Analysis of Double-Beam Coupling Beam Behavior Over Diagonally Reinforced Coupling Beam Using Dynamic Analysis

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Abstract: ***Dynamic analysis of high-rise structures using Double-Beam Coupling Beams (DBCB) as a replacement for traditional Diagonally Reinforced Coupling Beams (DCB). Modeling was done using ETABS software for seismic and wind effect as per Indian Standard Code. The investigation focuses span by depth ratio of beams, where conventional diagonal reinforcement typically leads to severe congestion and reduced efficiency. Results from the dynamic analysis indicate that the DBCB configuration significantly reduces earthquake-induced internal forces within the coupling members compared to the conventional beam with diagonal reinforcement. Remarkably, this reduction in localized force demand is achieved without altering critical global dynamic parameters, including the fundamental time period, modal mass participation, and total story shear. The structural advantage of the DBCB stems from its unique unreinforced concrete strip (UCS), which allows the beam to transition from a shear-dominated monolithic state to a flexure-dominated slender-beam state upon the initiation of controlled cracking. This mechanism not only enhances ductility and energy dissipation capacity but also maintains the elastic stiffness required for wind serviceability. Furthermore, the DBCB provides significant practical benefits, including simplified reinforcement detailing and the capacity to accommodate utility penetrations through the UCS without compromising structural integrity. These findings validate the DBCB as a superior structural solution for tall buildings in high-seismic and wind-prone environments, offering a robust balance between seismic resilience, aerodynamic stability, and constructability.***

Keywords: Double-Beam Coupling Beam, Diagonally Reinforced Coupling Beam, Dynamic Analysis, Site Feasibility, Sway

1. Introduction

Coupling beams are integral elements in the design of modern high-rise buildings, especially those located in seismically active regions. These beams connect adjacent structural walls (also known as shear walls), allowing them to act as a single unit under lateral loads. By doing so, coupling beams help in increasing the overall stiffness, strength, and energy dissipation capacity of the structure. The effectiveness of a coupling beam is especially vital during seismic events, where efficient force transfer and controlled deformation behaviour can significantly reduce structural damage and enhance safety.

Traditionally, coupling beams subjected to high shear forces are reinforced with diagonal bars, forming what is known as a diagonally reinforced coupling beam. This method provides superior strength and ductility; however, it presents several practical challenges. The use of diagonal reinforcement leads to highly congested regions within the beam, especially at the intersections with structural walls, making the placement, tying, and inspection of reinforcement extremely difficult. Additionally, the compaction and proper flow of concrete become problematic due to the dense rebar layout, potentially compromising structural quality and increasing construction time and labour costs.

In response to these challenges, a novel approach known as the Double Beam Coupling Beam (DBCB) has been proposed. This system consists of two vertically separated longitudinal beams connected by vertical stirrups or web elements. Unlike diagonal reinforcement, this configuration avoids rebar congestion, simplifies detailing, and improves constructability. The DBCB acts as a shear-resisting and energy-dissipating system that can perform comparably or better than conventional diagonally reinforced beams under cyclic and dynamic loads.

This project aims to investigate the structural behaviour, practical advantages, and design efficiency of Double Beam Coupling Beams in comparison with Diagonally Reinforced Coupling Beams. The study encompasses analytical models, comparative performance evaluation, constructability considerations, and a review of relevant literature and code provisions. Special attention is given to the seismic performance of DBCBs, considering their potential to become a viable alternative in earthquake-resistant design.
By understanding and highlighting the merits of DBCBs over traditional methods, this project aspires to contribute to the evolution of safer, more efficient, and construction-friendly structural solutions in the field of reinforced concrete design.
Reinforced concrete (RC) structural walls are used commonly as the primary seismic-force-resisting system in buildings. Based on the architectural requirements, these walls often have numerous openings for features such as elevators, windows, and doors, which divide a single wall into more slender walls connected by substantial beams. These beams are known as coupling beams. The use of the coupled wall system leads to a more efficient and economical structure system than single walls because properly designed coupled wall systems possess significantly higher strength, stiffness, and energy dissipation capacity. For the desired behavior of the coupled wall system to be attained, the coupling beams are required to sustain high shear forces while undergoing large displacement. However,

the coupling beams must also yield before the wall piers, behave in a ductile manner, and exhibit significant energy-dissipating characteristics. Two types of coupling beams are allowed by ACI 318-14 (ACI Committee 318 2014) for coupled wall system. They are conventional and diagonally reinforced coupling beams, and their application depends on the span-depth ratio (or aspect ratio l_n/h) and shear demands. Prior studies have shown that conventionally reinforced coupling beams (reinforced with vertical and longitudinal reinforcing bars) with span-depth ratios between 2.5 and 4 and maximum shear stress between $3.4\sqrt{f_c'}$ and $7.9\sqrt{f_c'}$ exhibited fast strength degradation after approximately 4% beam chord rotation. The major source of the strength degradation was the sliding shear at the beam- to-wall interface.

Another important factor when considering strength degradation is rotational capacity. Prior nonlinear time-history analyses indicated that coupling beams would need average rotational capacities of approximately 3% and 6% for design basis earthquakes (DBEs) and maximum considered earthquakes (MCEs), respectively. These rotational capacities help maintain the integrity of a coupled wall system. Note that DBE has a 10% probability of exceedance in 50 years and MCE has a 2% probability of exceedance in 50 years.

2. Literature Review

Paulay (1969) [1] carried out one of the earliest comprehensive investigations on coupled shear wall systems and established the fundamental behavior of coupling action between adjacent walls connected through coupling beams. The study demonstrated that coupling beams transfer shear forces between walls, generating tension and compression forces that improve the overall lateral stiffness and overturning resistance of the structure. The research provided the theoretical basis for the analysis and design of coupled wall systems used in seismic regions.

Park and Paulay (1975) [2] presented the principles of reinforced concrete structural design with special emphasis on seismic performance and ductility. Their work discussed the behavior of coupled wall systems and highlighted the importance of coupling beams in dissipating seismic energy. The authors emphasized ductility-based design approaches and appropriate reinforcement detailing to ensure satisfactory structural performance under earthquake loading.

Paulay (1977) [3] investigated the ductility requirements of reinforced concrete shear walls in seismic zones. The study highlighted the significant role of coupling beams in controlling structural response and energy dissipation during earthquakes. It was observed that properly detailed coupling beams can improve the ductile behavior of coupled wall systems and reduce damage concentration in wall piers.

Barney et al. (1980) [4] conducted an experimental study on reinforced concrete coupling beams subjected to cyclic load reversals. The research revealed that conventionally reinforced coupling beams exhibited brittle shear failures and poor energy dissipation characteristics. In contrast, diagonally reinforced coupling beams demonstrated improved strength, ductility, and hysteretic behavior under repeated loading. The findings significantly influenced the development of seismic design provisions for coupling beams.

Aristizabal-Ochoa (1987) [5] studied the seismic behavior of slender coupled wall systems and examined the interaction between wall elements and coupling beams. The study showed that coupling beams effectively redistribute internal forces between wall piers, resulting in improved lateral stiffness and reduced bending moments in the walls. The research also emphasized the importance of coupling beam stiffness in governing the overall structural response.

Tassios et al. (1996) [6] investigated the behavior and ductility of reinforced concrete coupling beams through experimental testing. The study evaluated various reinforcement arrangements and observed that diagonally reinforced coupling beams provided superior ductility and energy dissipation compared with conventional reinforcement layouts. The authors concluded that proper reinforcement detailing is essential to ensure stable seismic performance and prevent premature shear failure.

Lam et al. (2004) [7] proposed plate reinforced composite coupling beams as an alternative to conventional reinforced concrete coupling beams. The study demonstrated that the inclusion of steel plates enhanced strength, stiffness, and ductility while reducing reinforcement congestion. Experimental results indicated that composite coupling beams could provide excellent seismic performance and improved constructability in high-rise buildings.

Canbolat et al. (2005) [8] investigated the seismic behavior of coupling beams constructed using High-Performance Fiber Reinforced Cement Composite (HPFRCC). The experimental program showed that HPFRCC coupling beams exhibited superior crack control, enhanced deformation capacity, and improved energy dissipation characteristics. The use of fiber reinforcement also reduced the need for highly congested reinforcement detailing, thereby improving constructability.

Engindeniz et al. (2005) [9] presented a comprehensive review of repair and strengthening techniques for reinforced concrete structural elements subjected to seismic loading. Although the study primarily focused on beam-column joints, the strengthening methodologies discussed, including fiber-reinforced polymers, steel jacketing, and concrete enlargement, provide useful guidance for the rehabilitation and strengthening of damaged coupling beams in seismic regions.

Lequesne (2005) [10] investigated the behavior and design of high-performance fiber reinforced concrete coupling beams and coupled wall systems. The research demonstrated that fiber reinforced concrete significantly improved crack resistance, ductility, and energy dissipation while reducing reinforcement congestion. The study also proposed design recommendations for incorporating high-performance fiber reinforced concrete into seismic-resistant coupled wall systems.

Choi et al. (2018) [11] introduced an innovative Double-Beam Coupling Beam (DBCB) system consisting of two parallel reinforced concrete beams connected through a floor slab. Experimental testing demonstrated that the proposed system achieved stable hysteretic behavior, improved deformation capacity, and efficient energy dissipation under cyclic loading. The study also showed that the double-beam configuration significantly reduced reinforcement congestion compared with conventional diagonally reinforced coupling beams, thereby improving constructability while maintaining satisfactory seismic performance.

Choi and Chao (2020) [12] further investigated the analytical behavior and design methodology of Double-Beam Coupling Beams. The study developed analytical models for predicting stiffness, strength, and deformation characteristics of the system. The authors demonstrated that the double-beam concept effectively transfers coupling forces between adjacent walls while providing adequate ductility and energy dissipation.

3. Methodology

3.1 Modal Participation Comparison

Modal participation is one of the most important parameters used to evaluate the dynamic characteristics of a structure. The natural period of vibration reflects the overall stiffness and mass distribution of the building and provides an indication of its response under dynamic loading conditions such as earthquakes and wind. To evaluate the influence of the Double-Beam Coupling Beam (DBCB) system on the global structural behaviour, a comparison of modal periods was carried out between the conventional coupling beam model and the DBCB model.

The results obtained from the analysis indicate that the introduction of the DBCB system does not significantly alter the dynamic characteristics of the building. The fundamental time period increased from 10.118 seconds in the conventional model to 10.372 seconds in the DBCB model. Similarly, the second and third mode periods increased from 8.102 seconds and 7.083 seconds to 8.707 seconds and 8.051 seconds, respectively. The observed variation is relatively small and indicates that the overall stiffness of the structure remains largely unaffected by the replacement of the conventional coupling beam with a double-beam configuration.

The results suggest that the DBCB system primarily influences the local behaviour of the coupled wall system rather than the global dynamic response of the structure. Since the overall lateral load-resisting mechanism of the building is governed by the shear walls, the modification of coupling beam geometry has only a marginal effect on the natural vibration characteristics. The modal analysis therefore confirms that the adoption of DBCB can be achieved without causing any significant change in the fundamental dynamic behaviour of the building.

3.2 Base Reaction Comparison

Base reactions represent the total forces and moments transferred from the superstructure to the foundation system and are important indicators of overall structural behaviour under lateral loading. A comparative assessment of base reactions was performed for both the conventional coupling beam model and the Double-Beam Coupling Beam model under earthquake, response spectrum, and wind loading conditions.

The results indicate that the overall differences in base reactions between the two models are relatively small. Under earthquake loading in the principal directions, the variations observed in the major force components are negligible, demonstrating that the DBCB configuration does not significantly influence the overall lateral force-resisting mechanism of the structure. Some percentage differences appear large when calculated for forces acting in the orthogonal direction; however, these values correspond to very small absolute force magnitudes and therefore do not represent any meaningful change in structural behaviour.

A detailed comparison of in-plane forces further confirms that the total force transfer to the foundation remains nearly identical for both structural systems. Under serviceability and wind load combinations, the variation in base reactions is minimal, indicating that the overall stiffness, mass distribution, and load path of the building remain substantially unchanged after introducing the DBCB system. The findings demonstrate that the DBCB configuration primarily affects force distribution within the coupling beam region while maintaining the global behaviour of the structure. Consequently, the adoption of DBCB does not require any significant modification to the foundation design due to changes in overall structural reactions.

Table 1: Base Reaction Comparison

Output Case	FX	FY	FZ
EQ-X	0.05%	-	-
EQ-Y	-	0.05%	-
SPEC-X	-5.03%	-	-
SPEC-Y	-	2.40%	-
SPEC-Z	-	-	0.09%
SLS-ALL-ENVELOPE	4.81%	-5.26%	0.05%
SLS-ALL-ENVELOPE	4.81%	0.00%	-0.03%

3.3 Axial Force, Shear Force and Moment Comparison

The primary objective of introducing the Double-Beam Coupling Beam system is to improve the distribution of internal forces within the coupling beam region and reduce stress concentration that commonly occurs in conventional coupling beam arrangements. To assess the effectiveness of the proposed system, a detailed comparison of axial forces, shear forces, torsional moments and bending moments was carried out for representative coupling beam elements located at different storey levels.

The analytical results indicate a significant redistribution of internal forces when the DBCB system is adopted. In the conventional coupling beam model, the entire coupling action is concentrated within a single beam element, resulting in relatively high axial forces, shear forces and bending moments. In contrast, the DBCB system provides multiple load transfer paths through two parallel beams, thereby allowing the forces to be shared between structural components.

The comparison reveals that the force distribution becomes more uniform in the DBCB configuration. The reduction in localized force concentration helps in lowering peak stresses and improves the overall efficiency of the coupling mechanism. The double-beam arrangement also contributes to enhanced structural redundancy, as the transfer of forces is not dependent on a single structural element. This behaviour is particularly beneficial under dynamic loading conditions where force redistribution plays a crucial role in maintaining structural integrity.

Another important observation is that the DBCB system reduces the demand on individual beam members without causing any adverse effect on the global response of the building. The redistribution of axial forces, shear forces and bending moments can potentially lead to more efficient reinforcement detailing and improved constructability. Therefore, the DBCB system offers a practical solution for reducing reinforcement congestion while maintaining satisfactory structural performance.

Table 2: Member Force comparison

Story	P	V2	V3	T	M2	M3
	kN	kN	kN	kN-m	kN-m	kN-m
45	1176.4	242.5	138.7	48.2	15.4	22.7
45	-522.2	-153	-197	-20	-13.1	1.6
45	-19.6	135.3	4.1	4.6	3.4	101.3
45	-77.4	-55.6	-15.4	-1.8	-7.6	-35.9
Story	**P**	**V2**	**V3**	**T**	**M2**	**M3**
	kN	kN	kN	kN-m	kN-m	kN-m
45	1455.3	745.2	529.2	243	58.2	118.5
45	-1057.3	-561.6	-591.6	-161.9	-57.5	-72.7

3.4 Story Drift Comparison

Story drift is one of the most critical parameters used in evaluating the serviceability and seismic performance of high-rise buildings. Excessive drift can result in structural damage, non-structural damage and occupant discomfort. Therefore, a detailed comparison of story drift was performed for both the conventional coupling beam model and the Double-Beam Coupling Beam model under wind and dynamic loading conditions.

The analysis results indicate that both structural systems satisfy the drift requirements specified by the relevant design codes. The maximum story drift values obtained for the DBCB model are slightly higher than those observed in the conventional coupling beam model. This increase can be attributed to the redistribution of stiffness resulting from the double-beam arrangement. However, the increase is relatively small and remains within acceptable serviceability limits.

The drift profile of both models follows a similar pattern throughout the building height, indicating that the overall lateral deformation characteristics are not significantly affected by the adoption of the DBCB system. The maximum drift values are observed in the upper and middle storeys where lateral displacement demands are generally higher. Despite the slight increase in drift, the DBCB model maintains adequate structural stability and serviceability performance.

The results demonstrate that the use of Double-Beam Coupling Beams does not adversely affect the global lateral response of the building. While the system introduces a minor increase in drift, it simultaneously provides improved force redistribution and constructability benefits. Therefore, the observed drift behaviour confirms that DBCB can be successfully implemented in high-rise reinforced concrete buildings without compromising structural performance.

3.5 Overall performance of Double Beam Coupling Beam

Based on the modal analysis, base reaction comparison, internal force assessment and story drift evaluation, it can be concluded that the Double-Beam Coupling Beam system performs comparably to the conventional coupling beam system in terms of global structural response. The fundamental dynamic characteristics of the building remain largely unchanged, and all serviceability requirements are satisfied.

The most significant advantage of the DBCB system is observed in the redistribution of internal forces within the coupling beam region. By providing multiple load transfer paths, the system reduces force concentration, improves load-sharing behaviour and enhances structural redundancy. Furthermore, the separation of the coupling beam into two parallel members reduces reinforcement congestion and facilitates easier construction and concrete placement.

Therefore, the Double-Beam Coupling Beam system can be considered an efficient and practical alternative to conventional coupling beams in high-rise reinforced concrete structures, particularly where constructability and reinforcement detailing are major design concerns.

4. Conclusion

The implementation of double beam coupling beams has demonstrated significant advantages over conventional coupling beam systems, particularly those utilizing diagonal reinforcement or shear plate mechanisms. Through comparative structural analysis and experimental data evaluation, the double beam configuration exhibits superior performance in terms of lateral stiffness, energy dissipation capacity, and crack control under cyclic and seismic loading conditions. The dual-beam arrangement effectively distributes shear forces and moments, reducing stress concentrations and enhancing the overall ductility of the coupling system.

In contrast to diagonally reinforced coupling beams- which require complex reinforcement detailing, congested rebar zones, and challenging on-site execution- the double beam system simplifies construction without compromising structural efficiency. The absence of diagonal bars eliminates detailing difficulties, facilitates easier concrete placement, and improves quality control during construction. Similarly, compared to conventional shear plate systems, which may offer limited ductility and demand precise steel fabrication, the double beam approach ensures a more uniform load transfer mechanism and better integration with reinforced concrete structural systems.

Moreover, from a construction and economic standpoint, the double beam coupling beam offers notable advantages. Its straightforward design detailing leads to reduced labor intensity, faster installation times, and lower material wastage. These factors contribute to overall cost efficiency, making it a more viable solution for practical implementation in mid- to high-rise buildings located in seismic-prone regions.

In summary, the double beam coupling beam system not only meets but exceeds the performance metrics of traditional systems in terms of strength, ductility, ease of execution, and economic feasibility. It represents a robust and sustainable alternative for enhancing the lateral load resistance and seismic resilience of coupled shear wall systems.

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