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Research Article

Analysis Of Rehabilitation Strategies For Damaged Exterior Beam-Column Connections

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ABSTRACT

This experimental study focuses on examining the behavior of exterior beam-column connections under cyclic displacement at higher frequencies. We investigate three common deficiencies—beam weak in flexure (BWF), beam weak in shear (BWS), and column weak in shear (CWS)—using specimens of varying sizes. The specimens undergo initial testing as control specimens, are then subjected to damage simulating real-world conditions, and are finally rehabilitated using two different strategies. We clearly identify each specimen type and condition through a meticulous naming convention. The study offers valuable insights into the behavior of these connections under different flaws, sizes, and repair methods, shedding light on their performance during repetitive loading and unloading cycles.

Keywords: Rehabilitation strategies, Structural integrity, Retrofitting, Rehabilitation techniques, Retrofit

Introduction

In recent decades, the importance of infrastructure has been increasingly recognized, not only for its functional utility but also for its role in ensuring public safety and economic growth. Among the crucial elements of infrastructure, building structures stand out as the backbone of urban development. However, as infrastructure ages, deterioration becomes inevitable. One of the critical components prone to damage is exterior beam-column connections in buildings, especially in regions prone to seismic activity.
The integrity of beam-column connections is vital for the overall stability and safety of a structure. Damage to these connections can compromise the structural performance of a building, making it susceptible to collapse during seismic events or other extreme loading conditions. Therefore, the development of effective rehabilitation strategies for damaged exterior beam-column connections is of utmost importance in ensuring the safety and resilience of structures.
Exterior beam-column connections are critical structural elements that transfer loads between beams and columns, ensuring the overall stability and integrity of a building. These connections play a crucial role in resisting lateral loads, such as those induced by wind or seismic activity. The behavior of beam-column connections significantly influences the overall performance of a structure during extreme events.
Damage to exterior beam-column connections can occur due to various reasons, including seismic events, overloading, corrosion, poor construction practices, and material degradation over time. Common types of damage include concrete spalling, reinforcement corrosion, cracking, and joint shear failure. If left unaddressed, such damage can compromise the structural integrity of the building, posing significant risks to occupants and neighboring properties.

Existing Rehabilitation Techniques

Rehabilitation of damaged exterior beam-column connections involves repairing, strengthening, or retrofitting the connections to restore their structural integrity and enhance their performance. Various rehabilitation techniques have been developed and employed to address different types and extents of damage. These techniques can be broadly categorized as traditional methods and innovative approaches.

Traditional Methods: Concrete Jacketing: This method involves placing a new layer of concrete around the damaged connection to restore its strength and stiffness. Concrete jacketing is effective in enhancing the capacity and ductility of beam-column connections, especially in cases of concrete spalling and deterioration.

Steel Plate Bonding: In this method, steel plates are bonded to the damaged connection using epoxy adhesives. The steel plates provide additional reinforcement and improve the load-carrying capacity of the connection. Steel plate bonding is suitable for strengthening damaged connections subjected to shear and bending forces.

Grouting and Injection: Grouting and injection techniques involve filling voids and cracks in the damaged connection with grout or epoxy to improve its structural performance and durability. These methods are effective in repairing cracks, voids, and minor damage in beam-column connections.

Material and Method

The experimental investigation focused on the behavior of exterior beam-column connections under higher frequency cyclic displacement. Three common deficiencies were considered: beam weak in flexure (BWF), beam weak in shear (BWS), and column weak in shear (CWS). Three geometrically similar specimens, representing each deficiency type: full scale, two-thirds scale, and one-third scale, initially served as control specimens. We then subjected these control specimens to damage, simulating real-world conditions, and later rehabilitated them using two different strategies.
We adopted a naming convention to differentiate between specimens. The first three alphabets indicated the deficiency type; the fourth indicated the size; and the fifth alphabet indicated whether the specimen was a control (undamaged) or a rehabilitated specimen. For example, 'BWFLC' denoted a beam weak in flexure large control specimen; 'BWSMRe' denoted a beam weak in shear medium rehabilitated specimen; and 'CWSSC' denoted a column weak in shear small control specimen. This set-up for the experiment let us look closely at how exterior beam-column connections behaved with various flaws, sizes, and repair methods, teaching us a lot about how they work when they are loaded and unloaded many times.

Performance Evaluation of Flexurally Weak Beam Connections under Loading

The examination of the damaged specimen at the conclusion of testing, as depicted in Figure 1, revealed some significant insights. Initially, hairline cracks emerged during the initial loading phases, both at the joint region and the interface of the beam-column joint. As the loading cycles progressed, substantial damage became localized primarily at the beam-column joint interface. This manifested in the form of concrete crushing, observed in both the control and rehabilitated specimens. Notably, a wide crack, approximately 5 mm in width, was evident at the joint interface in both sets of specimens.
The control specimen reached its maximum load at 42.48 kN and 39.03 kN, occurring at displacements of 26.67 mm and 20 mm in the push and pull directions, respectively. Comparatively, the rehabilitated specimens exhibited slightly higher loads, peaking at 42.43 kN and 39.86 kN, at displacements of 33.33 mm and 30 mm in the push and pull directions, respectively.
Furthermore, the ultimate load carrying capacities for the BWFMC and BWFMRe specimens were determined to be 40.755 kN and 41.145 kN, respectively. This data provides valuable insights into the performance of the rehabilitated specimens compared to the control, indicating improvements in load-bearing capabilities following the rehabilitation process.

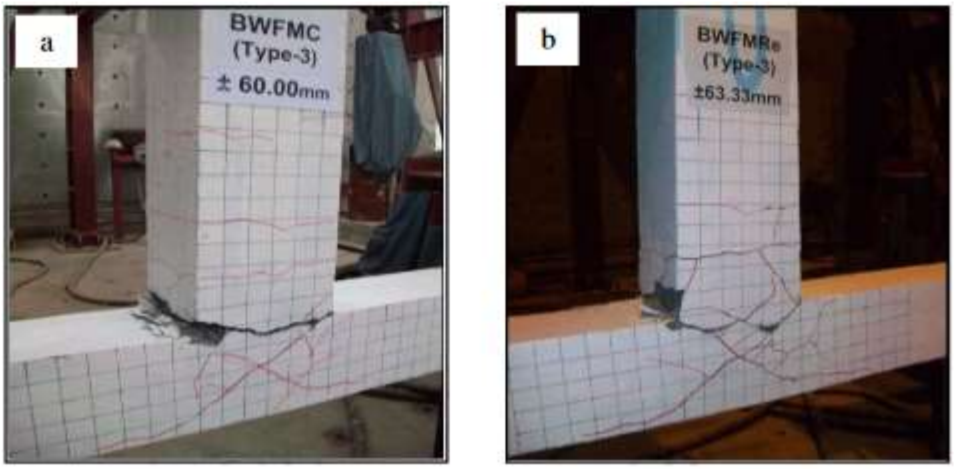
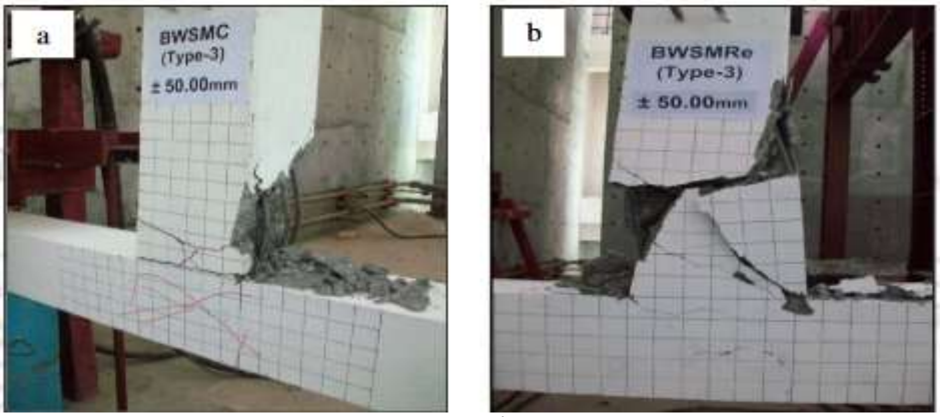


Figure 1. Control and Rehabilitated BWF Specimens under Loading

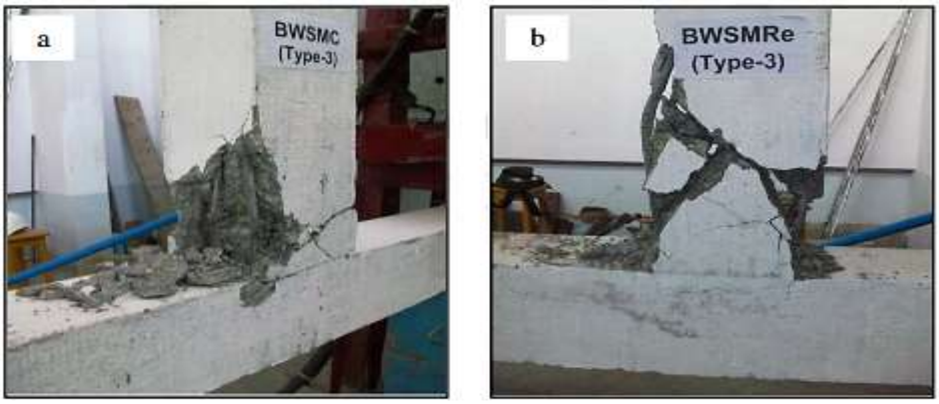
Analysis of Beam Behavior with Inadequate Shear Connections

Following the testing, an analysis of the specimen conditions revealed intriguing observations. Initially, both specimens showed minor cracks near the joint interface and the adjoining joint region at low amplitudes. However, as the loading cycles progressed, the damage became more concentrated in the beam adjacent to the joint interface. Ultimately, both the control and rehabilitated specimens experienced failure at the weakest shear zone within the beam without significant damage to the comparatively stronger joint region. The failure manifested itself in severe concrete crushing and buckling of the main reinforcements. The main reinforcing beam bars buckled due to a lack of adequate shear reinforcement.

Interestingly, the rehabilitated specimen exhibited more severe damage compared to the control specimen. This result makes us want to learn more about how well the rehabilitation methods used worked and points out places where they could be improved to make structures stronger and lessen damage in similar situations.



Front View



Rear View

Figure 2. Control and Rehabilitated BWS Specimens under Loading Type-3: Post-Test Condition Evaluation

Result and Discussion

In this analysis, we delve into the behaviors of various connections when exposed to different loading frequencies. The study compares the results from two specific loading types: type-2 and type-3. Interestingly, we excluded type-1 from the comparison because of its unique cycle-per-amplitude dynamics in contrast to the other two types. The focus of this study is on understanding hysteretic responses, discerning damage patterns, and evaluating the impacts of inertial forces across these different loading conditions.

By scrutinizing the hysteresis loops, researchers sought to understand how the connections responded under varying loading frequencies. These loops provide insight into the energy dissipation and structural behavior during loading and unloading cycles. Understanding the hysteretic responses aids in gauging the connections' resilience and stability under different dynamic conditions.

Moreover, the investigation delved into discerning the damage patterns exhibited by the connections under type-2 and type-3 loading. This aspect is crucial for assessing the structural integrity and predicting potential failure modes under different loading scenarios. Identifying and comparing these damage patterns aids in elucidating the connections' performance and susceptibility to fatigue and deformation.

Additionally, the study examined the effects of inertial forces on the connections. Inertial forces can significantly influence structural responses, especially in dynamic loading scenarios. By comparing the responses under different loading frequencies, researchers aimed to discern how these inertial forces interacted with the connections and whether they exacerbated or mitigated structural damage. The study checked how strong the specimens were in earthquakes by looking at their ultimate strength, stiffness degradation, energy loss, and ductility based on how they responded to hysteretic forces. The envelope curves of hysteresis loops for all control specimens were compared at lower and higher loading frequencies.

Figures 3 to 5 illustrate the envelope curves of hysteresis loops. It's evident that there's a consistent trend in the load-displacement curves for all specimens, regardless of the loading frequency. However, it's notable that the envelopes of hysteresis loops in specimens subjected to loading type 3 exhibit slightly higher load-carrying capacity in both push and pull directions. This suggests that loading type 3 may offer enhanced seismic performance compared to the other loading types.

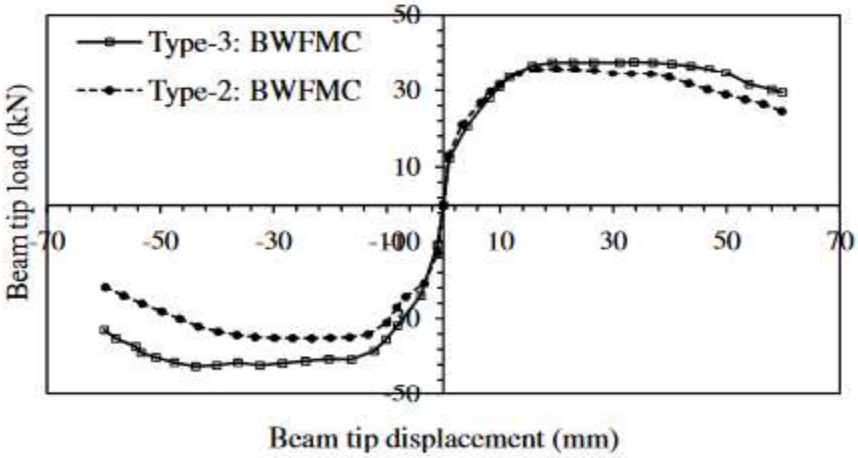


Figure 3. Assessment of Envelope Curves for BWFC Specimens under Loading Variations

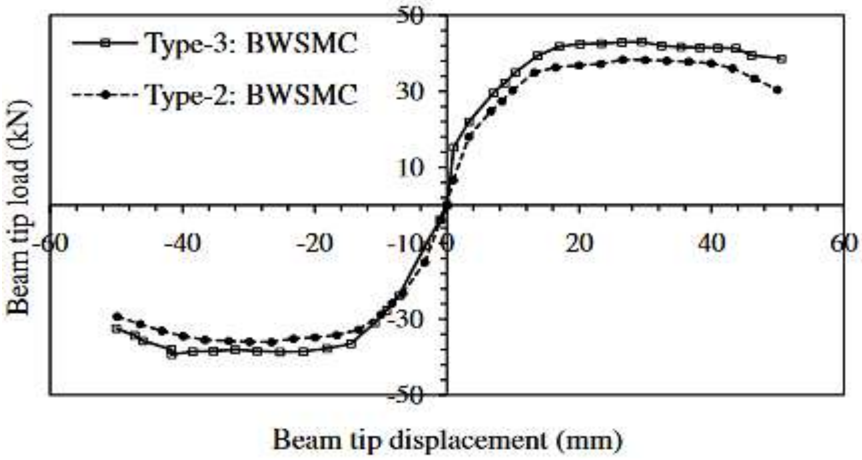


Figure 4. Envelope Curves of BWSC Specimens under Diverse Loading Scenarios

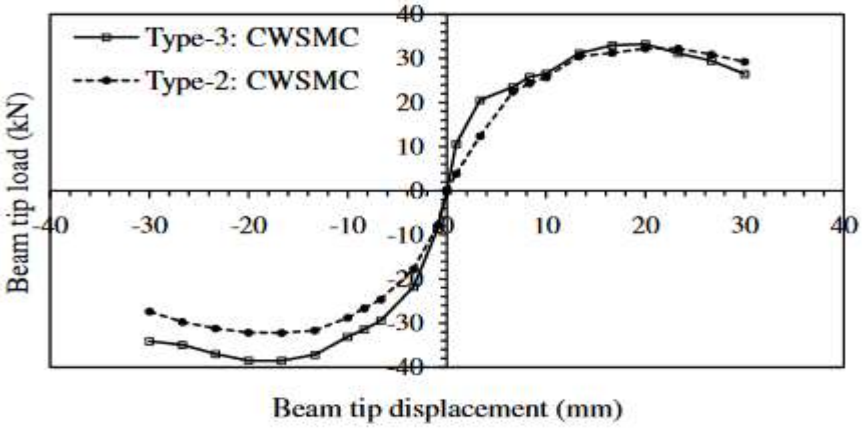


Figure 5. Envelope Curves for CWSC Specimens under Different Loading Regimes

Conclusion

The examination of damaged specimens reveals significant insights into their behavior under cyclic loading. Notably, both the control and rehabilitated specimens have small areas of damage, mostly at the joint where the beam and column meet, which shows that this area is weak. The rehabilitated specimens generally demonstrate slightly higher load-bearing capacities compared to controls, indicating the efficacy of the rehabilitation process in enhancing structural performance. Further analysis, however, reveals that inadequate shear connections result in severe damage to the beam, particularly in the absence of adequate shear reinforcement. Interestingly, in such cases, rehabilitated specimens exhibit more severe damage than controls, highlighting potential areas for improvement in rehabilitation methods. Overall, the study gives useful information about hysteretic responses, damage patterns, and the effects of inertial forces. This helps us learn more about how strong exterior beam-column connections are during earthquakes.

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