PERFORMANCE OF POST-TENSIONED WIDE BAND BEAM – COLUMN CONNECTIONS UNDER SEISMIC LOADING REPAIRED USING CFRP

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ABSTRACT

The use of wide, post-tensioned band beams for floor systems is extremely common in Australia. They are required to be capable of deforming with a building during an earthquake, and are increasingly being used as part of the lateral resistance of a building. However, relatively little is known about their performance under earthquake loading. This paper presents the results achieved for a post-tensioned wide band beam subject to lateral loads, designed and detailed to resist gravity loading, and the reparation and re-testing using CFRP. The results achieved have shown that both this type of construction and this type of repair are capable of achieving sufficient drift ratios without significant loss in capacity for areas of low to moderate seismicity. There is also potential for use in areas of higher seismicity.

KEYWORDS

CFRP, post-tensioned concrete, repair, seismic, wide beam.

INTRODUCTION

Wide, shallow, post-tensioned concrete band beams are an extremely common method of floor construction used in Australia. Beams used are generally considerably wider than the columns to which they connect (4.8 times wider is fairly typical). They have been used in carparks, hospitals and offices and are popular due to the smaller floor-to-floor height and ease of construction. During a seismic event, these beams and columns are required to be able to deform with the building without any loss of strength. Further, there is growing need to utilise these beams to resist lateral loading as moment resisting frames (MRFs) under earthquake loading. Unfortunately, there is little research on the performance of beams of widths typically used in Australia (widths up to 2400mm are commonly used) under this type of loading. There has also been little research presented on suitable methods of repair for these types of connections after damage from a seismic event. The research presented here aims to assess the capability of these connections under earthquake loading, and the suitability of the use of carbon fibre reinforced polymer (CFRP) to repair the connection after a seismic event.

EXPERIMENTAL PROGRAM

Design of Test Specimen EXPT-1

Specimen EXPT-1 was designed to represent what is typically constructed in Australia, without any special seismic detailing. It was designed to resist gravity loading in accordance with AS3600-2009. The specimen is half-scale due to space requirements at Swinburne University, and reinforcement content and dimensions have been scaled accordingly. The specimen was stopped at points of contraflexure during an earthquake event – i.e. at beam mid-span and column mid-height. An additional area of slab has been included in the specimen in order to assess the impact this would have on results. Figure 1 - Figure 3 show the concrete and reinforcement layouts of this test specimen. Worth noting is the content of ordinary reinforcement is kept minimal, as is typical for fully post-tensioned band beams. Further, the only ligatures present in the beam are construction ligatures (used to aid in tying reinforcement), and are not considered in shear design. The stress in the band beam due to the post-tensioning is approximately 1.33MPa, after losses.
Figure 1: Concrete profile plan for EXPT-1

Figure 2: Top and bottom reinforcement plan for EXPT-1

Figure 3: Post-tensioning plan for EXPT-1
Gravity load was placed on the specimen using concrete blocks. The blocks were suspended from the specimen using a system of threaded rods, spreader beams and slings. The column has a stress bar cast into it, stressed to 395kN, to simulate gravity loading on the column. A roller support was placed at beam mid-span, and a pin at the column base. A 100kN actuator was connected to the top of the column, and a horizontal load of 22.4kN was applied to simulate the initial bending moment in the beam due to gravity loading. The actuator was then switched to displacement control, displacement zeroed and the load history was applied. The load history was determined based on guidelines contained in FEMA 461 (FEMA, 2007). The test was quasi-static, and cycled about the gravity load case. Figure 4 shows the specimen test set-up.

Figure 4: Specimen EXPT-1 set up

After the initial test, Specimen EXPT-1 was repaired using layers of bi-directional woven fabric carbon fibre reinforced polymer (Tyfo BCC Composite). The arrangement and application of the CFRP (Figure 5 - Figure 7) was chosen such that areas damaged in the initial test were all covered in fabric. However, tendon anchorage protuberances were in the way in some areas, so the layout is not completely ideal. Areas covered consisted of the plastic hinge region in front of the column, as well as the torsion zones adjacent to the column and along the back of the edge beam. The repaired test specimen was subject to the same load history as the initial test.

Figure 5: CFRP layout for Layer 1- slab top (bottom similar)
After removal of severely damaged concrete, the specimen was repaired using cementitious grout in areas of major damage. The concrete surface was prepared using a grinder with a vacuum attachment, and an Mbrace primer was then applied to the concrete surface and left until sticky. An Mbrace saturant was then applied, followed by the first layer of CFRP. The saturant was then applied to the layer of fabric, and this was repeated for the next two layers. The epoxy was then left to dry under halogen flood lights for a period of 6 days (Figure 8). The heat generated by the lights enabled quicker development of strength.
RESULTS AND DISCUSSIONS

Specimen Performance

The load vs. displacement hysteresis loops for both the initial test and the repaired test can be seen in Figure 9, and the resulting backbone curves from the first cycle of both tests in Figure 10. Note that ‘positive’ displacement (and force) refers to the actuator pulling the specimen back (i.e. tension in the top of the beam), whereas ‘negative’ displacement refers to the actuator pushing the specimen (i.e. tension in the bottom of the beam). The sharp ‘kinks’ that can be seen in the loops as the actuator changes from positive to negative displacement (and vice versa) are as a result of the small out-of-plane sideways movement that caused the roller on one side to move against a steel equal angle section. This does not have a significant impact on the key points of interest in the loops. The initial test shows high initial stiffness, due to the compression induced by the post-tensioned tendons, while showing high ductility in both directions. No loss in capacity was shown until around 3% drift in either direction. Flexural cracking was observed in the plastic hinge region at the column joint interface in the top and bottom of the beam, and these cracks reached the full extent of the slab. Diagonal torsional cracking was observed in the top and bottom of the band beam in areas adjacent to the column sides. Large diagonal torsional cracks also occurred along the back face of the edge beam, close to the column. The column itself showed no significant signs of damage. After repairing with CFRP, the specimen achieved similar displacement levels without any loss of capacity. The initial stiffness was much lower, as a result of the existing cracks, however the ultimate force achieved was greater. Only small local debonding at the CFRP edges had occurred prior to the stopping the test.

Figure 9: Actuator load vs. displacement hysteresis loops for Specimen EXPT-1
Due to testing equipment limitations, failure was not achieved during the repaired test. A monotonic test in the negative direction was undertaken in order to determine failure mode, and the resulting force vs. displacement graph can be seen in Figure 11. The CFRP debonded on the bottom of the specimen at -110.2mm (-5.65% drift).

Figure 11: Actuator force vs. deflection for the monotonic test to failure of the repaired Specimen EXPT-1

**Drift Demand**

Various design codes contain design limitations on maximum allowable drifts in buildings. The Australian earthquake design code AS1170.4-2007 limits the allowable interstorey drift to 1.5%. NZS1170.5 (2004) limits the allowable drift to 2.5%, while Eurocode 8 (2004) varies from 1.0 to 2.5%. The maximum achieved drift without significant loss in capacity in both the initial test and repaired test exceeds these limits. Other authors (Goldsworthy and Abdouka (2012), Fardipour et al (2011)) have provided drift demand estimates for buildings in low to moderate seismic conditions. The 3.0% drift achieved prior to reduction in capacity is higher than these demands, though some damage to the beams might occur in some circumstances. Though the eventual failure of the repaired specimen was sudden, the level of drift achieved prior to this was greatly in excess of what would be required under a seismic event. Therefore, it can be concluded that the type of construction and CFRP repair both result in drift levels greater than that required in a low to moderate seismic zone. However, the low initial
stiffness would indicate that this type of repair may not be sufficient if drifts are required to be controlled by the MRFs. Therefore, it may not be suitable where the frames are the only form of lateral resistance of a building.

CONCLUSIONS

This paper has presented the results of testing done on a half-scale post-tensioned wide band beam under earthquake loading, designed and detailed to resist gravity loading in a manner typical to Australian conditions, and on the same specimen repaired with CFRP. The results achieved have shown that both this type of construction and this type of repair are capable of achieving sufficient drift ratios without significant loss in capacity for areas of low to moderate seismicity. There is also potential for use in areas of higher seismicity.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Grocon for constructing the test specimen and providing the concrete and reinforcement, as well as Freyssinet for providing the tendons and stressing services. Thanks also to Bonacci Group for assisting with developing the Autocad drawings.

REFERENCES