A Survey Report On Stress Level's Effect on Outside Beam Column Joints While Remodeling

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Abstract: ***Most structures, including industrial, commercial, and residential buildings, are constructed using reinforced concrete (RCC). While these structures generally perform well under normal conditions, they can sustain significant damage in the face of major earthquakes or higher load impositions. Retrofitting such structures presents a more complex challenge for structural engineers compared to constructing new buildings. This complexity arises from various factors such as non - engineered construction practices and general wear and tear that existing buildings may exhibit. Rather than demolishing the entire structure, a more feasible approach is to strengthen the deficient structural elements. Thanks to advancements in technology, non - destructive testing methods can easily identify these weak elements. Once identified, the optimal solution is to retrofit these elements. Retrofitting differs from repair or rehabilitation, as it involves strengthening and improving the performance of deficient structural elements or the entire structure as a whole. This can be achieved by enhancing the strength, stiffness, and/or ductility of specific components or the entire building, depending on the specific requirements. In some cases, a combination of these measures may be chosen. Retrofitting at the individual member or element level is known as local retrofitting.***

Keywords: Retrofitting, Reinforced concrete (RCC), Deficient structural elements, Non destructive testing, Strength, stiffness, and ductility enhancement, Concrete.

1. Introduction

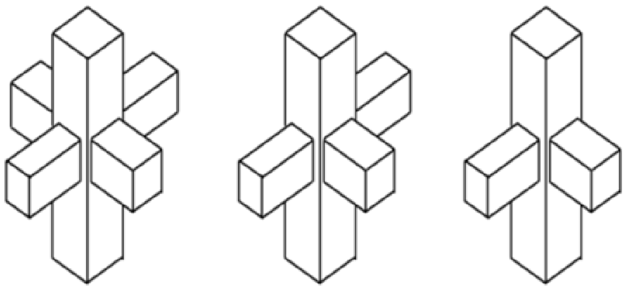
In the analysis of reinforced concrete moment resisting frames, it is common to assume that the beam - column joints are rigid. In Indian design practice, these joints are often overlooked in specific designs, with the focus primarily on providing adequate anchorage for the longitudinal reinforcement of the beams. This approach may be acceptable for frames not subjected to earthquake loads. However, there have been instances of catastrophic failures in past earthquakes, particularly in Turkey and Taiwan earthquakes of 1999, which were attributed to inadequate design of beam - column joints. The poor design practices in these joints are further exacerbated by the significant demand placed on them by the adjacent flexural members (beams and columns) when they undergo inelastic deformation to dissipate seismic energy. Unsafe design and detailing within the joint region can compromise the integrity of the entire structure, even if other structural members meet the design requirements. Over the past three decades, extensive research has been conducted to study the behavior of joints under seismic conditions, utilizing both experimental and analytical approaches. International codes of practice have undergone regular revisions to incorporate the findings from this research into practical guidelines.

2. Types of Joints in Frames

The joint in a reinforced concrete moment resisting frame refers to the section of the column within the depth of the deepest beam that connects to the column [Uma & Prasad]. In such frames, there are three types of joints that can be identified:

- Interior joint: When four beams connect to the vertical faces of a column, it is referred to as an interior joint.
- Exterior joint: When one beam connects to a vertical face of the column, while two other beams connect from perpendicular directions to the joint, it is called an exterior joint.
- Corner joint: When a beam connects to two adjacent vertical faces of a column, the joint is known as a corner joint. (Refer to Figure 1)

Due to the significant forces and demands placed on the performance of these joints, it is crucial to gain a deeper understanding of their behavior under seismic conditions. These forces give rise to complex mechanisms that involve bond and shear within the joint.



(a) Interior (b) Exterior (c) Corner

Figure 1: Types of Joints in a Frame

3. Applications of Ferrocement

Ferrocement has gained significant popularity in the housing sector, particularly for applications such as roofs, floors, slabs, and walls. Researchers have also explored the use of ferrocement in beams and columns. Various forms of ferrocement roofs have been investigated, including shell roofs, folded plates, channel - shaped roofs, box girders, and secondary roofing. For short spans, ferrocement proves to be an effective material for roofing. The technology package for ferrocement roofing employs advanced design principles to manufacture reinforced shells. These shells, commonly referred to as channels, are produced using specially designed vibrating tables and profiled molds. This production system ensures precise end details, consistent shape, and optimal thickness, all of which are essential for achieving high performance. Ferrocement roofing channels possess high density, excellent water resistance, and provide exceptional structural strength. In both rural and urban areas, ferrocement roofing technology offers a viable alternative to conventional flat roofing systems such as reinforced cement concrete, reinforced brick cement, and sandstone. Manufacturing ferrocement roofing channels involves using a carefully designed mixture of cement, sand, and water to create high - strength mortar. This mortar is reinforced with a layer of galvanized iron chicken wire mesh (22 gauge) and tor steel bars (8 - 12 mm diameter) provided in the bottom nibs of the channel. After a curing period of 14 days, ferrocement roofing channels can be safely transported for application.

4. Literature Review

Earthquakes pose a significant threat to buildings, and it is crucial to analyze and assess the damage they can cause. The goal is to ensure that a building does not experience total collapse, meaning that it should not suffer irreparable damage that necessitates complete demolition and rebuilding. If such damage does occur, it should be repairable in a quick and efficient manner to restore the building's functionality. Numerous papers have been published on the topic of retrofitting beam - column joints, focusing on strategies to strengthen these critical elements and improve their performance during seismic events. These papers present valuable research and findings that contribute to the development of effective retrofitting techniques, ultimately enhancing the resilience of buildings against earthquake - induced damage.

Jung - Yoon Lee et al (2009) In this study, a method is presented to predict the ductile capacity of reinforced concrete beam - column joints that fail in shear after the development of plastic hinges at both ends of the adjacent beams. When plastic hinges occur at the beam ends, the longitudinal axial strain in the center of the beam section within the plastic hinge region experiences a sudden increase. This is due to the neutral axis moving towards the extreme compressive fiber and the longitudinal bars accumulating residual strains with each cycle of additional inelastic loading. The increase in axial strain in the beam section after flexural yielding contributes to the widening of cracks in the beam - column joints, which subsequently reduces the shear strength of the joints. The proposed method takes into account the effect of the longitudinal axial strain in the plastic hinge region on the longitudinal strain of the joint and the subsequent strength deterioration. To verify the accuracy of the proposed method in predicting shear strength and corresponding deformability, the test results of RC beam - column assemblies were compared. The calculated shear strengths and their corresponding deformability were compared to the observed values from the tests. The comparison demonstrated reasonable agreement between the calculated and observed values.

Bing Li and H. Y. Grace Chua et al. (2009) In this study, the authors investigated the seismic performance of three non - seismically detailed interior reinforced concrete beam - column joints. The joints included one eccentric joint and two concentric joints. To strengthen these joints, the researchers proposed the use of fibre - reinforced polymer (FRP) wrapping configurations employing glass fibre - reinforced polymer and carbon fibre - reinforced polymer strips and sheets. The strengthened joints were subjected to constant axial compression load and reversed cyclic loading, simulating low to moderate earthquake forces. The seismic performance of the strengthened beam - column joints was evaluated and compared to that of the original, un - strengthened joints. The assessment considered factors such as hysteresis response, stiffness, and energy dissipation capacity. The results indicated that applying strips at a 45° angle on a flushed eccentric joint core, as well as using cross bracing on the beam and confinement around the column, proved to be highly effective in improving the seismic performance. All specimens exhibited gradual strength deterioration, with observed bond degradation and debonding of the FRP sheets near the joint core. However, the proposed strengthening schemes demonstrated efficiency and cost - effectiveness for the repair or upgrading of non - seismically detailed structures.

Kien Le - Trung et al (2009) In this experimental study, the researchers aimed to enhance the shear capacity of non - seismic beam - column joints using Carbon Fiber Reinforced Plastic (CFRP) materials. They developed and tested eight exterior RC beam - column joint specimens, which included a non - seismic specimen, a seismic specimen, and six retrofitted specimens with different configurations of CFRP sheets. The objective was to identify an effective approach to improve the seismic performance of the joints, specifically in terms of lateral strength and ductility. The study investigated various configurations of CFRP sheets, including T - shape, L - shape, X - shape, and strip combinations. The focus was on understanding the impact of using CFRP sheets in enhancing the strength and increasing the ductility of non - seismic beam - column joints. The test results demonstrated that the addition of CFRP composites to the non - seismic specimen significantly improved both the lateral strength and ductility of the tested specimens. Notably, the X - shaped configuration of wrapping, along with the application of strips on the column and two layers of CFRP sheets, resulted in the best performance in terms of both ductility and strength.

Tomoya et al (2017) Ongoing research and development efforts have been focused on the practical application of the Concrete Encase Steel (CES) composite structure system, which combines steel and fiber reinforced concrete. Previous studies have demonstrated the favorable seismic performance of CES structures through experimental investigations on columns, shear walls, and a two - story, two - span frame. The seismic performance of CES beam - column joints has also been examined, revealing their failure behavior, strengths, and restoring force characteristics, all of which indicate good seismic performance. The flexural strength of the CES beams has been evaluated using superposition strength theory, while the shear strength of the joint panel has been assessed conservatively using a formula specified in the AIJ SRC standard. The shear strength evaluation method in the SRC standard considers the effective area of concrete and the shear stress of the concrete at its ultimate state. In addition, three - dimensional finite element analysis has been employed to understand the stress transfer mechanism within the joint panel. The analysis revealed different stress states in the areas surrounded by the steel flange and those that were not. However, the structural performance of the joint panel is influenced by various factors, and the number of experiments on CES beam - column joints with shear failure of the joint panel remains limited. To address this, the present study conducted static loading tests on CES beam - column joints with different cross - sectional configurations of joint panels and column lengths. These tests aimed to comprehensively evaluate the structural performance and stress state of the joint panel and were supported by FEM simulation analysis.

Mariko et al. (2018) This paper addresses the issue of reduced strength and stiffness in reinforced concrete buildings with soft - first - stories. Typically, the columns in the first - stories of these buildings are enlarged compared to the columns in the upper stories to prevent collapse at the first stories. However, test results have shown that the actual strength and stiffness of these frames are lower than expected when assuming flexural failure at the top of the first - story column. This discrepancy is primarily due to damage occurring at the beam - column joint located at the top of the first - story column. In this paper, a method is proposed to calculate the strength of beam - column joints in situations where columns extend outside the building and the joints are subjected to closing loads. The method takes into account the observed failure mechanism in tests and can also consider anchorage failure of the beam's top bars. The proposed method considers two failure modes for a beam - column joint: the column failure mode and the beam failure mode. The column failure mode refers to the flexural failure of the first - story column at the bottom face of the beam. To calculate the moment capacity for the column failure mode, a flexural analysis is performed assuming the entire cross - section of the first - story column is effective. In summary, this paper presents a method for calculating the strength of beam - column joints in reinforced concrete buildings with soft - first - stories. The method focuses on cases where columns extend outside the building and the joints experience closing loads. By considering the observed failure mechanism and the possibility of anchorage failure, the proposed method provides a more accurate assessment of the joint's strength. Specifically, it calculates the moment capacity for the column failure mode by conducting a flexural analysis assuming the full cross - section of the first - story column is effective.

Santarsiero et al. (2019) Advanced numerical simulations have been instrumental in identifying the primary factors contributing to the sudden strength degradation observed in external reinforced concrete (RC) wide beam - column joints when subjected to lateral loads. Experimental tests conducted on two specimens under cyclic loading revealed that poor bond conditions led to slip phenomena affecting the bars bent outside the column core. This slip phenomenon resulted in reduced deformation capacity and limited ductility of the joints. However, bars bent within the column width did not experience such slip phenomena due to better bond conditions and the beneficial confinement provided by the column hoops. In addition to slip, another significant damage mechanism observed was cracking on the sides of the beam, where no confinement effects were present due to the absence of beam and column hoops. Furthermore, the high flexibility of wide beams caused a delay in their yielding point compared to beam - column connections with conventional beams (having greater depth than width), resulting in further reduction of available ductility.

Takeshi et al. (2020) In the analysis of reinforced concrete (RC) buildings, the flexibility of beam - column joints plays a crucial role in the overall behavior of the structure. However, accurately considering joint deformation in engineering practice can be challenging due to the complexity of existing joint models. In this paper, a simple approach is proposed to predict the contribution of joint deformation to the total deformation of RC interior beam - column joints under critical structural deformations. To develop this simplified approach, experimental and analytical studies were conducted on RC interior beam - column joints. Eight half - scale joint specimens were tested under reversed cyclic loading, and 39 full - scale finite element models were constructed, varying key parameters. The experimental and analytical results revealed that the "joint shear" is a useful indicator for beam - column joints with high shear stress levels ($v_j > 1.7$ fc'), but it is not suitable for defining failure in joints with medium or low shear stress levels ($v_j \approx 1.25 - 1.7$ fc' and $v_j \approx 1.0$ fc'). Based on these findings, three equations were developed to predict the joint shear deformation index (SDI) of RC interior beam - column connections for three different failure types: joint failure before beam yielding, joint failure after beam yielding, and beam flexural failure. The proposed equations successfully correlate the SDI predictions with 50 test results of beam - column joints available in the literature.

Krishnan et al (2022) Recent earthquakes have highlighted the vulnerability of existing reinforced concrete (RC) beam - column joints to lateral loading. These joints play a critical role in RC moment resisting frames, as they experience high shear forces and large moments. The behavior of exterior beam - column joints significantly influences the response of the overall RC structure. This study focuses on the numerical analysis of an exterior reinforced beam - column joint. Two scenarios were considered: one with adequate shear reinforcement at the joint following IS: 13920 - 2016, and the other without shear reinforcement as per IS: 456 - 2000. The seismic performance of a G+5 RC building located in seismic Zone III was analyzed using SAP2000. Maximum shear forces and bending moments were obtained, and the design of one exterior beam - column joint at an intermediate storey adhered to the strong column and weak beam concept. The seismic analysis of the RC building considered all the modifications specified in IS 1893: 2002 (Part - I) for seismic loading. Dead and live loads were considered according to IS: 875, and the design followed the codes IS 13920: 2016 and IS 456: 2000. Full - scale specimens were numerically modeled in ANSYS 19.0, applying a constant axial load on the column top and cyclic loading on the beam end. One specimen was detailed according to IS 456: 2000, and the other according to IS

13920: 2016. The specimens were tested, and their responses were obtained.

Wang et al. (2022) This paper focuses on the simulation of the damage process of beam - column joints in steel frames under ultra - low cycle fatigue loading, considering the presence of welding residual stress. The ABAQUS software is used to simulate the behavior of the joints, and the crack initiation positions are determined. Based on this, the influence of welding residual stress on the development of tensile and bending fatigue damage in beam - column joints is analyzed. Additionally, the effect of welding residual stress on joints with different loading modes and varying beam flange widths is discussed. The results indicate that, under ultra - low cycle tensile and bending fatigue loading, cracks are initiated at the welding holes of the beam flange, but the cycle number required for crack initiation differs between the two loading modes, with bending fatigue requiring more cycles for crack initiation. Welding residual stress accelerates crack initiation and advances it by approximately two cycles. In the case of bending fatigue damage, the crack first originates from the tension side of the flange. Furthermore, the average cycle number to failure of the flange is found to be 12.85% higher than that of the other flange. Additionally, as the flange width decreases from 150 to 130 mm, the effect of residual stress on the cycle number to failure increases from 5.30% to 13.56%.

Kumar et al. (2023) The experimental research conducted on bituminous mixes, including Stone Matrix Asphalt (SMA) and Bituminous Concrete (BC), yielded the following conclusions. All three types of fillers used in BC met the required specifications, making them suitable for use. While BC with cement filler provided the highest stability, the use of fly ash and stone dust as fillers proved feasible and cost - effective. Adding fibers up to 0.3% increased the stability of BC, but further fiber addition did not significantly improve stability compared to SMA. Incorporating fibers reduced flow value in BC, but 0.5% fiber addition increased flow value. SMA exhibited higher tensile strength than BC, and adding fibers reduced deformation in both mixes. SMA with sisal fiber showed excellent performance for flexible pavement applications, indicating its potential in construction.

Furusawa et al (2023) This paper presents a study on RC interior step beam - column joints with headed anchors for beam longitudinal bars. The aim of the research is to streamline the reinforcement work for these joints. Typically, the beam longitudinal bars in step beam - column joints are given a 90° hook. However, in some cases where step beam - column joints are planned for architectural reasons in RC buildings, the longitudinal bars become congested, and the hooks of the left and right beams may overlap. To address this issue, the researchers developed a design method for interior step beam - column joints. Four specimens were tested, with column to - beam moment capacity ratios of approximately 1.0 and 1.5. The crack behavior of the step beam - column joints was observed, and the stress transfer mechanism was analyzed. It was found that the stress transfer mechanism relies on positive and negative loading and involves two struts formed by the compressive forces at the ends of the column and beam, as well as the reaction forces from the headed anchors. This stress transfer mechanism was termed the "double strut model. "Based on the double strut model, the researchers proposed a design method for RC interior step beam - column joints. This method was validated through experimental tests, and it demonstrated satisfactory results in terms of meeting the requirements for these joints.

Kumar et al. (2023) The use of manufactured sand in concrete has several advantageous effects on its performance. Both M40 and M50 grade concretes produced with manufactured sand exhibit reduced water absorption when compared to concretes made with conventional sand. By employing a lower water - binder ratio, the concrete becomes impermeable, further enhancing its resistance to water penetration. The incorporation of manufactured sand also leads to a decrease in chloride ion penetrability, indicating lower permeability and improved durability. Additionally, concrete mixes containing synthetic sand demonstrate enhanced resistance to acid and alkaline attacks, resulting in reduced weight loss compared to traditional sand concrete. Moreover, manufactured sand concrete exhibits improved resistance to impact and abrasion, making it more resilient in demanding conditions. Overall, the utilization of manufactured sand positively impacts the performance of concrete in various aspects.

Marchisella et al (2023) The issue of reinforced concrete (RC) beam - column joints in existing structures, which were constructed without considering seismic provisions, remains highly relevant. These joints have often been identified as a primary factor in building collapses following strong earthquakes, as demonstrated in the recent event in Turkey in February 2023. This paper presents an experimental investigation focused on RC beam - column joints subjected to bi - axial loading conditions. Three full - scale joints were tested in both their as - built condition and after retrofitting with haunches. The testing protocol involved applying load in one direction at double the magnitude compared to the other direction. The results obtained from the as - built joints were added to a database of corner joints tested under bi - axial loading and analyzed with respect to the influence of bi - axial loading on the shear strength of the joints. Numerical analyses using brick finite elements were conducted to comprehensively assess the structural response under coupled loading conditions. The findings revealed that bi - axial shear demand had a detrimental effect on the joints, but the confinement of the joints had a mitigating effect. However, a conclusive statement on the subject could not be reached. The haunch retrofit was found to effectively reduce the shear demand at the joint, providing satisfactory results.

5. Summary

The survey report focused on investigating the impact of stress levels on outside beam - column joints during the process of remodeling. The study aimed to understand how the stress levels affect the performance and behavior of these joints when subjected to remodeling activities. Through a comprehensive survey, data was collected from various construction projects where remodeling work was carried out on outside beam - column joints. The findings of the survey revealed that higher stress levels imposed during remodeling activities significantly influenced the structural integrity and overall performance of the joints. It was observed that increased stress levels led to a higher risk of joint failure, including cracking, deformation, and reduced load - carrying capacity. The report highlighted the importance of considering stress levels and implementing appropriate mitigation measures during the remodeling of outside beam - column joints to ensure the structural stability and longevity of the building. The information gathered from the survey provides valuable insights for engineers, contractors, and stakeholders involved in remodeling projects, emphasizing the need for careful planning, monitoring, and implementation of stress management strategies to safeguard the integrity of outside beam - column joints during remodeling activities.

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