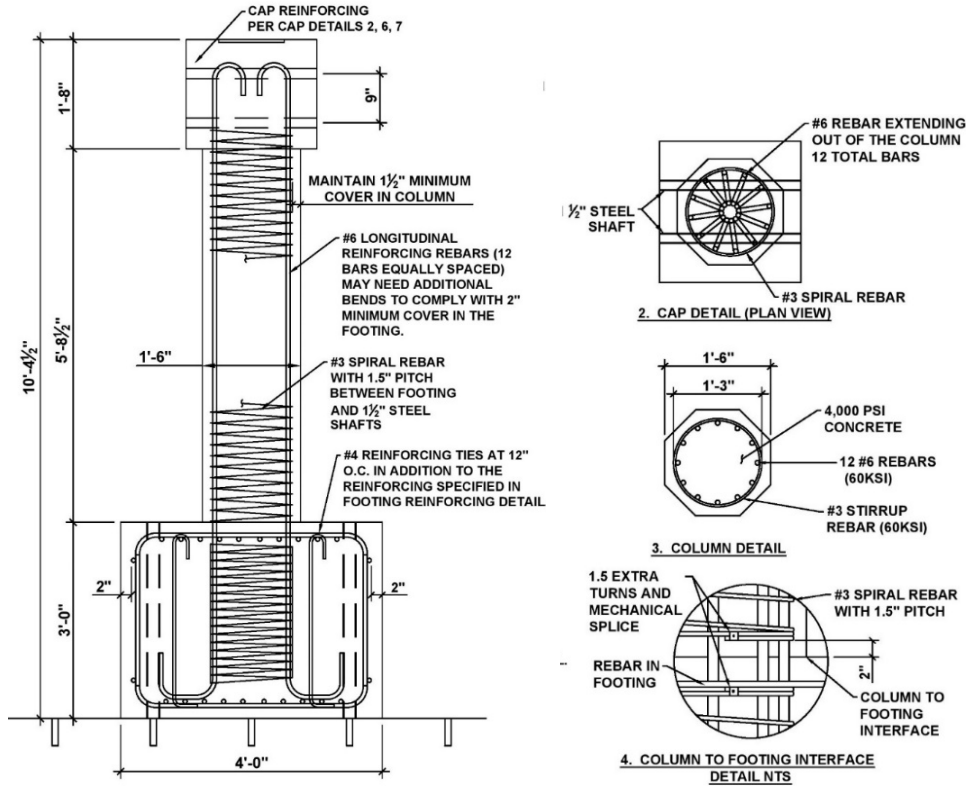


Figure 5. Cast-in-place specimen.

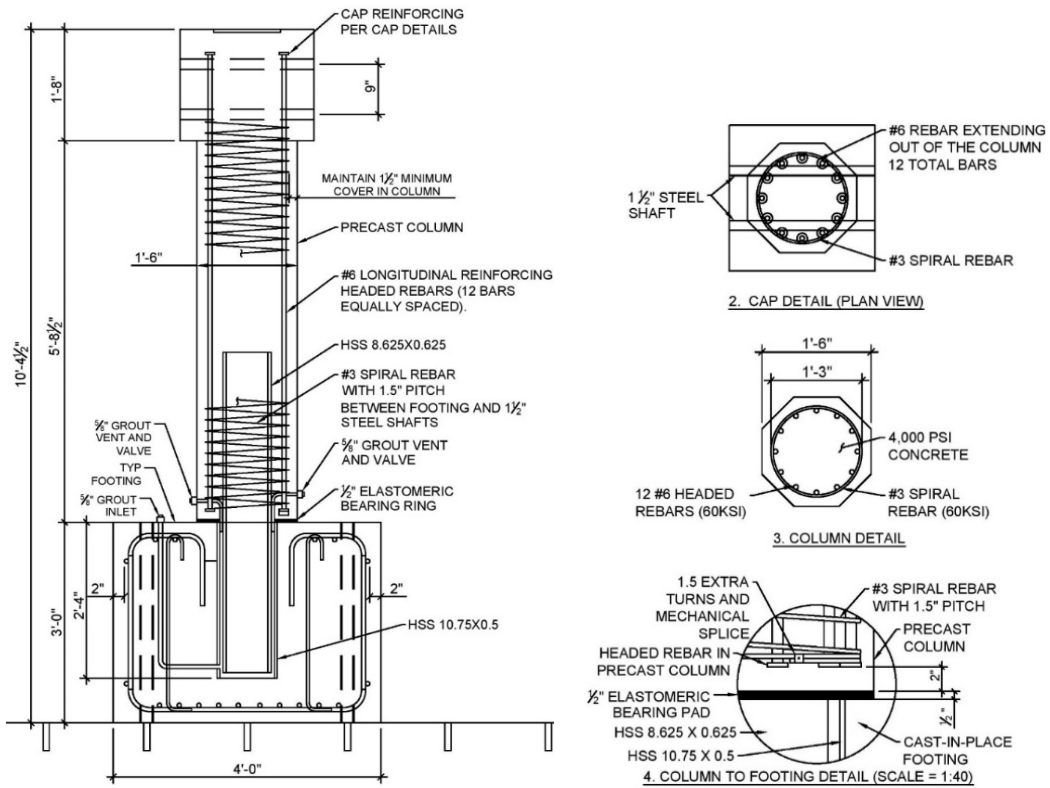


Figure 6. Precast specimen.

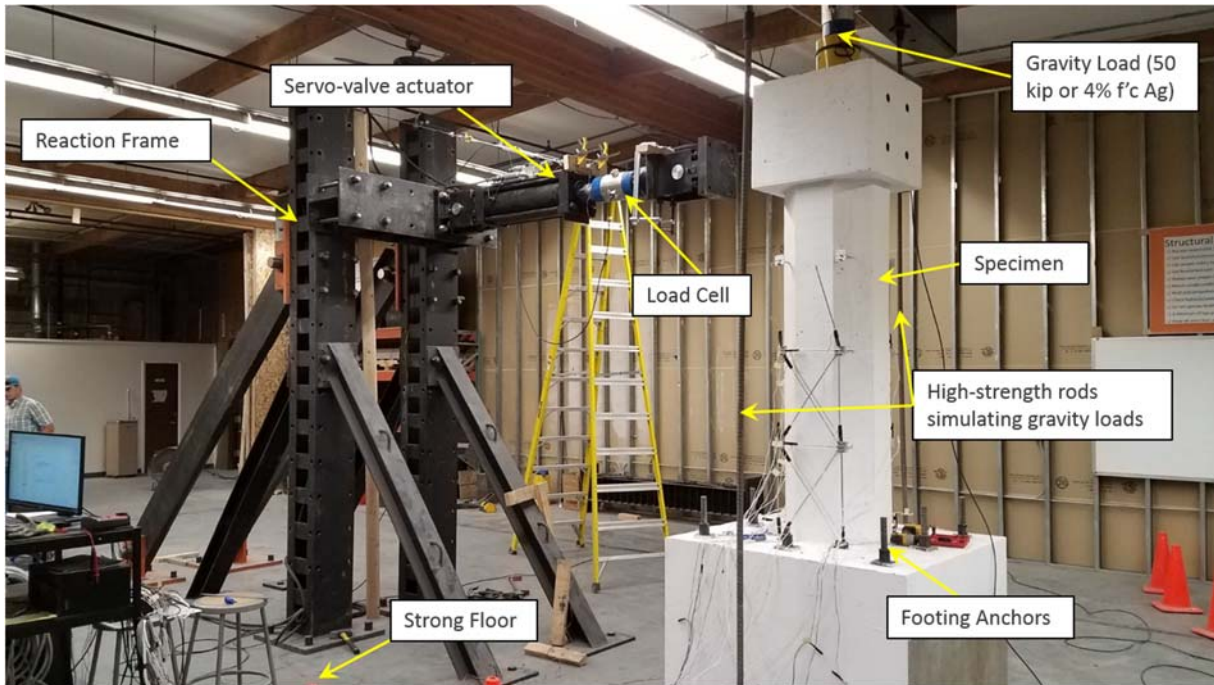


Figure 7. Testing arrangement.

RESULTS

Figure 8 presents the force-drift hysteresis for the cast-in-place specimen. The performance is very similar to what can be expected to cast-in-place construction (e.g. formation of plastic hinge). First rebar rupture occurred during the second cycle of the 8.5% drift ratio. Two other rebars ruptures can be seen during subsequent cycles. Figure 9 shows progression of damage in the plastic hinge region.

Figure 10 presents the force-drift hysteresis for the precast specimen. The performance is different than a traditional cast-in-place. The hysteresis is fatter and more ductile. Figure 11 shows progression of damage in the plastic hinge zone with increasing drift ratios. There is less cracking to the column during cycles of lower drift ratios compared to cast-in-place construction. With increasing drift ratio, extensive spalling of the unconfined cover concrete occurs in the plastic hinge region. The specimen starts degrading rapidly during the second cycle of 10.7% drift ratio. The failure mechanism is triggered by “elephant-leg” buckling of the steel pipe over the un-bonded region.

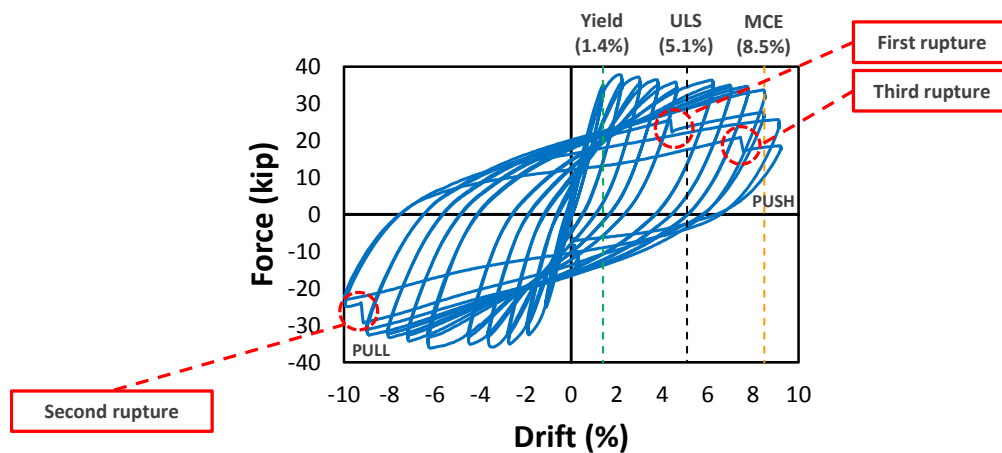


Figure 8. Force-drift hysteresis for the cast-in-place specimen (ULS = Ultimate Limit State; MCE = Maximum Considered Earthquake).



2.2% Drift Ratio

3.8% Drift Ratio

9% Drift Ratio

Figure 9. Damage progression in the cast-in-place specimen.

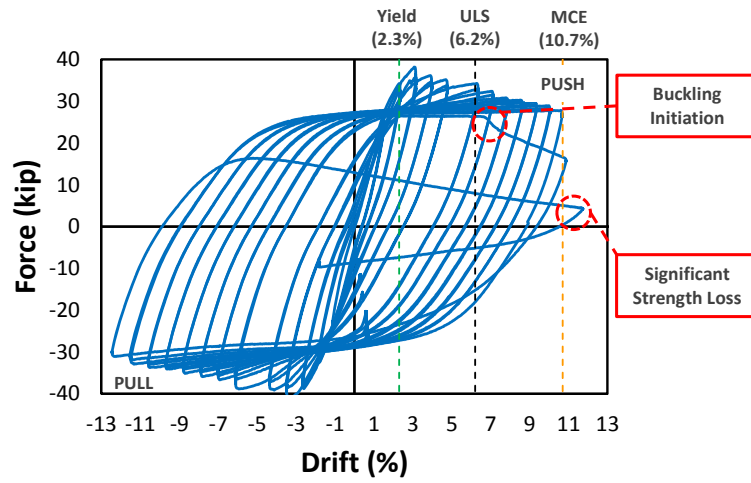


Figure 10. Force-drift hysteresis for the precast specimen (ULS = Ultimate Limit State; MCE = Maximum Considered Earthquake).



2.35% Drift Ratio

3.97% Drift Ratio

8.8% Drift Ratio

Figure 11. Damage progression in the precast specimen.

CONCLUSIONS

A precast pier system for seismic regions is proposed. The concept offers advantages such as: ample construction tolerance, easy erection, hollow cap beam to reduce weight, non-proprietary materials, use of ABC methods, and flexibility to accommodate smaller earthquakes without cracking to the piers. Two large-scale cantilever piers are constructed for uni-directional quasi-static cyclic loading. Experimental results show better performance of the precast pier compared to the cast-in-place construction. The project is ongoing at Idaho State University. In the second phase of the research, two bents (one cast-in-place and one precast) will be tested under quasi-static cyclic loading protocol. The project also includes developing Finite Element (FE) modeling for the specimens. Based on the outcomes of the research, the Idaho Transportation Department (ITD) may use the proposed concept in this paper in a real-life project in southeast Idaho which is located in a seismic region.

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