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Study on Seismic Resilience of High-Performance Concrete Beam-Column Joints

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Abstract

Beam columns and slabs play a vital role as structural elements in any framed structure. When these components come together, they create a cohesive structural system. In a reinforced concrete moment-resisting frame, the beam-column joints are critical areas for effectively transferring loads between the beams and columns. These joints are particularly important because they experience significant forces during intense ground shaking. The primary function of a joint is to allow the connected members to reach and maintain their ultimate capacity. Under seismic loading, the demands on this relatively small element can be quite severe, which is why beam-column joints need to possess adequate strength and stiffness to handle the internal forces generated by the adjacent members. Traditional methods like steel and reinforced concrete jacketing come with their own set of drawbacks. This highlights the need for innovative techniques to address the limitations of conventional strengthening systems. Fiber-reinforced polymers have emerged as a solution for enhancing the strength of beam-column joints made from standard concrete. In this approach, the beam-column joint is built using normal strength concrete, while the core of the joint is made with high-performance, high-strength concrete. These joints are then reinforced with various patterns of fiber-reinforced polymers, and their performance is evaluated to inform the design of FRP systems for strengthening such structures".

Keywords: Brick, Concrete, Fibres, Masonry Columns.

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Introduction

Inadequate shear reinforcement in beam-column joints, particularly the exterior ones, is considered a major factor behind the failure or collapse of moment-resisting Reinforced Concrete (RC) framed buildings. Recent earthquakes around the globe have highlighted just how vulnerable existing RC beam-column joints are to seismic forces. Poorly detailed joints, especially those on the exterior, have been pinpointed as critical structural components that tend to fail prematurely, acting as "weak links." A common failure mode in these poorly designed joints, which lack sufficient transverse reinforcement, is shear failure, often manifesting as diagonal tension. Additionally, bond failure of rebars has been noted, particularly in interior joints where the rebars aren't properly anchored with standard hooks. RC frames that are designed without considering seismic provisions often exhibit unsatisfactory structural behaviour due to their limited ductility and insufficient strength, which can lead to global failure mechanisms (Wang et al., 2017). In these structures, columns usually have minimal cross-sectional dimensions, and their longitudinal steel reinforcement is inadequate to meet the flexural and shear demands imposed during an earthquake. This creates a weak column-strong beam connection, which is likely to develop local hinges in the columns during a seismic event. This type of failure mode represents a critical weakness, as it is marked by brittle and catastrophic structural failure. During a severe earthquake, significant stress concentration can occur at the beam-column joint area, especially when the shear capacity of the joint falls short. Such brittle shear failures in the joint area can result in severe damage and even total collapse of buildings. Some specific details in construction can be seen as key factors that lead to local failure mechanisms. For instance, if the ties in columns aren't the right size or spaced properly, it can lead to column collapse, which in turn crushes the non-confined concrete, destabilizes the steel reinforcing bars under compression, and even causes these bars to pull out under tension (Wang & Zhao, 2018). According to ACI – ASCE 352 R [09], the critical region in a reinforced concrete (RC) frame is identified as the beam-column connection—whether it's interior, exterior, or at a corner—based on its vertical and horizontal placement within the structure. Strengthening these beam-column joints to boost shear capacity is particularly important in the realm of seismic design for RC structures. During seismic events, the beam-column joint area experiences horizontal and vertical forces that can be significantly greater than those acting on the surrounding beams and columns. Traditional concrete tends to lose its tensile strength after just a few cracks form. It's crucial to prevent the formation of plastic hinges in columns, as this can compromise the integrity of the entire structure (Wang et al., 2019).

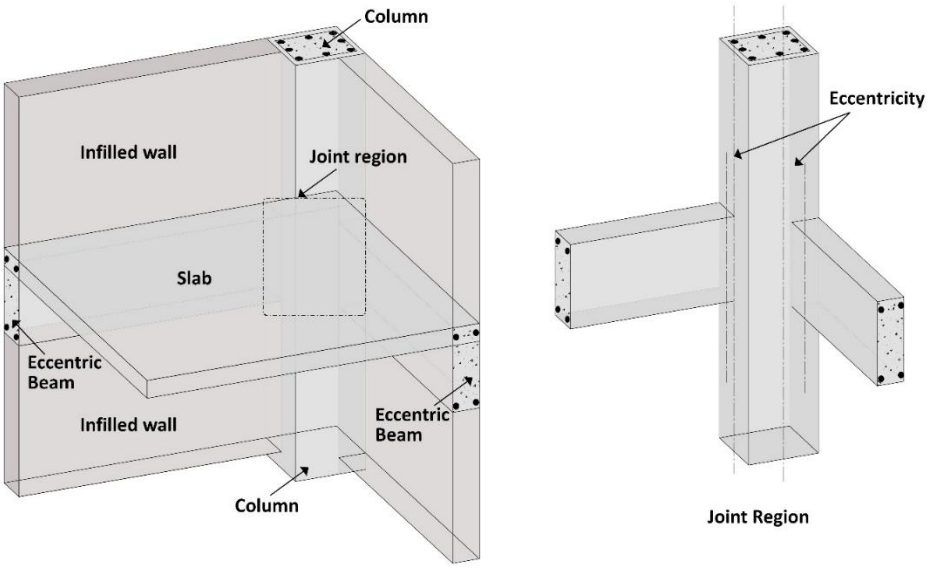


Fig. 1: Beam-column joints

Over the years, a lot of research has been done to explore how Fibre Reinforced Polymers (FRP) fabric can be used to strengthen the joints between beams and columns in reinforced concrete (RC) structures. In the last ten years, both analytical and experimental studies have looked into how applying FRP plates and wraps externally to these joints can enhance their performance. However, it's important to note that these findings aren't specifically tailored for high-performance concrete that incorporates fiber reinforcement. Using FRP materials on the outside is a practical way to boost the overall performance of RC framed structures without making drastic changes to the original design (Saghafi

et al., 2019). When we talk about high performance, we mean a well-balanced mix of qualities like quasi strain hardening, multiple cracking, toughness, energy absorption, stiffness, durability, and resistance to corrosion.

Literature Review

Concrete that has many of these characteristics often achieves greater strength. As a result, High-Performance Concrete (HPC) is typically known for its high strength, but it's important to note that not all high-strength concrete qualifies as High Performance. Thanks to advancements in material technology and production methods, we can now create concrete with strengths reaching up to about 130 MPa through specialized production techniques. However, this type of HPC tends to be less ductile compared to normal strength concrete. In critical structural areas, like beam-column joints, the strength doesn't always increase in direct proportion to the concrete's strength (see Figure 1.1). Research from the early '90s showed that HPC members often failed in a brittle manner in the anchorage zone, revealing significant bond deterioration of the beam reinforcement in the joint area (Wang et al., 2018). In these high-performance composites, closely spaced fibers can help control the growth of microcracks and prevent strain localization, which can lead to failure.

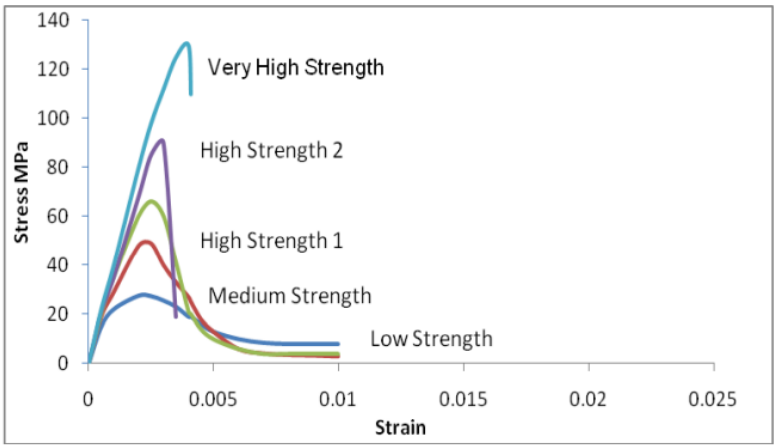


Fig. 2: Stress– strain relationship for concrete

This significantly boosts the strength capacity of structural components. While there's been a lot of research on corner and exterior joints, not much has been done on interior joints. When these joints are designed solely for gravity loads and follow older seismic codes, they can experience serious damage during a major earthquake, especially during opening cycles that create flexural tensions on the inside of the joints.

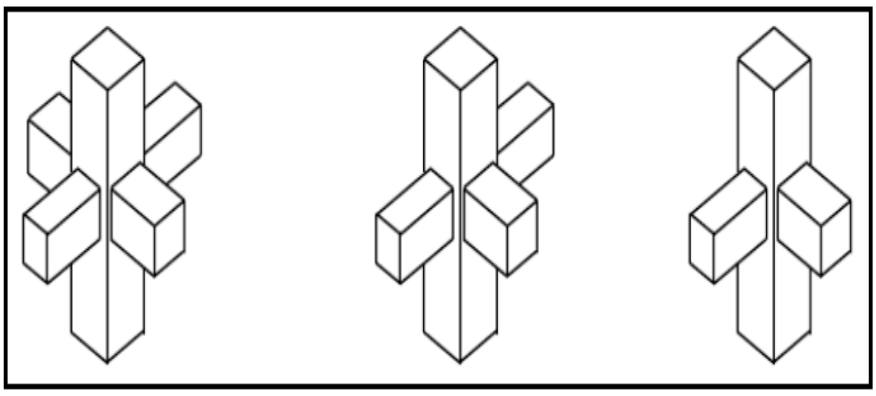


Fig. 3: Types of Joints in a Frame

Mechanism of Strengthening Beam - Column Joints Using Fibre Reinforced Polymers

Fibre reinforced polymers, or FRPs, are made by weaving together strong, thread-like fibres with a polymer or resin. This combination results in a material that’s not only rigid but also lightweight and incredibly strong. The fibres

provide the strength and stiffness, while the polymers keep everything in place. The main job of fibre reinforcement is to support the load along the length of the fibres, giving strength and stiffness in one direction, while the resin helps transfer stress between the fibres and shields them from mechanical wear and environmental damage (Khan et al., 2018). The characteristics of FRP depend heavily on the orientation of the fibres, as they are the key players in determining the material's strength and stiffness. If the fibres are aligned mainly in one direction, the FRP will exhibit impressive strength and stiffness in that direction, but it may not perform as well when forces are applied perpendicularly. In the construction world, common resins include epoxy, vinyl esters, and polyesters, with epoxies being the go-to choose because they serve a dual purpose as both resin and adhesive for concrete. FRP can be applied to concrete in various forms, such as rigid plates or flexible fabrics. The most frequently used fibres in FRP are carbon fibres, E-glass (or fibreglass), and Aramid (commonly known as Kevlar). The use of FRP in construction is often seen as a cost-effective solution for strengthening structures, thanks to its lower installation costs compared to traditional methods."



(a) **(b)**

Fig. 4: Beam-column connection failure

Importance of the Study

Here's the text we're looking at: "High-performance concrete is known for its early strength, impressive long-term mechanical properties, enhanced toughness, and durability in harsh environments. However, during seismic events, the joint areas, which face significant horizontal and vertical forces, can fail due to insufficient steel reinforcement (Deng et al., 2018). This highlights the need to reinforce these beam-column joints to withstand greater horizontal and vertical forces during severe earthquakes. Traditional methods of strengthening, such as steel plate bonding and concrete jacketing, have their drawbacks, as mentioned earlier. Thus, it's essential to explore new techniques that can address the limitations of these conventional systems. Fiber-reinforced polymers (FRP) have been utilized to strengthen beam-column connections in standard reinforced concrete structures, but there's a lack of information on using FRP for high-performance beam-column joints in the existing literature. Therefore, this study aims to develop specialized strengthening techniques for HPC beam-column joints using fiber-reinforced polymers." Even though the maximum strain values are quite similar, examples with ferrocement encasement can support heavier loads compared to simpler designs. This is because ferrocement encasement enhances the strength and flexibility of standard block stonework segments. The impact of increasing the cross-sectional size of the jacketed section on the slenderness ratio is compared to the predetermined slenderness ratio of the control example (Khan, 2017). This comparison looks at the slenderness ratio between the control example (C) and the retrofitted column (Cf).

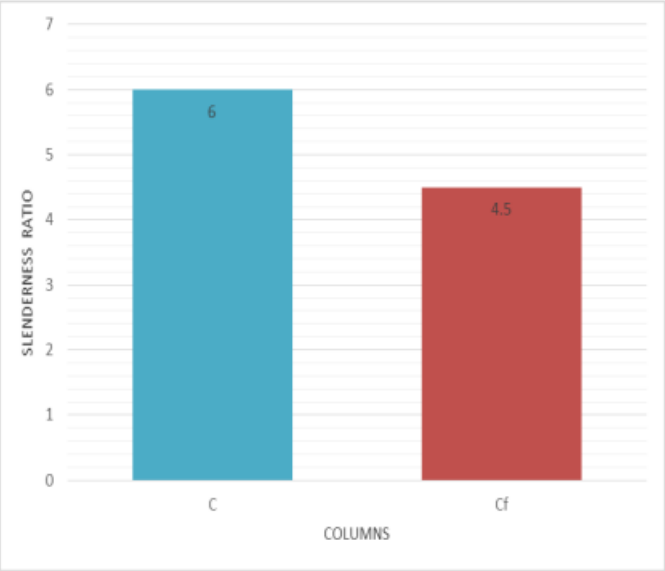


Fig. 5: Slenderness Ratio

Conclusion

A lot of research has been done around the seismic behaviour of beam-column joints globally. It's become clear that many building joints designed according to older standards are a significant factor in the severe damage or collapse during earthquakes. The devastating quakes in various countries have highlighted that concrete frame, especially those that are non-engineered or designed without taking seismic forces into account, are particularly at risk. This vulnerability is a major contributor to the loss of lives. High-performance concrete does offer early strength, long-term mechanical properties, improved toughness, and durability in harsh environments. However, during seismic events, the joint area, which faces intense horizontal and vertical forces, can fail due to insufficient steel reinforcement. This underscores the urgent need to strengthen these beam-column joints so they can better withstand higher levels of horizontal and vertical forces during severe earthquakes.

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