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Experimental Assessment of Bond Behavior and Structural Performance of High-Strength Concrete Beam-Column Joints under Static Load

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Abstract - This study explores the bond characteristics and structural behavior of reinforced concrete (RC) beam-column joints constructed with High Performance Concrete under static loading conditions. Beam-column joints are critical structural elements whose failure can compromise the entire frame integrity, especially during seismic events. Twelve specimens, including L- and T-shaped configurations with M30 and M60 concrete grades, were fabricated and assessed. The investigation focused on reinforcement detailing, development length provisions, and HPC's influence on load-displacement responses. Findings demonstrate that HPC enhances joint strength, reduces deflections, and improves ductility compared to conventional concrete. Particularly, T-section joints with M60 HPC achieved superior load capacity and lower deflections. Incorporating development length in L-section joints raised strength and decreased deflections by over 20%. Numerical simulations using ANSYS closely matched experimental data, confirming the reliability of the computational model. These results support the use of HPC in beam-column joints for improved performance in high-rise and earthquake-resilient structures.

Key Words: High Performance Concrete, beam column joint, static loading, reinforcement detailing, ANSYS simulation.

1.INTRODUCTION

In reinforced concrete structures, the regions where beams intersect with columns are identified as beam-column joints. These joints have limited load capacity due to the inherent strength constraints of their materials. During seismic events, forces exceeding these limits can inflict severe damage on the joints. Since repairing such damage is often difficult, it is essential to design beam-column joints capable of resisting earthquake-induced forces effectively. Utilizing High Performance Concrete (HPC) strengthens these joints, which is especially beneficial for tall buildings.

Employing high-strength materials enables a reduction in cross-sectional sizes of structural elements, thereby optimizing usable space and lowering labor costs due to smaller member dimensions. The term "high performance" means concrete mixtures specifically formulated with optimized proportions to achieve targeted properties like higher strength and reduced permeability. Hence, HPC is essentially an enhanced version of conventional concrete, with mineral and chemical admixtures significantly improving its mechanical properties and durability.

HPC meets strict performance and uniformity standards that conventional concrete may not consistently attain using typical mixing, placing, and curing methods. The increasing demand for taller buildings with greater rentable areas and aesthetic appeal has driven the widespread adoption of high-strength, slender reinforced concrete columns.

The resistance to multiple cracking, and corrosion resistance, while also considering material and production costs. Compared to conventional concrete, HPC requires a lower water-to-binder ratio and a higher cement content[2]. Growing emphasis on sustainable construction and efficient use of resources has further accelerated HPC's popularity, particularly in high-rise projects[2].

2. EXPERIMENTAL PROGRAM

In this investigation, two types of reinforced concrete mixes were employed to fabricate beam-column joint specimens: a conventional concrete mix targeting a compressive strength of approximately 30 MPa (M30), and a high-performance concrete mix designed for a compressive strength near 60 MPa (M60). The properties of constituent materials and their mix proportions for both concrete grades are presented in Tables 1.

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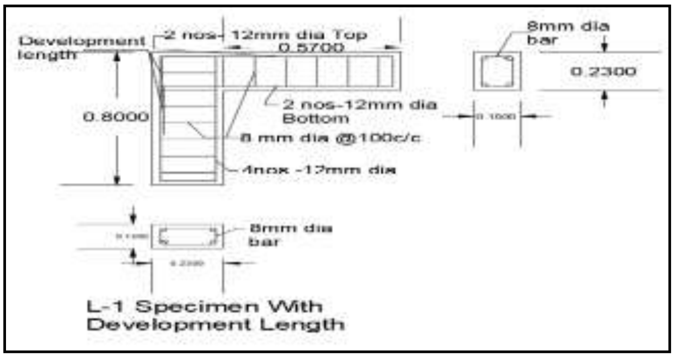
Table1: Mix Proportions and Material Characteristics for M30 and M60 Concrete Grades

Material	Proportion (M30)	Proportion (M60)	Material Details
Cement	1	1	Portland Pozzolana
CA	1.84	1.23	Size: 12 mm; S.G: 2.8; F.M: 3.1
FA	1.34	0.89	Size: 4.75 mm; S.G: 2.7; F.M: 2.60
WCR	0.45	0.45	-
Super plasticizer	0.02	0.04	Cico-fluid ME1

3. GEOMETRY CONFIGURATION OF SPECIMENS, STRENGTHENING PROCEDURE

A total of twelve beam-column joint specimens were produced and tested, using M30 and M60 grade concrete along with Fe 500 (TMT) steel reinforcement. The molds were placed on a flat surface and coated with oil to prevent moisture absorption and ease specimen removal. Reinforcement cages were positioned inside with a 25 mm concrete cover, maintained using cement mortar spacers.

i)



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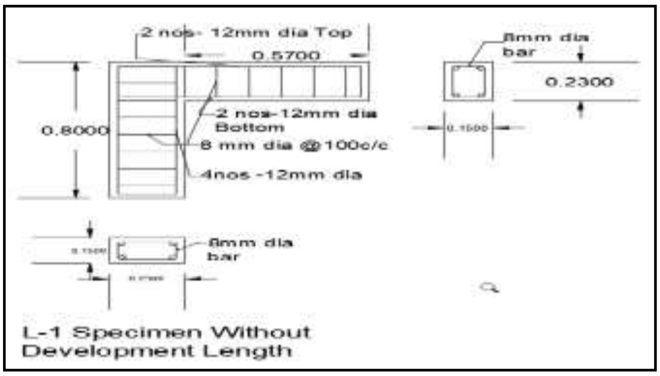

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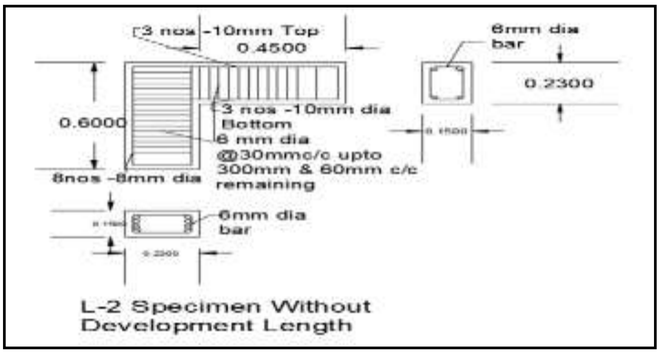

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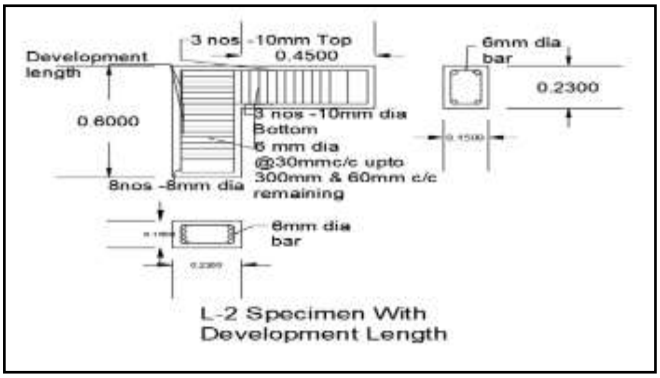

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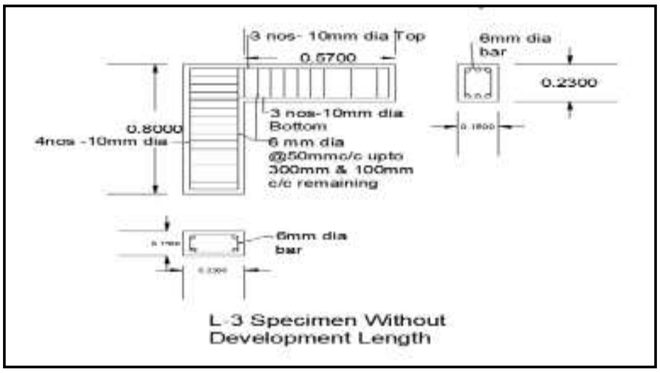

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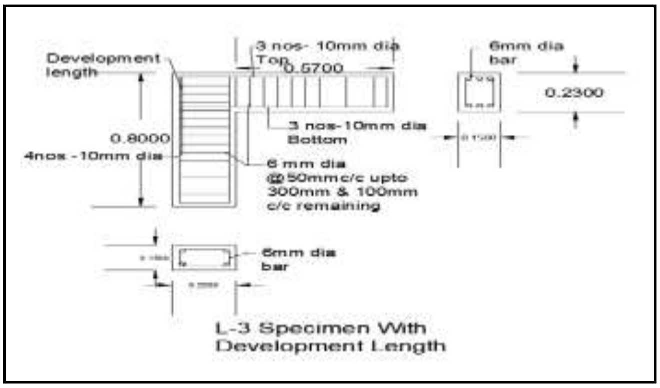

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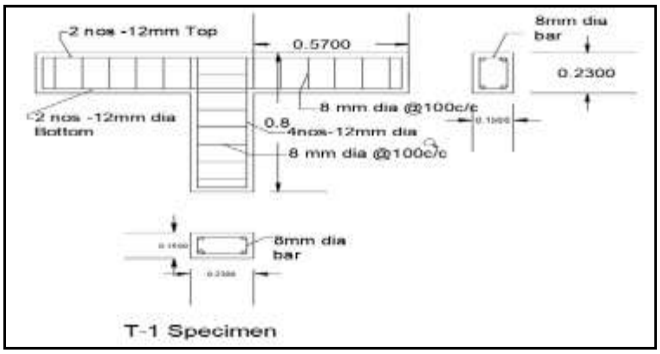

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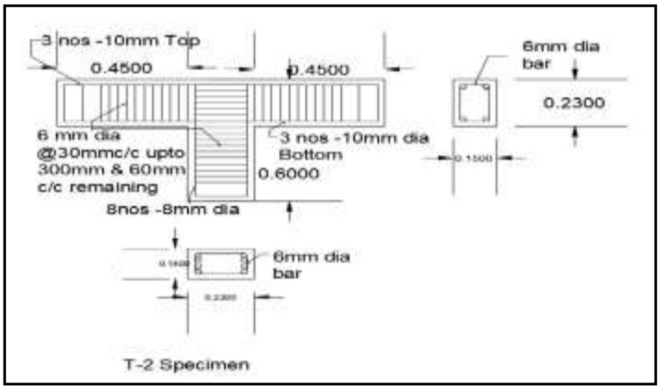

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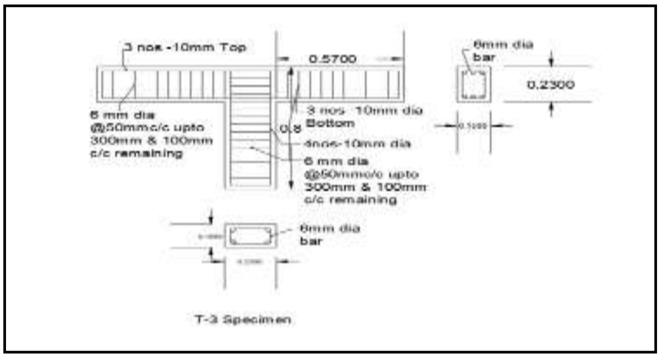


x)

Fig. 1. illustrates the reinforcement details for various specimensi) L1 with development length, (ii) L1 without development length, (iii) L2 with development length, (iv) L2 without development length, (v) L3 with development length, (vi) L3 without development length, (vii) T1 with development length, (viii) T2 with development length, (ix) T3 with development length, and (x) a close-up view showing the steel reinforcement arrangement in the beam–column joint area.

4. Test Setup

The specimens were tested using the setups shown in Figures 2 and 3 for the section T and L, respectively. Deflections at the beam tip were recorded with dial gauges. The column was secured inside a steel plate box using bolts to keep the beam stable during testing. Load was increased incrementally, and corresponding deflections were measured, showing a proportional increase with load.

The concrete had a 28-day compressive strength of 60 N/mm², with a maximum aggregate size of 10 mm. The mix demonstrated good workability under mild exposure conditions.

Ordinary Portland Cement (grade 53) with a specific gravity of 3.15 was used. Coarse and fine aggregates had specific gravities of 2.8 and 2.7, with water absorption rates of 0.5% and 1%, respectively.

Table 2. Specimen detailing for casting

5. TESTING PERFORMANCE

The specimens were tested setups shown in Figures 6 and 7 for the sections. A hydraulic jack applied load to the beam-column joint via a loading frame at both beam ends, with loading points 600 mm from the column center. Deflections at the beam tip were measured using dial gauges. The column was secured inside a steel plate box with bolts to hold the beam in place during testing. Load was applied gradually in increments, and corresponding beam tip deflections were recorded, showing a proportional increase with the applied load.

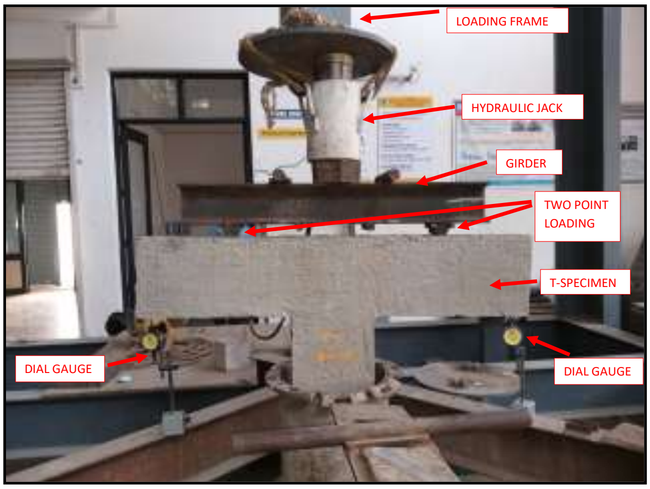


Fig. 2. Schematic of load application and test setup for Sections: T

Fig. 3. Typical failure mode of the specimens tested for: T

6. LOAD–DISPLACEMENT RESULTS

With increasing load levels, the specimens exhibited greater deformation, and cracks began to form during forward loading. As the load continued to rise, these cracks widened progressively. An increase in the concrete grade corresponded to an improvement in strength.

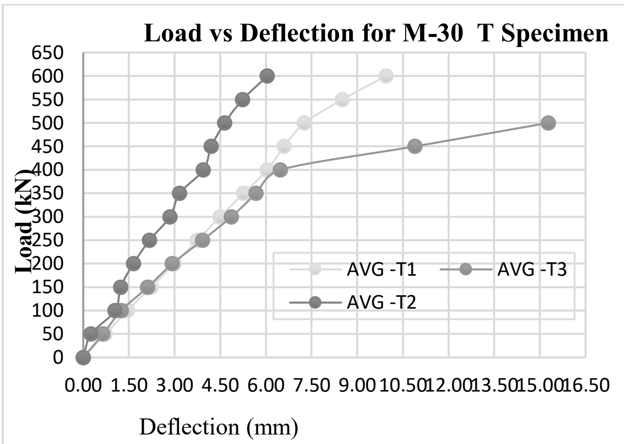
Specifically, for the T1 specimen, the deflection in the M60 grade concrete was approximately 8.77% lower compared to the M30 grade. Similarly, the T2 specimen showed a deflection reduction of about 15.78%, and the T3 specimen exhibited a 24.79% decrease in deflection for M60 concrete in comparison to M30.

For L-section specimens with development length, the deflections in M60 concrete were reduced by 33.20% for L1, 20.83% for L2, and 21.77% for L3 when compared to their M30 counterparts. When comparing L1 specimens in M30 concrete, those with development length demonstrated a 23.06% lower deflection compared to those without development length. The reduction was even more pronounced in M60 concrete, with a 30.49% decrease observed for specimens with development length versus those without.

Similar trends were noted for L2 and L3 specimens: in M30 concrete, deflections decreased by 20.33% and 23.14%, respectively, with development length; in M60 concrete, the decreases were 23.19% for L2 and 22.39% for L3 specimens compared to those without development length.

Overall, the inclusion of development length in L-section specimens an average deflection reduction of approximately 26.04%. Additionally, T-section specimens exhibited a more balanced structural behavior, leading to higher load-carrying capacity compared to L-section specimens.

The experimental outcomes are illustrated in the following graphs.



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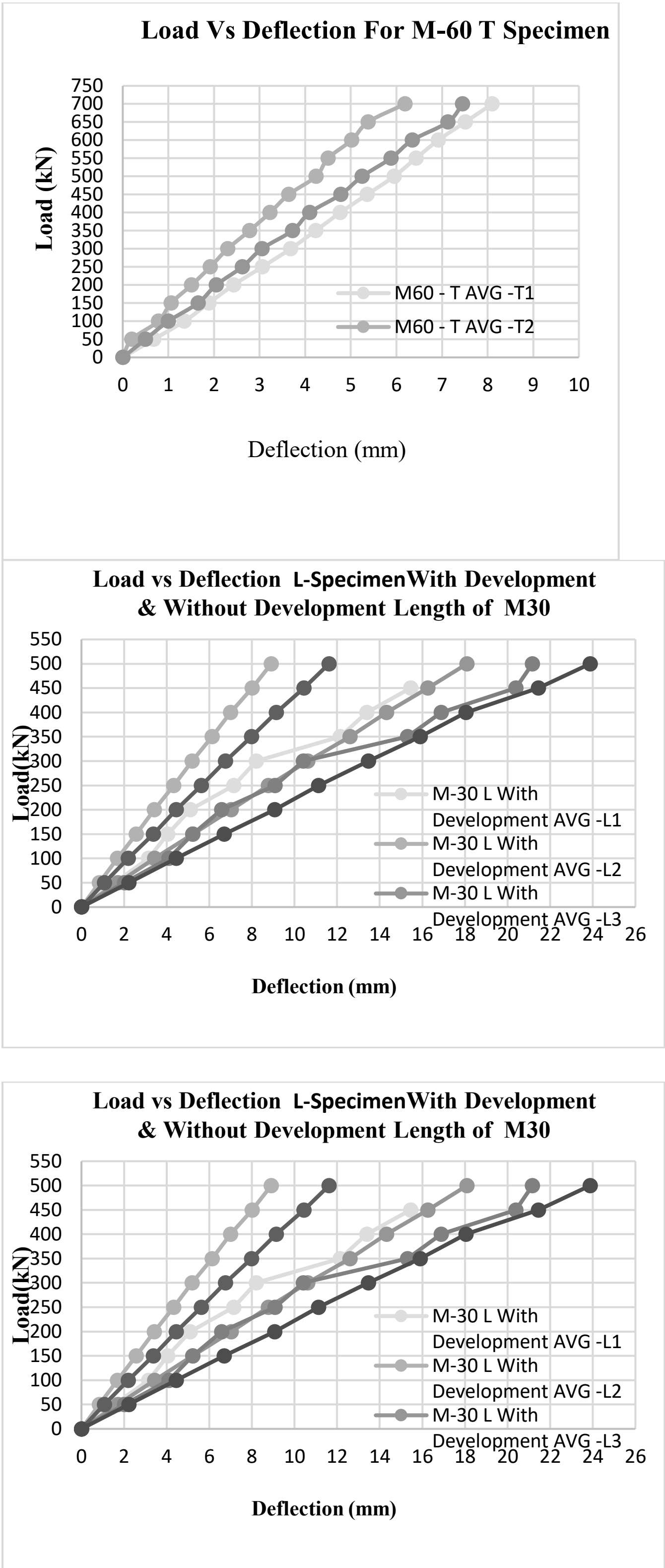

Fig.4. Graph Load Vs Deflection L-Specimen by comparing development Length Of M30 ,M60 Grade

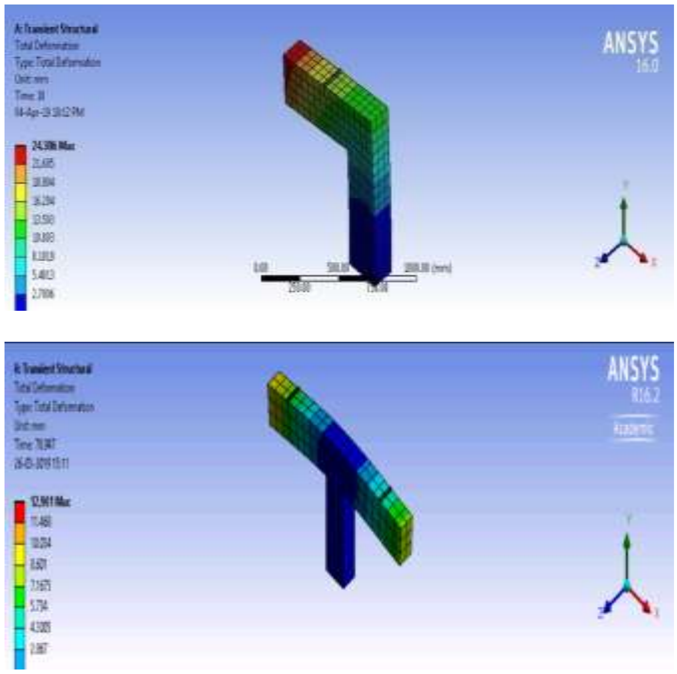

Fig 5. ANSYS modeling of M30 grade concrete: deformation patterns of (a) L-shaped specimen and (b) T-shaped specimen.

7. Conclusion

The experimental study reveals that HPC significantly enhances structural behavior compared to traditional concrete. The major conclusions from this research are:

1. **Increased Load Capacity**: Specimens using M60 grade HPC demonstrated greater load resistance and superior strength compared to those with M30 concrete.
2. **Lower Deflection and Better Ductility:** HPC joints experienced reduced deflections under similar loads, indicating improved stiffness and ductile behavior. Additionally, T-section joints outperformed L-section joints in these aspects.
3. **Importance of Development Length:** Incorporating sufficient development length in L-section joints resulted in over a 20% increase in load capacity and around a 26% reduction in average deflection, highlighting the critical role of reinforcement detailing.
4. **Numerical Model Correlation:** Finite Element Analysis using ANSYS produced results closely aligned with experimental data, confirming the reliability of computational models to predict the structural response of these joints.

In summary, the use of HPC in beam-column joints enhances their strength, durability, and control over deformation, supporting its suitability for use in tall buildings and seismic-resistant designs. Proper reinforcement detailing, especially development length, further improves joint performance.

Future investigations could extend to cyclic and dynamic loading conditions to better replicate earthquake effects and assess long-term behavior.

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