SEISMIC PERFORMANCE OF ONE-PIECE PIPE PINS AND PRECAST REBAR HINGES IN BRIDGE PIERS

A. Mehrsoroush1, M. S. Saiidi2, and K. L. Ryan3

ABSTRACT

Rebar hinges are the most commonly used type of bridge column hinges in the United States. The previous use of rebar hinges has been limited to cast-in-place construction. Previous earthquakes and studies revealed that rebar hinges suffer severe damage during strong seismic events due to shear failure and sliding. A new generation of pipe pins (labeled as one-piece pipe pin connection) was developed as an alternative for rebar hinges to improve the seismic performance and simplify construction. This connection type is constructed using a grout or concrete-filled steel pipe embedded at the column end and extends into a pocket in the adjoining member. To investigate and compare the seismic performance of precast rebar hinges and one-piece pipe pin connections, a large-scale precast two-column pier model was designed, constructed, and tested on a shake table at the University of Nevada, Reno. The pier columns were connected to a precast cap beam using a combination of rebar hinge and pocket detail for one column, and one-piece pipe pin and pocket detail for the other. The pier model was tested to failure under increasing amplitudes of the Sylmar Converter Station ground motion record. The proposed pipe pin and rebar hinge connections were found to be successful even under high drift ratios. Test results showed an enhanced seismic performance for pipe pins compared to rebar hinges.

1Professional Engineer, Nevada Dept. of Transportation, 1263 South Stewart Street, Carson City, NV 89517 (a.mehrsoroush@nevada.unr.edu)
2Professor, Dept. of Civil and Environmental Engineering, University of Nevada, Reno, NV 89557 (saiidi@unr.edu)
3Associate Professor, Dept. of Civil and Environmental Engineering, University of Nevada, Reno, NV 89557 (kryan@unr.edu)

Seismic Performance of One-piece Pipe Pins and Precast Rebar Hinges in Bridge Piers

A. Mehrsoroush¹, M. S. Saiidi², and K. L. Ryan³

ABSTRACT

Rebar hinges are the most commonly used type of bridge column hinges in the United States. The previous use of rebar hinges has been limited to cast-in-place construction. Previous earthquakes and studies revealed that rebar hinges suffer severe damage during strong seismic events due to shear failure and sliding. A new generation of pipe pins (labeled as one-piece pipe pin connection) was developed as an alternative for rebar hinges to improve the seismic performance and simplify construction. This connection type is constructed using a grout or concrete-filled steel pipe embedded at the column end and extends into a pocket in the adjoining member. To investigate and compare the seismic performance of precast rebar hinges and one-piece pipe pin connections, a large-scale precast two-column pier model was designed, constructed, and tested on a shake table at the University of Nevada, Reno. The pier columns were connected to a precast cap beam using a combination of rebar hinge and pocket detail for one column, and one-piece pipe pin and pocket detail for the other. The pier model was tested to failure under increasing amplitudes of the Sylmar Converter Station ground motion record. The proposed pipe pin and rebar hinge connections were found to be successful even under high drift ratios. Test results showed an enhanced seismic performance for pipe pins compared to rebar hinges.

Extended Abstract

The concepts of prefabricated bridge elements and systems (PBES) and slide-in construction have been used by the Nevada Department of Transportation (NDOT) for accelerated construction of single-span bridges. Single-span bridges are known to have adequate earthquake resistance. For NDOT to expand its accelerated bridge construction (ABC) program, reliable and practical

¹Professional Engineer, Nevada Dept. of Transportation, 1263 South Stewart Street, Carson City, NV 89517 (a.mehrsoroush@nevada.unr.edu)
²Professor, Dept. of Civil and Environmental Engineering, University of Nevada, Reno, NV 89557 (saiidi@unr.edu)
³Associate Professor, Dept. of Civil and Environmental Engineering, University of Nevada, Reno, NV 89557 (klyran@unr.edu)

earthquake-resistant systems need to be developed for bridges with two or more spans. To address this need, a 1:3 scale two-column bridge pier model was designed and tested to failure on a shake table. The experiment was designed to evaluate the seismic performance, response, and behavior of the most promising ABC connections that suit the needs of NDOT: (1) pocket connections with full moment transfer, (2) a pocket connection with partial moment transfer through a rebar hinge and (3) a pocket connection with partial moment transfer through a new one-piece pipe pin.

Pocket connections are constructed by making a pocket in the footing or cap beam, extending a fully precast column into the pocket, and grouting the gap between the column and the pocket. Rebar hinges are the most commonly used type of column hinges in the United States. These connections are composed of a central reinforcement cage with a diameter smaller than that of the column to reduce the moment transfer between adjoining members. A simple one-piece pipe pin was developed in the present study as an alternative to top or base rebar hinges to improve the seismic performance and simplify construction. The one-piece pipe pins are constructed by replacing the central element of the rebar hinge with an in-filled pipe embedded in the column and adjoining member crossing through a gap at interface.

Figure 1 shows the two-column pier model details. The model was composed of four conventional reinforced concrete precast segments: two precast columns, one precast cap beam, and one precast footing. The columns were connected to the cap beam using pocket connections combined with a rebar hinge for one column and a one-piece pipe pin for the other column to simulate hinge behavior. The column connections at the base were also pocket connections for full column moment transfer to the footing.
The rebar hinge was included in the model to compare directly its response with a one-piece pipe pin. Both columns were 7 ft 10.5 in. (2400 mm) in height and 1 ft 2 in. (357-mm) in diameter, with longitudinal steel ratio of 1.23% and volumetric transverse steel ratio of 1.81%. The cap beam was a 1 ft 10 in.×1 ft 8 in.×11 ft (559×508×3,353 mm) member with two circular pockets at the column locations. The footing was also a precast member with two circular pockets at the column locations. The columns were embedded in the footing pocket at the base and cap beam pocket at the top and the gap between the pockets and the columns protruded segment was grouted.

An external vertical load of 80.0 kips (355.9 kN) was applied on the pier cap, resulting in an axial load index of 6.8%. The internal forces of the pier were determined using equilibrium when plastic hinges formed at the top and bottom of the columns (collapse limit state). The rebar hinge was designed using the shear-friction method [1]. To allow for better spread of plasticity in the rebar hinge, the longitudinal reinforcement within the hinge gap was debonded from the surrounding concrete. To compare the performance of rebar hinges and one-piece pipe pins, a pipe pin was designed so that its flexural capacity was nearly the same as that of the rebar hinge. The pipe was debonded over a length equal to 0.4 times the pipe diameter in the pocket to spread flexural strains in the pipe. As capacity protected members, the cap beam, footing, and pocket connections were designed to remain elastic when the column underwent large plastic deformations. The columns were extended to a length of 1.2 times the column diameter into the pocket to ensure that the full moment capacity of the column would be developed at the top of the footing. More information on the details of the connections and the pier model is available in [2].

The 142-degree lateral component of the Sylmar Northridge 1994 record was simulated on the shake table tests through eight motions with increasing amplitudes. The condition of the column tops and bases at failure is depicted in Fig. 2. The column with rebar hinge and pipe pin are referred to as RH-Col and PP-Col, respectively, hereafter. The precast rebar hinge failed due to hinging within the hinge throat. The damage did not penetrate into the grout surrounding the rebar hinge in the cap beam pocket or the column top. The pipe pin, the grout around the pipe in the cap beam pocket, and the column top adjacent to the hinge area were all free from any damage. The base pocket connections were successful in hinging the columns outside the connection zone with no damage in the footing. Except for minor flexural cracks in the cap beam, no other damage was detected on the cap beam faces.

Figure 3 shows the cumulative hysteresis curves and the envelope. The measured displacement ductility capacity was 11.3. The top rotations of the two columns were comparable prior to the pier failure. The top hinges in RH-Col and PP-Col reached an absolute maximum rotation of 0.1604 and 0.1494 rad, respectively, at failure. PP-Col underwent higher bond-slip rotations at the base compared to RH-Col, which was attributed to the lower axial load in PP-Col caused by overturning moment.

The pipe yielded during run 4 (with the maximum drift ratio of 3.14%). The maximum tensile strain on the pipe was approximately 6.8 times the yield stain of the pipe recorded during run 6 (with the maximum drift ratio of 6.65%). The maximum measured shear strains on the pipe at the hinge gap center indicated that the pipe remained elastic with respect to shear. The rebar hinge longitudinal bars first yielded during run 3 (with the maximum drift ratio of 1.23%). The
maximum tensile strain in the bars was more than 20 times the yield strain. Under the design earthquake, the maximum rebar hinge and the pipe tensile strains were 11.7 and 2.3 times the associated yield strains of the bars and the pipe, respectively, indicating that the one-piece pipe pins are expected to undergo much less plastic strains at the design earthquake compared to commonly used rebar hinges. The maximum strains in the cap beam longitudinal and transverse reinforcements were smaller than the associated yield strains. The small measured strains with no apparent damage indicated that the cap beam indeed acted as a capacity protected member.

Figure 2. Condition of connections at failure (a) rebar hinge; (b) pipe pin; (c) RH-Col base; (d) PP-Col base

Figure 3. Cumulative force-displacement relationship of pier model

References
