LARGE-SCALE TESTING OF A PRECAST BENT SYSTEM FOR ACCELERATED BRIDGE CONSTRUCTIONS: SEISMIC PERFORMANCE AND COMPARISION WITH CAST-IN-PLACE

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ABSTRACT

Accelerated Bridge Construction (ABC) has been gaining popularity around the United States. ABC offers many advantages over traditional cast-in-place, such as reduced traffic disruption and rapid erection, among numerous others. Despite these advantages, application of ABC in seismic regions is still a challenge due to difficulties associated with developing equivalent or better response from precast connections as that of cast-in-place during seismic loading. In this research, a new precast pier system is proposed to emulate the traditional cast-in-place seismic design (e.g. formation of plastic hinges during earthquakes). The precast elements are connected using fully encased concrete-filled steel tubes. Large-scale experimental testing of equivalent precast and cast-in-place bents is carried out to investigate the seismic performance of the proposed pier system and to compare it against the traditional cast-in-place construction. Experimental results exhibit good ductility and performance of the precast connection when subjected to quasi-static cyclic loading. The performance of the precast connection during experimental testing of piers has outperformed the cast-in-place benchmark specimen in ductility and strength. The Idaho Transportation Department is planning to implement the research in this paper in an actual bridge over I-15 in Southeast Idaho in the near future.

Keywords: Accelerated Bridge Construction (ABC), Pier, Seismic, Bridge, Construction, Precast

INTRODUCTION

Accelerated Bridge Construction (ABC) has been increasingly accepted as a suitable approach for bridge construction within the United States. Coinciding with the rapid adoption of ABC is the use of precast concrete elements in structures. Bridge construction in particular has seen major benefits from the implementation of ABC and precast elements. Consistent challenges in bridge construction are onsite space availability and traffic disruption and delay. Through the use of precast elements, the onsite space demand has been reduced due to the ability to allow for offsite casting of bridge elements. This practice has increased construction site safety and construction speed, while reducing the demand for onsite construction and fabrication. The use of precast elements has thus extended to the precasting of girders, pier caps, and piers, even in some cases to precast foundations on smaller projects. In the cases of fully precast bridge structures, precast substructure and superstructure, construction speed is increased significantly. However, one area where precast has failed to adapt is achieving seismic performance similar to or better than cast-in-place construction. This has resulted in ABC practices for bridge substructures struggling to be applied in areas of seismicity. Studies have been performed proposing many differing connection types for application within seismic regions. Grouted coupler connections[1] and grouted ducts[2,3] have been implemented by several Departments of Transportation (DOTs) in the United States. The connections were able to deliver good seismic performance and successfully emulated traditional cast-in-place behavior, consistently developing the plastic hinge within the column. Grouted couplers are shown in Figure 1 below[4].

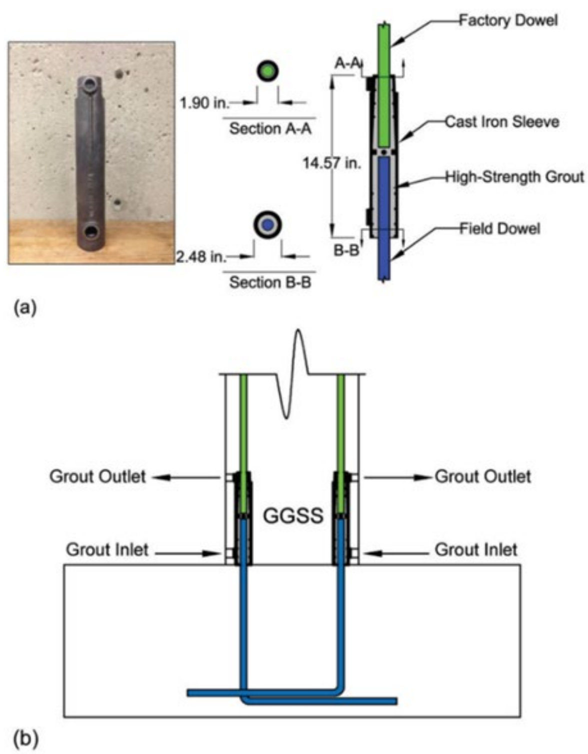


Figure 1: Grouted splice sleeve connection located in plastic hinge of the column[4]

The use of grouted ducts as proposed proved to be a beneficial approach to precast connections for low to moderate seismic regions. The connection also proved to be difficult as it required very tight tolerances and extensive construction detailing. This has resulted in multiple reports of mis-cast and mismatched precast elements causing extensive revenue losses. The alignment and placement of multiple ducts across foundations, piers, and caps have proved to be extensively strenuous. As the members of the substructure are far larger than the super structure elements handling and transportation become far more cumbersome as any damage to protruding rebar incurs large revenue losses. Furthermore, the individual grouting of each duct increases material use and construction time. Any of the errors or combination of the above-mentioned errors is likely to result in a recast of the original elements or even a switch to a cast-in-place construction mid project.

PRECAST CONNECTION

In this research, an alternative simplified connection using steel pipes is proposed for precast pier systems in seismic regions. In this type of connection, a steel pipe is protruding from the concrete column that will go inside a larger pipe placed in the footing/cap beam during prefabrication. Centering fins are welded to the column steel pipes to ease on-site assembly. The proposed precast pier system offers the following advantages.

- Fast construction (use of ABC)
- Simple construction
- Ample installation tolerance
- Ease of erection
- Use of hollow precast pier shell
- Option for solid precast pier shell
- Non-proprietary components/materials
- Improved on-site safety
- Faster construction
- Allows deformation during smaller movements without cracking and crushing of concrete

The column-to-footing and column-to-cap connections are detailed such to act as moment connections. The plastic moment capacity of the connection depends on the size of the pipe and material properties. For simplicity, the interface at the column-to-footing and column-to-cap beam can be considered as a Concreted Filled Steel Tube (CFST). The methodology presented in the Washington Department of Transportation Bridge Design Manual[5]can be used to calculate the moment capacity of the CFST. The size and material properties for the pipe are chosen such that it closely matches the capacity of an equivalent cast-in-place section for the pier.

The gap between the pipes is grouted after the assembly on-site. For the column-to-footing connection, the grout is pumped through an inlet left in the cast-in-place footing. Grout vents are left in the precast column to allow the displaced air to escape. For the column-to-cap beam connection, the grout is poured from the top of the cap beam utilizing gravity, with an air vent present.

At the interface of the column-to-cap beam and column-to-footing, an elastomeric pad is used to allow for added flexibility of the connection during smaller earthquakes without causing any damage or cracking to the column. The steel pipe is debonded over a certain length in the plastic hinge zones to provide enhanced ductility and fatigue resistance. This length can be chosen to limit the strain in the portion of the steel pipe with plastic deformation to 5% at the design level earthquake. This is consistent with the recommendations presented in the PRESSS Design Handbook[6]

The embedded length of the pipes inside the precast column, cap beam, and cast-in-place footing would have to be sufficient to develop the capacity of the CFST. The embedment length should be calculated in accordance with existing literature for CFSTs. Two methodologies are recommended in this research. These are based on the formulas presented by Wasserman et al.[7] and WSDOT Bridge Design Manual[5]. The two equations given are the suggested approaches to determining the required embedment length. Where l_e is the calculated embedment length, D is the diameter of the embedded pipe, t is the wall thickness of the embedded pipe, F_u is the ultimate strength of the embedded pipe, and f'_c is the compression strength of the concrete with all variables in kips and inches.

Wasserman:

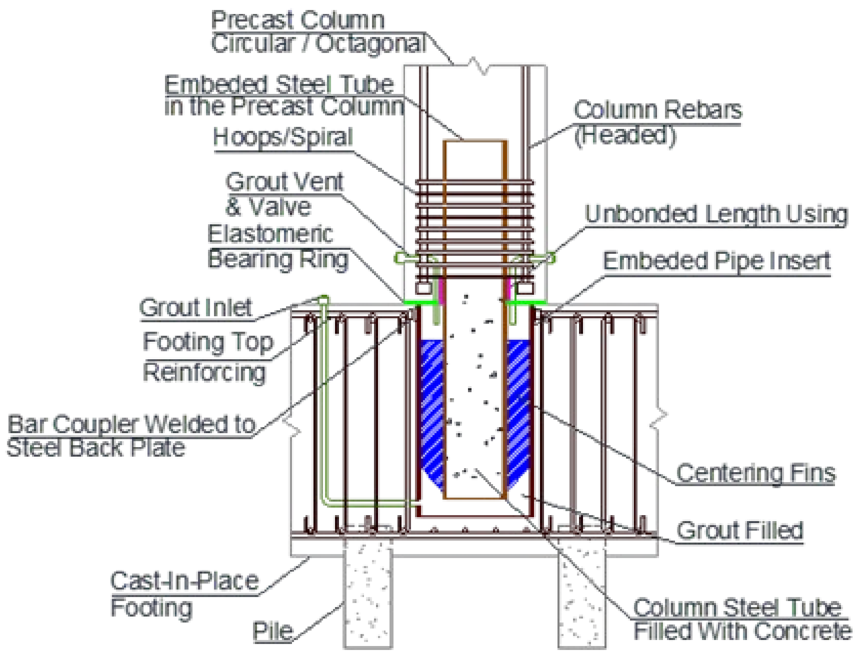
$$l_e \geq \frac{2F_yZ}{\sqrt{700f'_c b}}$$

$$b = \frac{\mathrm{d}\sqrt{\pi}}{2}$$

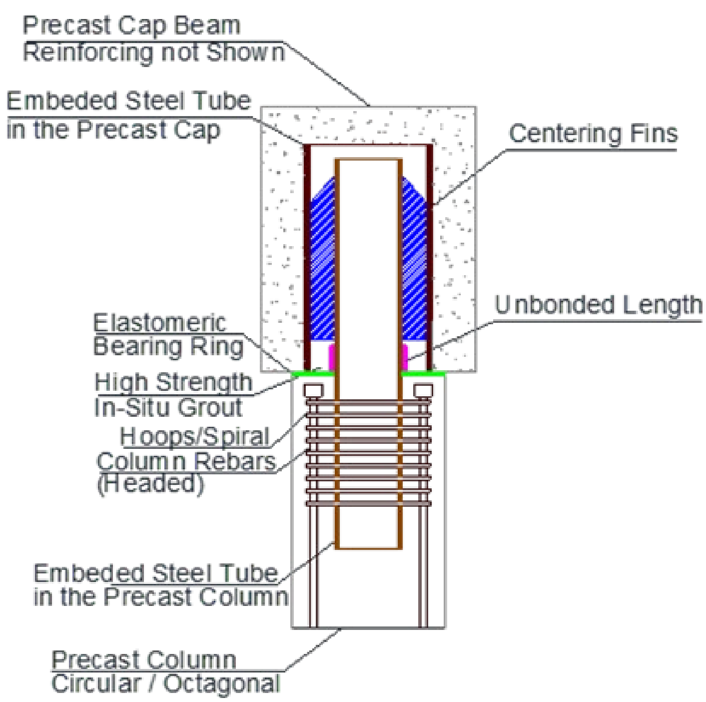
WSDOT:

$$l_e \geq \sqrt{\frac{5.27DtF_u}{\sqrt{f'_c}}}$$

The cap beam is precast and can be either a solid or hollow shell, depending on the size and weight. The hollow shell solution helps with reducing the weight during transportation. The cap is later filled with high-early strength concrete on-site. Figure 2 below provides a general detail of both a column-to-footing connection, (a), and a column-to-cap connection (b).



(a) Column-to-footing connection



(b) Column-to cap connection

Figure 2: Proposed Precast Connection Details

SPECIMENS

As the experiment followed the testing of two large-scale cantilever piers the purpose was to further investigate the reaction of the proposed connection in a bent substructure. For this, two large-scale bent systems were constructed. The first specimen was a scaled cast-in-place specimen and used as a benchmark specimen for the seismic performance of the specimens. The cast-in-place specimen was designed and constructed in accordance with AASHTO LRFD Bridge Design Specifications[8]. Details of the specimen are presented in Figure 3. The second specimen constructed with the proposed precast connections at all four column connections was designed to be identical in dimension and targeted moment capacity as that of the cast-in-place specimen. The overall size and strength of the specimens was determined from review of existing Idaho bridges and the space and handling confinements of the Idaho State University Structural Laboratory. The details of the second precast specimen are provided in Figure 4.

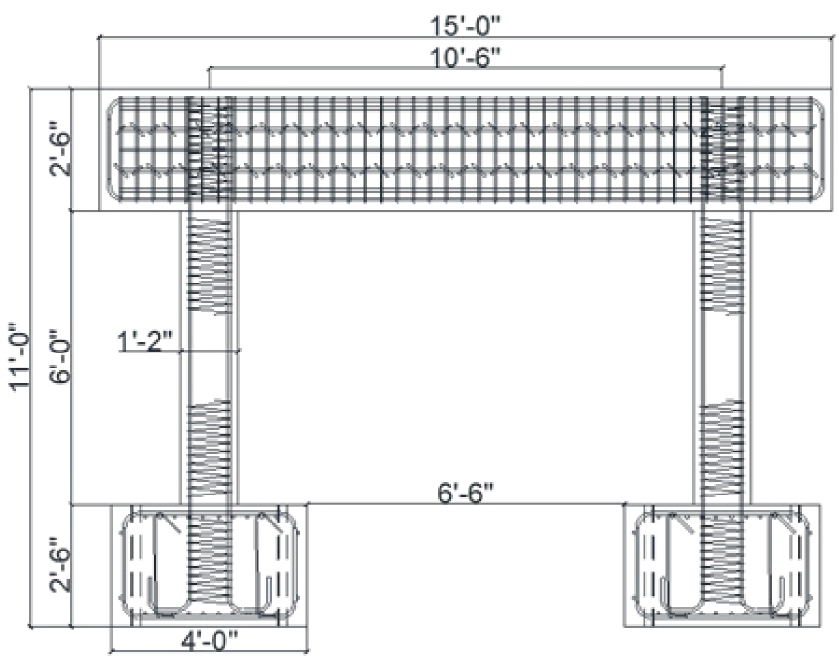


Figure 3: Cast-in-place bent benchmark details

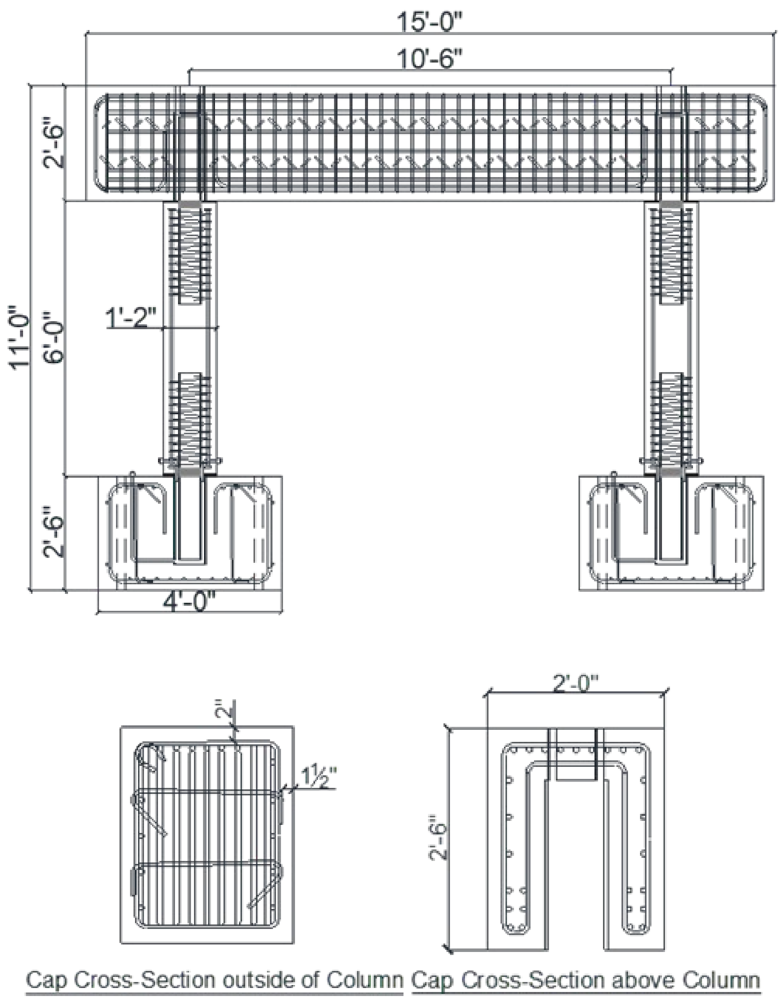


Figure 4: Precast bent details

EXPERIMENTAL WORK

Subjecting the constructed specmens to the quasi-static loading protocal shown in the Figure 5 was determined in accordance with American Concrete Institute (ACI). It can be observed two cycles were performed at each displacement increasing until failure or 20% strength degradation. The testing arrangement of the bent structures can be viewed in Figure 6.

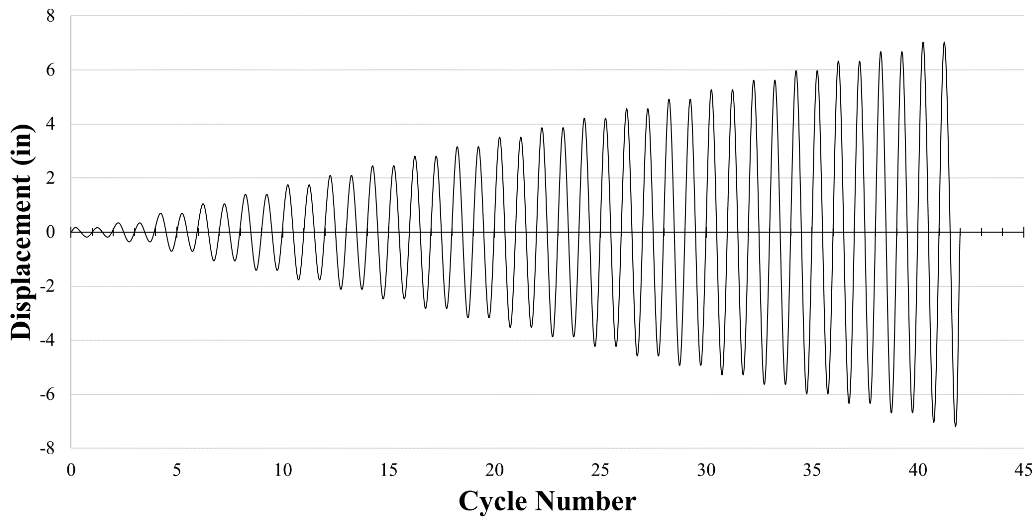


Figure 5: Quasi-static loading protocal

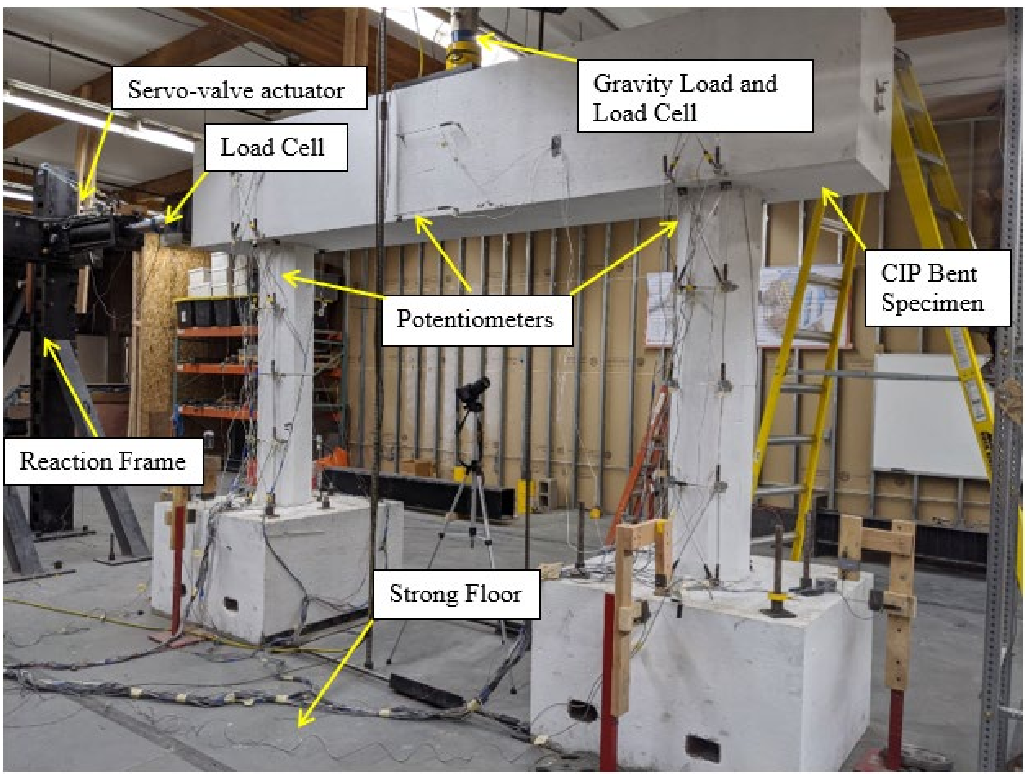
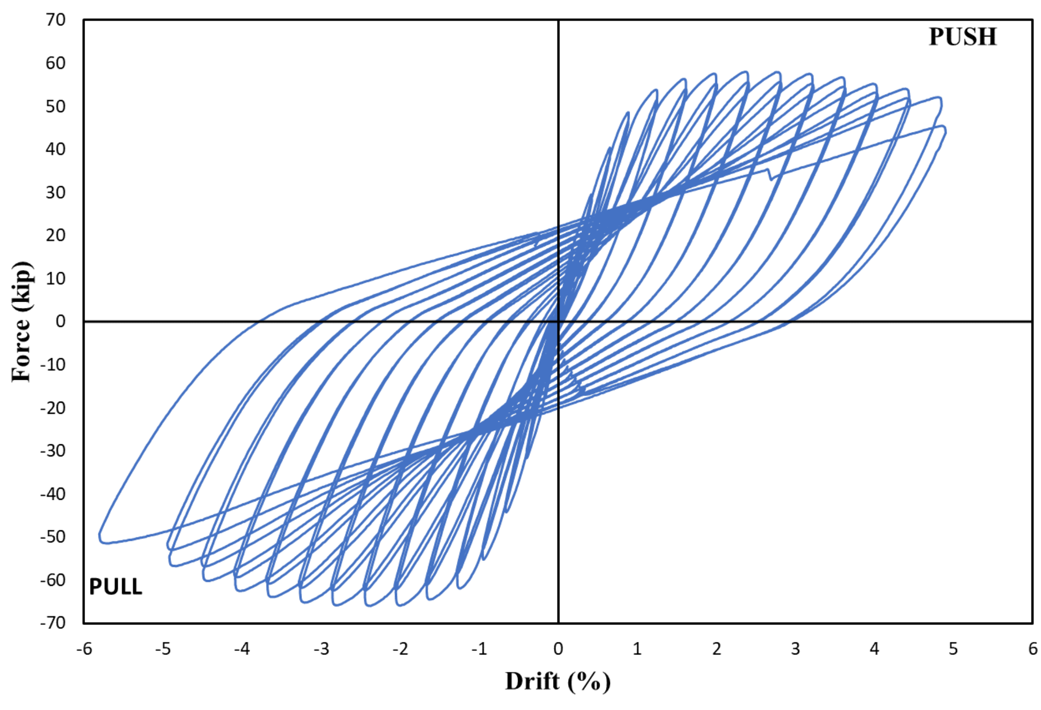


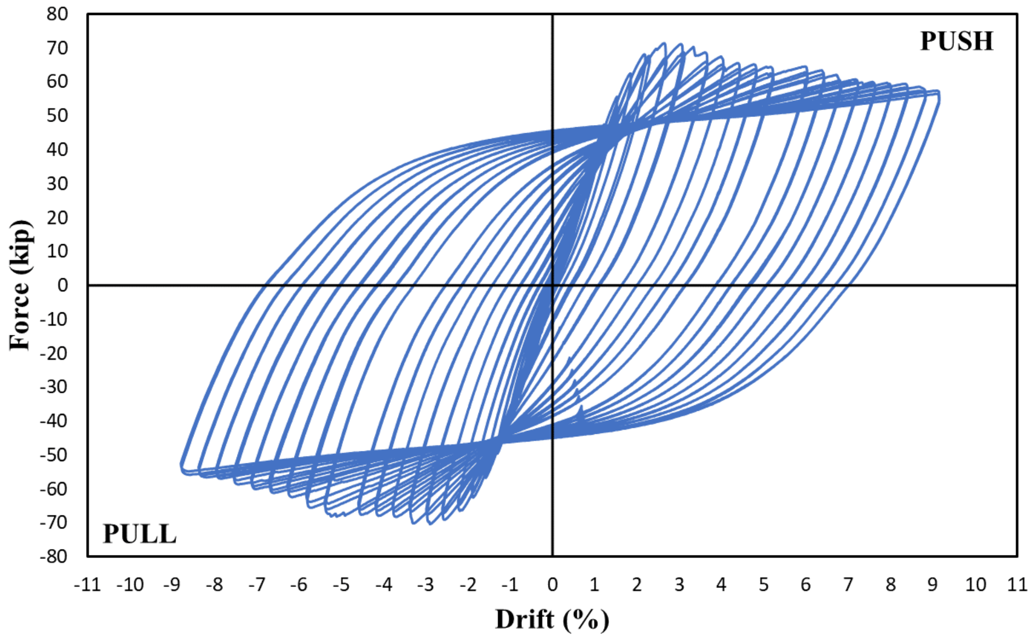
Figure 6: Bent Testing Arrangement

RESULTS

Figure 7 presents the resulting force drift hysteresis from the cast-in-place bent, (a), and the precast bent, (b). The cast-in-place specimen showed good ductility through out the test showing consistency in response through 15 cycles ultimately degrading 20% of the ultimate strength, 66 kip, at 15 cycles. The specimen produced a plastic hinge at each column connection. Failure initiated at each connection through cracking which progressed into spalling ultimately resulting in fracture of the longitudinal rebar in the column on the actuator side. From the precast bent hysteresis, it can be seen the proposed connections resulted in a stiffer bent structure resulting in a higher ultimate strength of 71 kip. The specimen ultimately completed 24 cycles compared to the cast-in-place's 15 completed cycles. The precast bent maintained strength through a higher drift percentage nearing 8% prior to resulting in a major degradation of strength. Similar to the cast-in-place the precast bent produced a plastic hinge at all four column connections and failure began through cracking. The cracking of the precast bent was far less with a concentrated gap opening at the interfaces. This allowed for the unbonded portion of the pipe to experience the most strain during testing resulting in slight bucking/bulging of the column pipe within the unbonded region. After test completion observation of the specimen showed a tear of the column pipe just inside of the footing and cap embed pipes providing the explanation for the large loss of stiffness in the final cycle.



(a) Cast-in-place bent



(b) Precast bent
Figure 7: Force-Drift hysteresis

CONCLUSION

From the research presented in this paper, an innovative precast connection for use in adapting ABC to seismic zones has been proposed. The proposed precast connection has the intentions of providing an emulative cast-in-place connection using precast elements while simplifying construction. The proposed connection provides high ductility and higher strength than that of cast-in-place under uni-directional quasi-static loading during experimentation of large-scale bent specimens. The investigated connection was designed with a bearing pad to allow for slight displacements to take place without sacrificing the cover concrete. The proposed connection also implemented an unbonded portion of the pipe to provide enhanced fatigue performance at higher drifts thus allowing a larger area of steel to yield during loading. This unbonded region experienced significant buckling upon reaching 7% drift, where it ultimately failed shortly after. The experimental testing of the cast-in-place and precast bent provided further experimental validation of the performance and ability of the proposed precast pipe connection. The Idaho Transportation Department has plans to implement the results from the research in the construction of an actual bridge in Idaho.

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