Innovative Retrofit Solution for Exterior Unreinforced R.C. Beam-Column Joints

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ABSTRACT

Most reinforced concrete (RC) frame buildings in New Zealand constructed pre-1960s have no transverse reinforcement in beam-column joints. Following MBIE/NZSEE assessment guidance, the seismic performance of RC frames with unreinforced beam-column joints is often limited by the strength of the joint, especially for exterior joints with plain longitudinal beam reinforcement terminating in 180º hooks. Previous testing has shown that for this joint type, due to bond deterioration and bar slip, a compression force develops in the concrete wedge at the back of the joint which can cause it to spall out, compromising the gravity-load carrying capacity of the column.

In this paper, an innovative retrofit approach is investigated using a bidirectional test on a corner beam-column joint with the aforementioned deficiencies, based on a 1930s RC frame building in Wellington, NZ. This retrofit uses drilled and epoxied reinforcement bars at the face of the joint to increase the tensile strength of the joint and prevent the concrete wedge spalling failure.

1 INTRODUCTION

One of the typical deficiencies in reinforced concrete structures designed pre-1970s is lack of joint transverse reinforcement and lapped splices located close to the joints. Severe damage in a joints may result in deterioration of the structure during a seismic event.

Different strengthening techniques for beam-column joints has been widely studied by a number of researchers (Realfonzo 2014) (De Vita 2017) (Prota 2004) (Sharbatdar 2012) (Shafaei 2014) (Maddah 2020) (Pampanin 2007). Pampanin et al. (Pampanin 2007) proposed wrapping the columns, beams, and the joint with GFRP. Their study showed the load-carrying capacity can be enhanced by about 200%; however, strength deterioration starts to happen at 2% drift. Shafaei et al. (Shafaei 2014) proposed joint enlargement using pre-stressed steel angles to shift the plastic hinges away from the joint panel. Their proposed method was shown to significantly enhance the seismic capacity of the joints, in terms of strength, stiffness, energy dissipation and ductility capacity. Shaaban and Seoud (Shaaban 2018) investigate the efficiency of an added ferrocement layer (i.e. steel wire mesh embedded in cement mortar) to retrofit beam-column joint with insufficient confinement reinforcement. Their proposed technique improved the seismic performance and increased the dissipated energy. Wang et al. (Wang 2019) used externally CFRP sheet and near-surface mounted CFRP strips to shift the plastic hinge away from the joint.

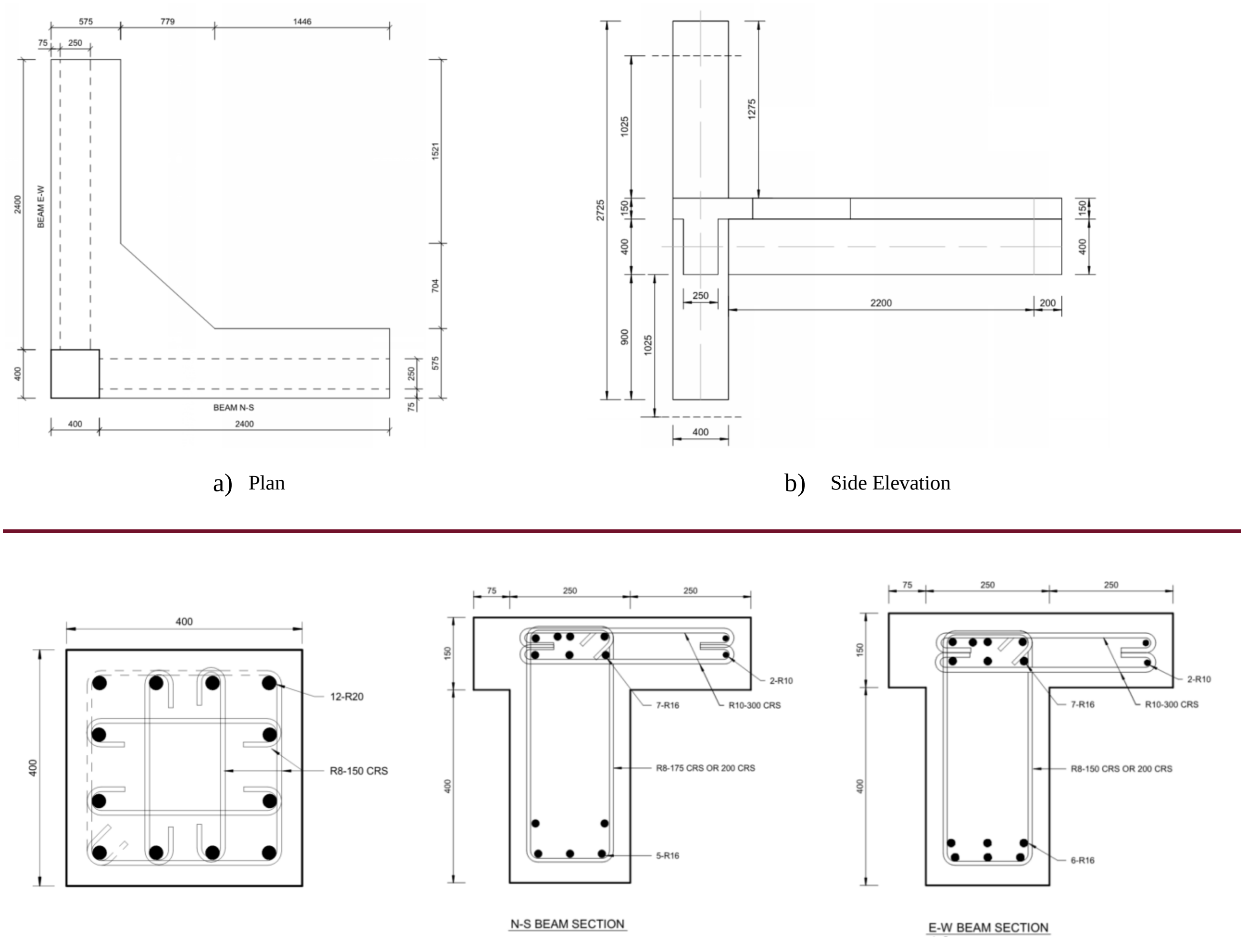
Most beam-column joint strengthening techniques using FRP, steel/concrete jacketing or pre-stressed rods require skilled workers to partially demolish around the joint to gain access before installation. In most cases these techniques are not considered practical for on-site construction, particularly for heritage buildings.

In this study, a new retrofit method is proposed to strengthen corner beam-column joints using post-installed rebar embedded into the joint.

2 EXPERIMENTAL PROGRAM

2.1 Test Specimen

The specimen was developed to represent an exterior corner beam-column joint for a seven-storey building constructed circa 1930s in Wellington, New Zealand. Figure 1 illustrates the designed specimen, which was scaled to 70% of actual. The subassembly was isolated to the point of contraflexure in the beams and columns. To investigate the effect of slab on the performance of the joint, a portion of the slab width included in the specimen.



a) Plan

b) Side Elevation

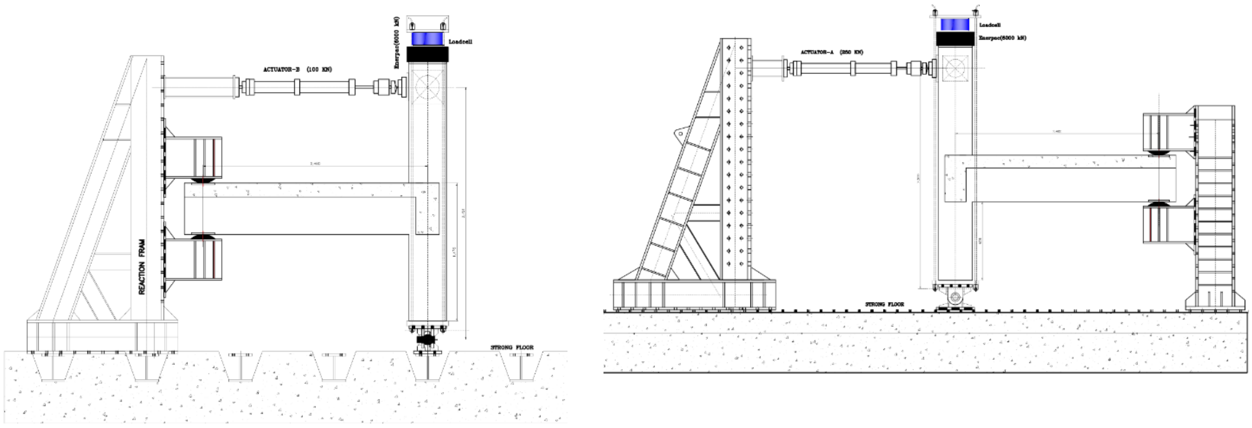
c) Column Section

d) Beam Section

Figure 1: Reinforcing and geometry details of the specimen.

2.2 Test setup, and Loading Protocol

Figure 2 illustrates the schematic test setup and loading system. In this setup, beam and column elements were extended to the contraflexure point with pin connections. Bi-directional inter-storey drift was applied through the horizontal hydraulic actuator at the top of the column. An octo-elliptical loading pattern with an aspect ratio of 0.5 was applied as per the suggestions by Bueker et al (Raza 2019), as illustrated in Figure 3.



a) **N-S direction**

b) **E-W direction**

Figure 2: Test Setup

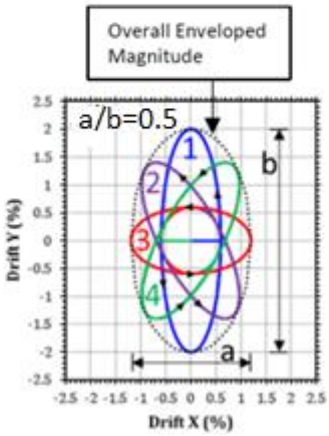


Figure 3: Loading protocols proposed by Raza et al. for bidirectional loading (Raza 2019).

3 PROPOSED STRENGTHENING SOLUTION

The proposed strengthening is a passive solution where the intention to improve the principle tensile stress capacity in the joint region. The proposed solution consists of post-installed rebars drilled into the joint with an epoxy resin. Since the principle tensile stress in the joint is diagonal, the holes were drilled diagonally.

Due to the lack of transverse stirrups or confining reinforcement in the joint region, the column vertical reinforcement is vulnerable to buckling once the damage extends into the joint. Figure 4 shows the retrofitted joint reinforcement details. The drilled hole diameter was 12mm, and the post-installed rebar were 10mm diameter with Hilti HIT RE-500 epoxy resin. Figure 5 shows the inclined bars and finishing.

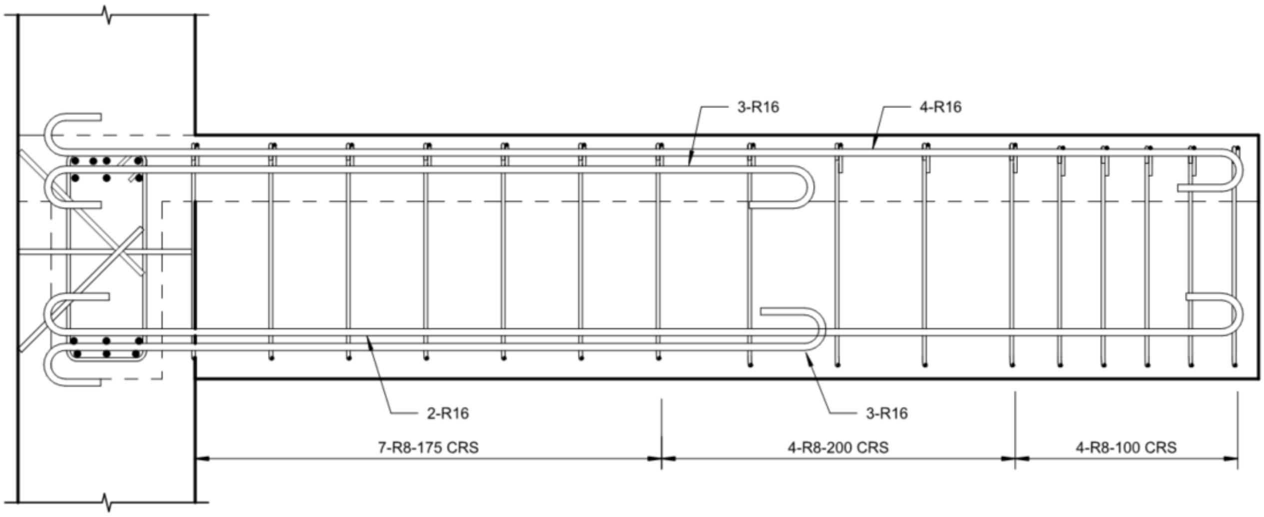


Figure 4: Retrofit solution.

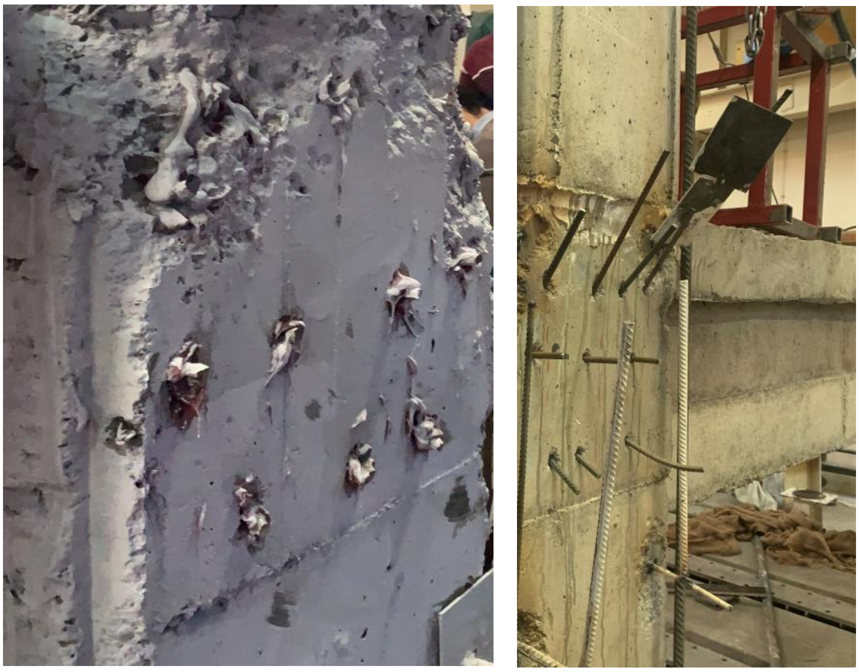
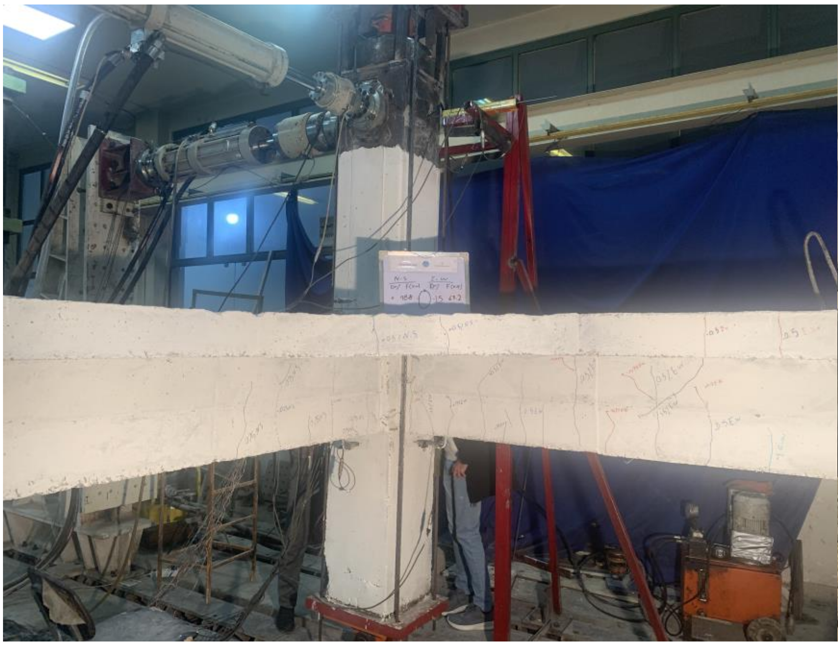


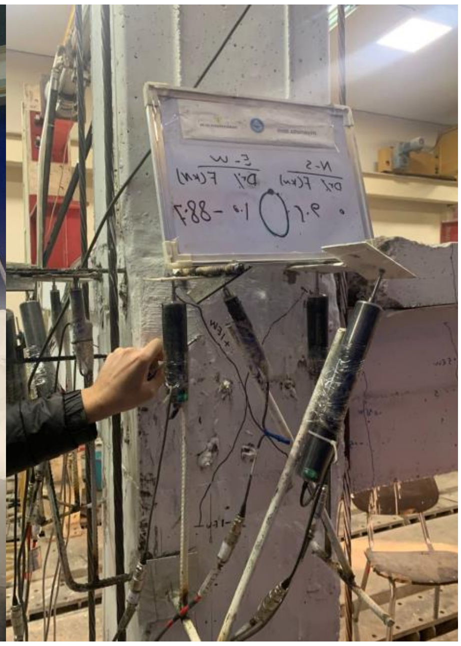
Figure 5: Detail of drilling and rebar installation into the joint.

4 TEST RESULTS

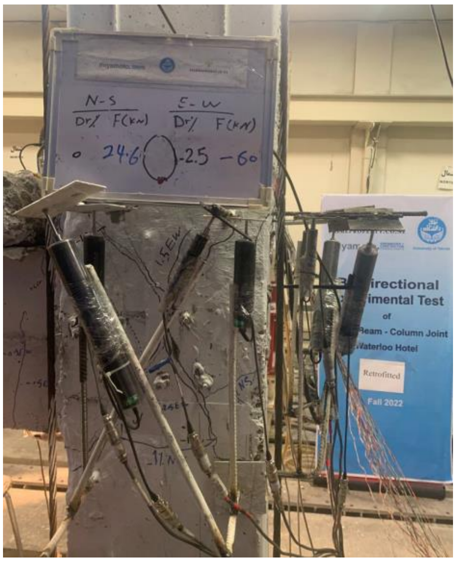
During the testing, flexural cracks on the beams start to form at a drift ratio of 0.25% and continued to increase at 0.5% drift. A vertical crack was opened at the beam-column interface at 0.5% drift. Diagonal cracking of the joint in the E-W direction formed at 1% drift and was opened to 1.5mm at 3.2% drift. No joint strength degradation was observed up to 3.2% drift. The test was terminated at 3.2% drift as there was minor misalignment in the embedded plate which transfers the load from the actuator and there was a concern this would induce torsion at high levels of drift.



a)



b)



c)

d

Figure 6: Observed cracking pattern of E-W cycle of a) +01.5%; b) 1.5%; c) +2.5% and d) end of test 3.2%

The force-displacement hysteresis plot for the specimen is given in Figure 7.

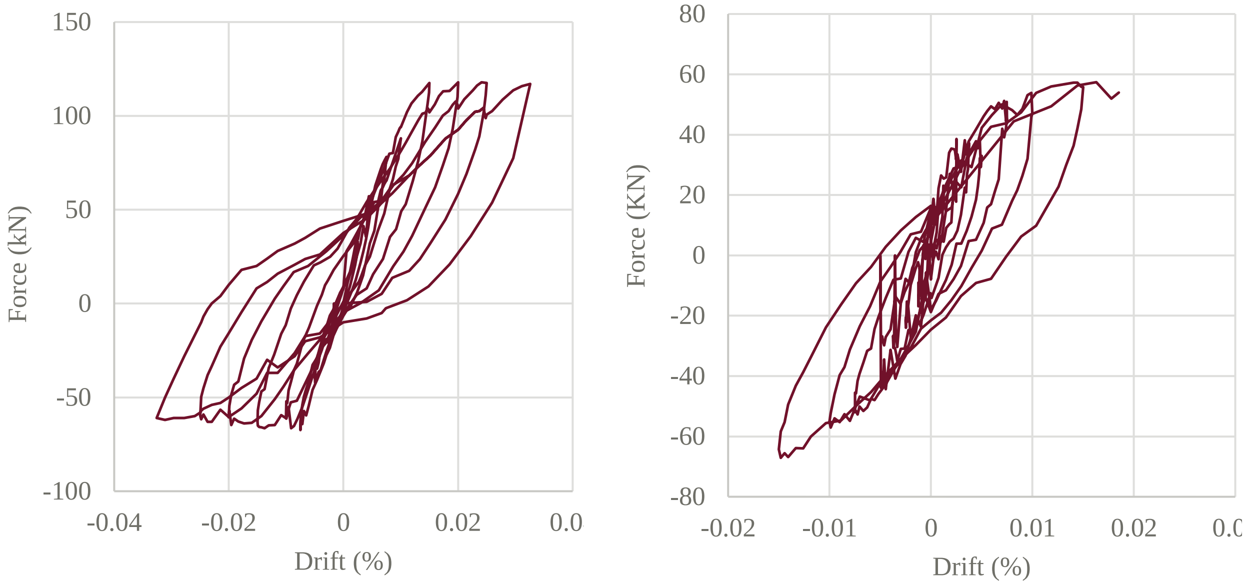


Figure 7: Top column lateral force versus drift, right) N-S direction; left) E-W direction.

Following the test, the beam column joint was demolished to investigate any potential cracking at the end of the hooks which would suggest bar slippage. As seen in Figure 8, no separation between concrete and reinforcing bars was observed at the end of the hooks.

Figure 8: The beam-column joint after demolition

A comparison of the force-displacement response of the reference specimen and the retrofitted one is illustrated in Figure 9. From this figure it can be seen that even though there was no significant difference in the lateral strength between the two specimens, the ductility of the retrofitted specimen was at least 50% more than the intact specimen. It is worth noting that the testing of the retrofitted specimen was terminated on 3.2% drift due to a deficiency in the test setup and further ductility would be expected if the test is repeated.

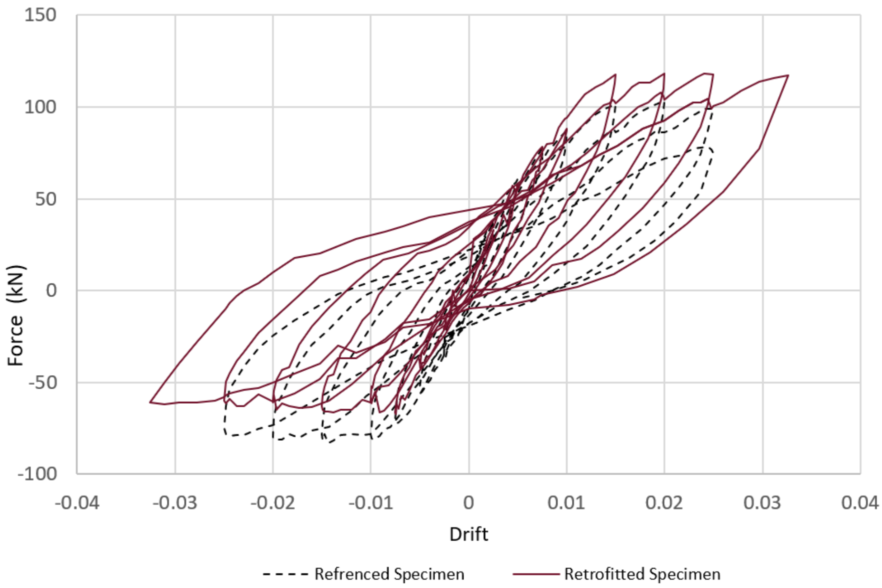


Figure 9: Comparison of the intact specimen and the retrofitted one

5 CONCLUSIONS

In this study, the performance of a proposed retrofit solution for the beam-column joint was investigated using cyclic bidirectional quasi static test. The retrofit solution includes post-installing diagonal reinforcing bars with epoxy resin into the beam-column joint. The main purpose of the retrofitting method was to increase the principle diagonal tensile strength in the joint. Comparison of the results of the retrofitted specimen with the original specimen showed a significant increase in ductility capacity with no significant improvement in lateral strength. The retrofitted specimen also shows a more stable response in comparison with the unstrengthen specimen for out-cycle strength degradation at high drifts.

This retrofit solution showed good seismic performance and is significantly less intrusive making it a practical solution for heritage buildings.

6 ACKNOWLEDGMENT

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