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Experimental Validation of a Low-Damage Rocking Precast Concrete Cladding System

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ABSTRACT

This paper presents experimental validation of an innovative precast concrete cladding panel system that can resist design level inter-story drifts through 'rocking' of panels without incurring any significant damage. Two precast panels are manufactured with four vertically-slotted steel-embeds, allowing the bolts connecting the panels to the structure to slide and the panels to rock up to an intended lateral drift demand. The panels are placed adjacent to each other with a 15 mm wide vertical joint in between them, interjected with sealant, on a single-story steel frame, and subjected to quasi-static in-plane drift cycles. The test results show the ability of the 'rocking' panels to accommodate large lateral drifts (up to 4% in this test) without any noticeable damage to the panels or their connections requiring repair. The only damage observed during the test was distortion and tear of the sealant at close to 2% drift levels.

Introduction

Non-structural elements (NSEs) play a major role in fulfilling the operational and functional requirements of buildings. They have been recognized to contribute significantly to the overall building cost [1, 2]. Among the NSEs, precast concrete cladding panels are among the few components that pose a direct life-safety threat [3, 4]. Hence, they should be designed and installed to remain attached to the structure during earthquakes. In New Zealand and the United States, precast concrete cladding panels are generally 'isolated' from the movements of flexible structures using tie-back connections (slots or oversized holes) and bearing connections [5, 6]. The tie-back connections restrain the panels in out-of-plane direction while allowing in-plane translation of the panels during an earthquake, whereas the bearing connections transfer the gravity loads to the structure. In this system, drift incompatibility is expected during seismic events at building corners where two panels meet from orthogonal directions. Therefore, a vertical joint (usually filled with sealant) is provided at building corners to accommodate such relative movements [7].

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During the 2010/11 Canterbury earthquake sequence, several panels were found to be damaged. The damage sustained by the panels included: tear in sealants at joints, failure of connections, and cracks and collapse of panels [3, 4]. The slotted tie-back connections were reported to have insufficient capacity to accommodate the seismic deformation of the structure. In some cases, they were either inadequately detailed or improperly installed. These damages ultimately led to financial loss due to costly repairs and posed a significant threat to life safety [3]. It is, therefore, essential to design and detail the panel-to-structure connections to not damage in earthquakes.

The low-damage rocking connections details, shown in Fig.1, comprise two weld-plates and four steel-embeds with vertical slots. The weld-plates transfer the weight of the panels to the structure and they also act as the rocking surfaces during lateral movement. Each weld-plate consists of a steel plate with reinforcement bars welded to it. The weld-plates avoid the local chipping of the concrete during the rocking of the panels. Steel-embed consists of a steel plate with a vertical slot, steel studs, a cap, a bolt, and a washer. The length of the vertical slot and horizontal distance between the steel embeds determines the drift capacity of the panels. The steel studs resist the out-of-plane loads; the cap guides the bolt sliding facilitated by the grease injected into the slot. Detail description on the design method and fabrication process of these connections can be found in Bhatta et al. [8].

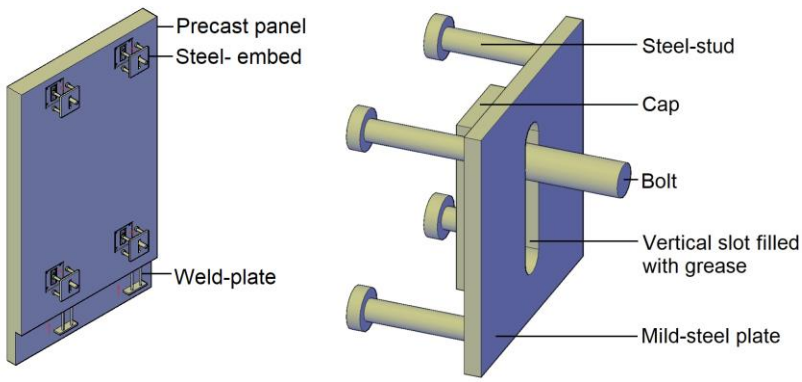

Figure 1. Precast panel with rocking connections (left) and steel-embed with vertical slot (right) [8].

Panel Specimens and Experimental Setup

Two identical panels of 2m height were designed and fabricated to rock up to 8% inter-story drifts before the vertical slot engaged and started transferring loads to the panels. The panel dimensions, locations of the rocking connections, and section details are shown in Fig. 2. The panels were attached to the structural frame designed to deform in a shear mode, as shown in Fig. 3. The top and the bearing connections between panels and the structural frame are shown in Figs. 4 and 5, respectively. The weld-plates rested on the rectangular hollow sections welded to the beam's web and transferred the panel's weight back to the structure. The horizontal slots provided tolerance to adjust the panels during the installation. The panels were adjusted, and a 15mm vertical gap was maintained between the panels using plastic shims. Once the panels were in position and the washers were tack-welded to the steel plate, the plastic shims were removed, the vertical gap was filled with sealant to depths of about 10mm. The panels were instrumented with potentiometers to measure their uplifts and change in the width of the vertical joint.

Experimental Results and Discussion

A 300kN actuator with a stroke length of $\pm$200mm applied the drift cycles following the FEMA-461 loading protocol [9] up to 4% drift, as shown in Fig. 6. The inter-story drift vs. overall lateral load response is shown in Fig. 7. The panels simultaneously rocked under the imposed drift demands causing shear deformation in the intermediate sealant. Because of the subsequent shear forces induced in the sealant, the lateral load increased with the increasing drift level. The sealant first tore locally at 1.92% drift (categorized as damage state DS1). It then tore the entire length (categorized as damage state DS2) at 2.70% drift, as shown in Fig. 8. It is assumed that the sealant had reached its ultimate shear strain capacity just before the tear. A drop in lateral load can be observed at these drift levels in the load-drift hysteresis curves. However, no noticeable damage to the concrete panels and their connections was observed during the tests.

The change in the vertical width between the panels was found to be negligible as the bolts of the top and bottom connections were prohibited from moving in the horizontal direction as the washers were tack-welded to the steel plate. As such, the griding of the bolt with the edges of the vertical slots introduced frictional resistance in the panel system. It can be observed in Fig. 7 that the load-drift curves are above the characteristic curve (developed considering free rocking of the panels at their bases) even after the sealant completely tore at 2.70% drift, which is attributed to such frictional resistance. A detailed discussion about the cause and effects of frictional resistance and ways to overcome it are presented in Bhatta et al. [8].

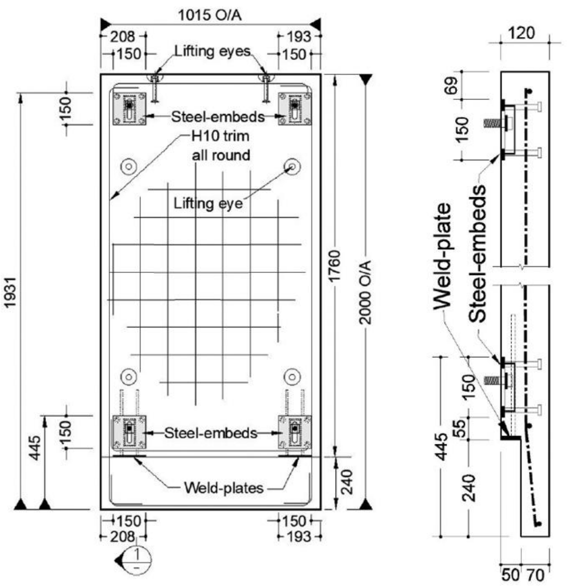

Figure 2. Panel details.

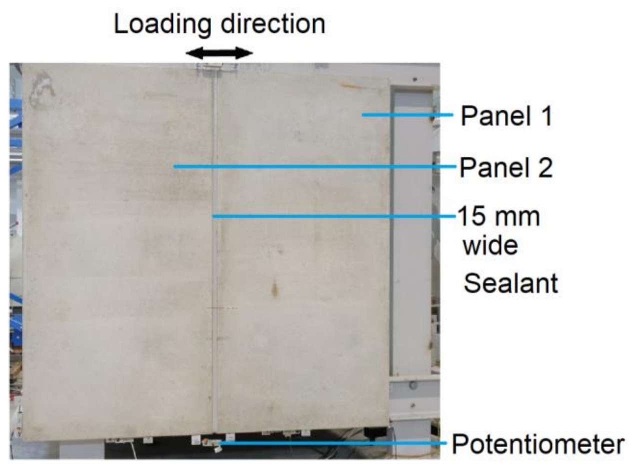

Figure 3. Experimental setup.

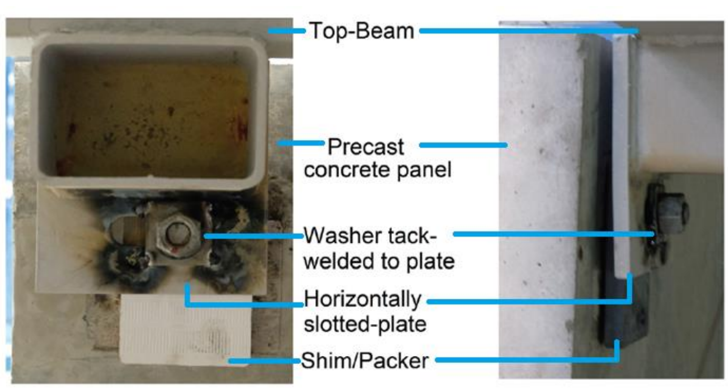

Figure 4. Top connections [8].

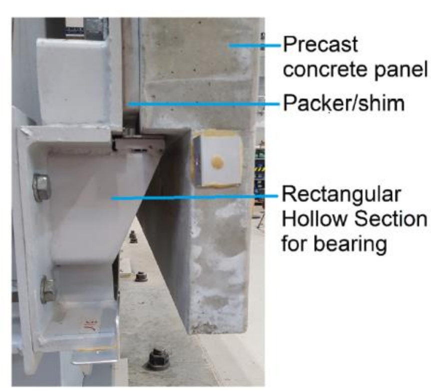

Figure 5. Bearing connections [8].

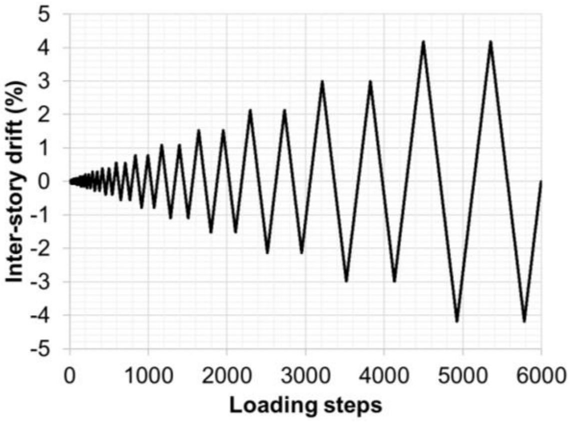

Figure 6. Loading protocol [9].

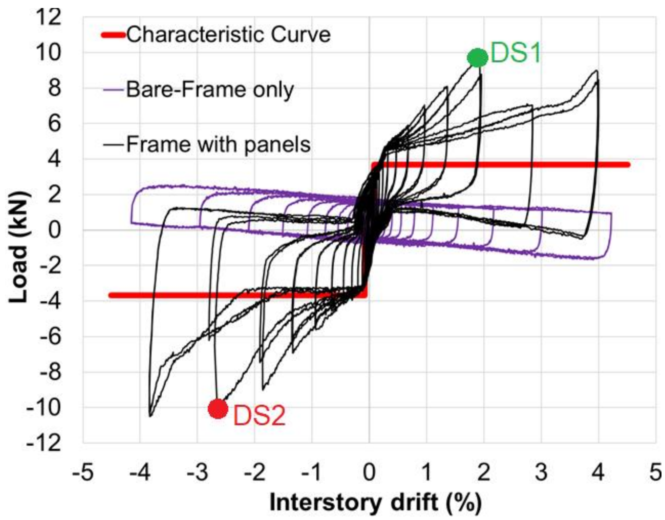

Figure 7. Force-drift hysteresis loops.

Figure 8. DS1 (left) and DS2 (right) in sealant.

Conclusions

A pair of adjacent precast concrete cladding panels, incorporating four steel embeds with vertical slots and two weld plates, were subjected to lateral cyclic drift demands (up to 4%) following FEMA-461 loading protocol. The panels were separated by a 15mm wide sealant joint. The panels accommodated the applied inter-story drifts, through rocking motion, without any significant damage (that required repair) to the concrete panels and their connections. However, tearing in the sealant was observed at an inter-story drift of 1.92%. Moreover, lateral forces increased due to frictional forces developed between the bolt and the edges of the vertical slots in the steel embeds. It is acknowledged that the novel rocking panel system needs further validation to confirm its performance under out-of-plane actions and dynamic loads. However, this research provides preliminary evidence that the low-damage rocking panel system can potentially have much superior seismic performance compared to its incumbent counterparts.

Acknowledgments

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