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# A COMPREHENSIVE REVIEW ON STRUCTURAL PERFORMANCE AND DESIGN OPTIMIZATION OF PRESTRESSED TRANSFER BEAMS IN FLOATING COLUMN SYSTEMS

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## ABSTRACT

*This study discusses the prestressed transfer beam in a floating column system that is widely adopted in contemporary high-rise construction to establish open spaces on lower stories. Although floating columns are beneficial to architectural flexibility, they are problematic in terms of structural design because they are not continuous. Transfer beams that are instrumental in reallocating the loads of floating columns must be able to resist high bending moments, shear forces, and compressive loads. Prestressed concrete considerably enhances the performance of such transfer beams by providing a higher load-bearing capacity, deflections, and controlling cracking. These systems exhibit complex behaviour, and the analysis of their structures is performed using advanced methods such as Finite Element Analysis (FEA) to capture the dynamic behaviour of the structures when subjected to dynamic forces such as seismic and wind forces.*

*This study also highlights the significance of adequate redistribution of loads within floating column systems because improper redistribution of forces may cause the structures to collapse. The findings highlight the importance of prestressing to improve the performance of transfer beams, particularly under dynamic conditions. High-performance concrete and fibre-reinforced polymers (FRP) are advanced modelling and material enhancement features that are suggested to streamline the design and guarantee the stability of the floating column systems of high rises.*

**Keywords:** Floating column system, Prestressed transfer beams, Seismic analysis, Finite Element Analysis, Dynamic loads, Load distribution, Structural performance, High-performance concrete.

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## 1. INTRODUCTION

The swift urbanisation and necessity to use taller buildings in contemporary cities have contributed to the development of new structural systems, among which the Floating Column System (FCS) is one of the most obvious. In these structures, columns are not run through all the way to the bottom up to the roof, and instead they end in the middle levels, where they pass the loads to transfer beams [1]. This architectural and construction method is common in high-rise structures, particularly in commercial, residential, and mixed-use developments, where vast open areas on the lower levels are required to allow parking or other purposes. Although floating columns offer a solution to space and design limitations, they present distinct problems in terms of structural functioning, load dispersion, and stability. The importance of transfer beams in the stability and safety of these floating columns is vital to the stability and safety of the entire structure. Transfer beams are used as bridges to support the weight of the floating columns on the other beam or column below [2]. The floating column load causes high bending moments, shear forces, and axial loads in these beams. This implies that the transfer beams should be designed to withstand these forces without interfering with the stability of the structure.

The use of prestressed concrete transfer beams is an established approach for improving the performance of concrete beams. Prestressing is the process in which internal forces are applied to concrete to negate the tensile stresses generated when external forces are applied to the structure. This technique greatly enhances the capacity of the beam to resist bending and shear forces which enhances its performance as far as the beam is concerned [3].

The stress performance of prestressed transfer beams in floating column structures is a significant concern in structural engineering [4]. Compared to normal reinforced concrete, prestressed concrete has several benefits, including increased load-bearing capacity, decreased beam size, and increased durability. However, these beams are not easy to analyse and design because of the common forces that they face, including the high vertical forces imposed by the floating columns and the extra horizontal forces imposed by the lateral forces (such as wind or earthquakes) [5]. In addition, floating column system analysis is a complex process that considers the interaction of transfer beams and floating columns, the distribution of the load on various floors, and the effects of vertical and lateral loads [6]. Simple structural analysis techniques may not yield sufficient data on the structural responses of these types of structures. Thus, using advanced analytical techniques, such as computerised finite element analysis (FEA), is important in determining how these structures respond to several types of loads [7]. The analyses are useful for optimising the design of the transfer beams and the safety and stability of the entire building.

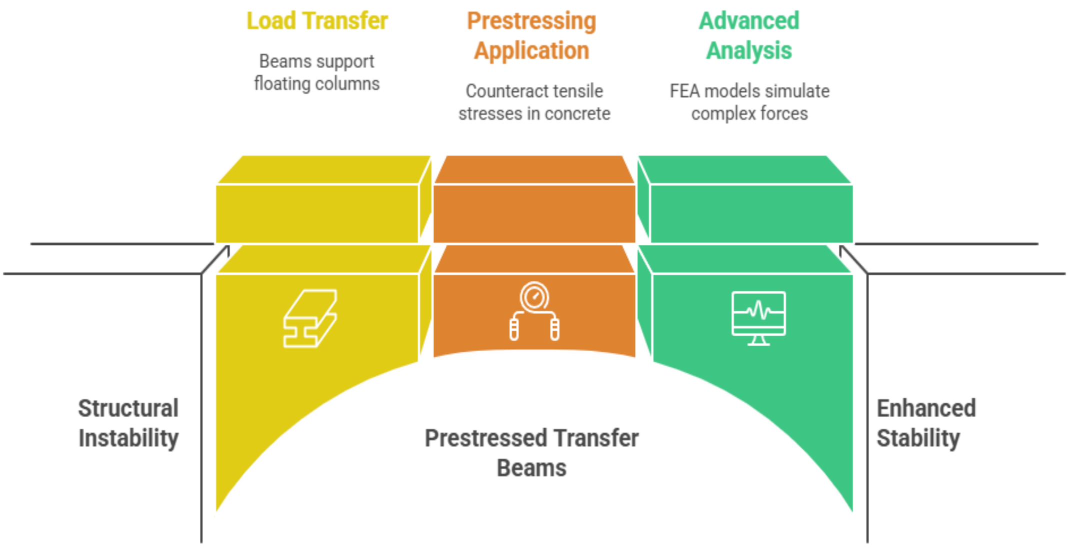


**Fig 1.** Enhancing Floating Column System Stability

The difficulty of structural design is not confined to transfer beams in floating-column systems. Floating column structural systems not only result in difficult structural design owing to the transfer beam, but also create stress concentrations caused by column discontinuities. Stress concentration must be addressed when designing transfer beams and support columns. In addition, exterior loads, such as earthquakes and wind, create dynamic forces on both the transfer beams and their support columns, potentially magnifying the load effects on the transfer beams. Therefore, structural engineers consider dynamic and vibration analyses during the design process to account for these variables. To address these issues, structural engineers have combined analytical and experimental methods to evaluate the functionality of transfer beams [8]. Conventional hand calculation methods typically require advanced computational tools, such as finite element modelling (FEM) and finite difference methods. Engineers can analyse transfer beam behaviours under different load conditions with the assistance of these techniques, helping them predict the different potential failure modes of the transfer beam and design it to be both safe and economical for use [9]. However, experimental studies provide actual data on the performance of transfer beams in the real world and can be used to adjust the analytical model and confirm the assumptions made when designing them. In addition to structural performance, the design of transfer beams should also consider other factors such as durability, cost of construction, and ease of construction. The construction of one type of transfer beam, the prestressed concrete, involves particular methods, such as laying tendons and applying prestressing forces, which may make it more complex and expensive to build [10]. However, these difficulties are generally offset by the advantages of prestressing, including increased load-bearing capacity and smaller beam size, especially in floating column systems, where space utilisation is a design factor.

## 2. LITERATURE REVIEW

**Pang et al. (2024)** studied the seismic behaviour of precast post-tensioned high-performance concrete frame beam-column joints. Four different joints with varying prestresses and L-shaped steel at the beam-column junction were tested under a low-cycle reversed load in order to conduct a test. The hysteresis curves, stiffness degradation, deformation capacity, energy dissipation, and residual deformation were considered seismic performance indicators. The findings indicated that high-performance concrete was the most effective method for reducing local crushing of concrete owing to over-stressing. Moreover, steel plates bent in the shape of L are included in the beam-column junction to avoid damage in the early stages to a greater extent.

The experimental regression analysis used to develop the three-line restoring force model of the joint is a more accurate model of how the joint behaves under stress at any given stage. A finite element analysis model was also created, and the results obtained were very close to the experimental data. The study indicated the strengthened seismic performance and sustainability of precast concrete joints, as well as high-performance materials and effective design changes [11].

**E.N. Thejesh et al. (2020)** This research paper discussed the seismic performance of a building G+7, focusing on three models, one of which had no floating columns, the other had floating columns on a normal reinforced transfer beam, and the third had floating columns on a prestressed beam in seismic zone 3. All three models underwent linear dynamic, response spectrum, and time history analyses. The models were compared in terms of seismic parameters, including time period, base shear, storey displacement, and storey drift. In addition, a time analysis history was applied to plot the response of each model. ETABS and SAP 2000v17 software were used for modelling and analysis. The results provide useful information on the structural behaviour of buildings with floating columns under seismic loads and the effects of various types of transfer beams on the seismic behaviour of buildings. Recent studies on prestressed beams have shown that the tendon profile, eccentricity, prestressing force variation, and beam depth significantly influence the deflection, cracking, stress distribution, and ultimate load capacity. Parabolic and draped tendon profiles improve load balancing, whereas proper eccentricity and optimised prestress levels enhance flexural resistance. Beam depth optimisation improves stiffness and serviceability without unnecessary self-weight [12].

**Deok Hee Won et al. (2021)** studied the structural performance of joints between modules of a submerged floating tunnel (SFT), where underwater construction is performed by modularizing modules on land and assembling them underwater. The emphasis is laid on a steel-concrete composite hollow idea, whereby a prestressing technique is employed to stabilise the joints and outer loads. The bending of the module joints was randomly tested to determine their safety during bending deformation, which is a leading determinant of SFT design. The test outcomes showed that the performance of the module joints varied depending on the availability of an inner steel tube. A significant difference in strength was detected, although the bending stiffness of the joints was similar. The peak force increased to 1200 kN compared to 700 kN, whereas the remaining displacement increased to 40 mm compared to 15 mm when the inner tube was attached.

This observation indicates that both techniques which permit ductility behaviour in the inner tube and the use of tight connections, can be considered depending on the purpose of the SFT. In addition, the failure criterion for bending behaviour may be based on the maximum load or limit of deformation [13].

**Bashir et al. (2022)** discussed the effect of vertical load on concrete buildings with and without floating columns. This study examines the behaviour of the transfer beam, which supports the floating columns, and the parameters explored include the moment, shear force, and deflection. ETABS, SAFE, and Midas software were used to analyse a G+4 building. These findings indicate the redistribution of loads in buildings that use floating columns. In traditional structures, the bending, shear, and deflection values of all beams are the same. However, the above parameters in buildings with floating columns had different values in the beams above the transfer beam, and the magnitudes of the values decreased with increasing height. This study highlighted the role of floating columns and transfer beams in load distribution and structural behaviour, providing significant information for building designs with column-free planning, including parking facilities on lower levels [14].

**Xiuhua Guo et.al (2024)** This research proposes a new load transfer system (LTS) to strengthen column when it is supported by beams, especially in large section size, heavy load and defective columns. The proposed LTS is a vertical load transfer system that takes the form of a bracket. It consists of a reinforced concrete system supported by columns. The mechanism of load transfer of the system was simulated using finite elements with the bottom pressure force and pressure distribution curves of the cross sections being two important parameters. The net distance between the supporting column and the original column and the ratio of the horizontal lap length between the supporting columns were found to be important parameters that influenced the bottom pressure force distribution. The deformational behaviour of the frame beam between the supporting and original columns was examined, and the maximum permissible net distance was obtained. The pressure distribution curves showed an inner arched curve, where the load was transferred. In real-time engineering applications, real-time monitoring ensures that the LTS is effective in facilitating the transfer of loads, which enhances the stability of the structure [15].

**Priya Singh et al. (2022)** examined the dynamic behaviour of reinforced cement concrete (RCC) wound buildings under dynamic loads. RCC wound buildings are also compared with various twist rates, especially 10°, 12.5 °, and 15 °, at the centre of the RCC wound structure. ETABS software was used for modelling and analysis.

The study considered numerous loads, including dead, live, seismic, and wind loads, exerted on the modelled structures. The key parameters analysed in the results included displacement, story drift, time period, and base shear. The results show that the structural response is sensitive to different twist angles, which is an important insight into the behaviour of RCC-wound buildings under dynamic conditions. A literature review of tall building analysis is also presented in this paper.

**Vishal N et.al al.(2020)** discussed the significance of the sequential application of loads in the construction of multi-storey buildings and how the structural members vary with the construction; therefore, there is a need to carefully analyse the structure. Conventional structural analysis normally assumes that the total load is exerted at the completion of the entire construction which ignores the fact that storey loads occur during the construction process. This negligence causes an improper distribution of force throughout the building. A 20-storey building with vertical setback irregularity was modelled and analysed using the response spectrum method in CSI ETABS V16, in accordance with BIS 1893:2016 (Part 1). This was analysed in the presence and absence of Construction Sequence Analysis (CSA). The results compared in the study are axial force, shear force, bending moment, story displacement, story shear, and story drift in various structural systems. The results highlight the role of implementing CSA in ensuring structural safety and cost-effectiveness in high-rise structures [16].

**Hyun-Sung Kim et.al (2018)** In this paper, the dynamic analysis of the structure of connections of a modular floating structure of a solar power generation system has been provided [17]. The modular floating system consists of several concrete blocks that act as buoys and are joined by connection beams. The finite element method (FEM) was used in 2D and 3D conditions to analyse the entire structure, and the results of the two conditions were compared. The Froude–Krylov equation was used in the 2D analysis to approximate the wave force on the concrete blocks. In contrast, the 3D analysis employs the high-order boundary element method (HOBEM) to compute the wave force more precisely. The comparison of the wave load distribution of the 3D analysis with the Froude-Krylov force is made comparable because the Froude-Krylov force is uniformly applied in the 2D analysis. The results of the wave load analyses were used to assess the connection beam stresses and compare them over time. Moreover, unit module structure analysis was performed and compared with the outcomes of the full modular structure. This study draws attention to the disparities in the modelling of wave forces and how they can affect the structural performance of floating solar systems.

**Nie et al. (2020)** conducted a literature review on the strong column–weak beam design philosophy, which is an essential philosophy of seismic design application to frame structures. This review discusses the concept and historical background of this design philosophy, which has contributed to the accurate determination of the flexural capacity of beams and the calculation of the column-beam flexural strength ratio. The contributions of the four countries in terms of design provisions are discussed with reference to their contributions to this approach. The strong column–weak beam hierarchy is examined in a real structure design application, where the challenges and limitations that exist are examined. This study concludes by examining a number of methods for the seismic retrofit of existing reinforced concrete frames, providing insight into the enhancement of the seismic resilience of structures. This study highlights the need to design and retrofit structures to increase the earthquake resistance of frame buildings [18].

**Hamza et al. (2020)** conducted a seismic investigation of a G+9 building with architectural complications, such as external floating columns, subjected to earthquake excitation. Floating columns are another common characteristic of modern high-rise structures, which are normally not allowed in construction according to IS: CODE-1893:2016 Clause 7.1, but they are also under research. Both the static and dynamic analysis of the building is done based on earthquake zones IV and V. This study will limit the structural damage under seismic conditions by determining the worst-case scenario and suggesting relevant strengthening measures. Displacement and drift graphs were drawn to determine the performance of the building during earthquakes. SAP2000.v20 software was used to perform the analysis. This research offers meaningful information regarding the behaviour of buildings using floating columns and proposes ways to improve their seismic strength to make them safer in earthquake-prone areas [19].

## 2.1. Research Gap

The reviewed studies show that floating column systems and transfer beams have been widely analysed for seismic response, load redistribution, drift, displacement, and bending behaviour. However, limited focused research is available on the combined performance optimisation of prestressed transfer beams supporting floating columns, especially considering the tendon profile, eccentricity, prestressing force, beam depth, L/D ratio, and ultimate load capacity. Most studies are based on conventional RCC transfer beams or general seismic comparisons, whereas detailed parametric FEM-based investigations of prestressed transfer beams under combined gravity, seismic, and lateral loading remain insufficient.

Further research is required to develop an optimised and economical design approach that improves stiffness, reduces deflection and cracking, enhances load transfer efficiency, and ensures safe floating column performance in high-rise buildings.

# 3. LITERATURE SUMMARY

| Sr. No. | Author(s) & Year | Method | Results | Findings & Outcomes |
|---|---|---|---|---|
| 1 | Xuefei Pang et al., 2024 | Low-cycle reversed load test, FEM analysis | Seismic performance indicators: hysteresis, stiffness, energy dissipation | Use of high-performance concrete mitigates crushing, L-shaped steel prevents early damage |
| 2 | E.N. Thejesh et al., 2020 | Linear dynamic analysis, Response spectrum and Time history | Time period, base shear, storey displacement, storey drift | Insights on floating columns' effect on seismic loading, impact of transfer beams |
| 3 | Deok Hee Won et al., 2021 | FEM, Bending behavior analysis | Maximum strength 700 kN to 1200 kN, residual displacement increased | Inner steel tube improves strength and displacement; both ductility and tight connection methods considered |
| 4 | Abdelrahim Abdalla Bashir et al., 2022 | ETABS, SAFE, Midas software | Moment, shear force, deflection analyzed for floating columns | Redistribution of forces observed in floating column buildings |
| 5 | Xiuhua Guo et al., 2024 | FEM, Load transfer system analysis | Bottom pressure force distribution, inner arched load transfer | LTS facilitates effective load transfer, ensuring stability |
| 6 | Priya Singh et al., 2022 | ETABS software, Dynamic load analysis | Displacement, storey drift, time period, base shear | Seismic response of RCC wound buildings under dynamic conditions, impact of twist angles |
| 7 | Vishal N et al., 2020 | Response spectrum, with/without CSA | Axial force, shear force, bending moment, storey displacement, shear | Importance of Construction Sequence Analysis (CSA) for structural safety |
| 8 | Hyun-Sung Kim et al., 2018 | FEM, 2D & 3D wave load analysis | Stress evaluation on connection beams | Differences in wave force modeling and structural performance in modular floating systems |
| 9 | Xuefei Nie et al., 2020 | Literature review, seismic design analysis | Flexural capacity, column-to-beam strength ratio | Strong column-weak beam design improves earthquake resistance |
| 10 | Parveen Hamza et al., 2020 | Static and dynamic analysis with SAP2000.v20 | Displacement, drift, shear, base shear | Seismic analysis of buildings with floating columns in zones IV and V |
| 11 | Naaman (2012); Lin & Burns (2010) | Parametric study | Deflection, stress distribution, cracking, ultimate load capacity | Tendon profile, eccentricity, prestressing force and beam depth significantly improve structural performance and serviceability |

## 4. PRESTRESSED TRANSFER BEAMS IN FLOATING COLUMNS

The structural performance analysis of prestressed transfer beams in floating column systems has been of high interest in contemporary structural engineering owing to the growing need for flexible and efficient building designs for high-rise buildings. Lower levels are usually made open with floating columns, and as a result, support beams must be used to redistribute the load to the supportive columns on the upper levels. In this type of system, the transfer beams experience complicated loading conditions and should be engineered to support heavy bending and shear loads. One of the main methods of these transfer beams is to prestress them to increase their load-carrying capacity, minimise deflections, and control cracks. Prestressed concrete transfer beams permit the transfer of loads across longer distances more efficiently, which is required in floating column structures where the supporting structure is not usually continuous. Different researchers have aimed to examine the behaviour of stressed transfer beams, considering the length of the span, distribution of load, material properties, and method of stressing (pre-tensioning or post-tensioning). It has been established that prestressing is very important in the performance of transfer beams, as it increases their resistance to bending and shear, resulting in even more optimised designs. In addition, the prestressed transfer beam in floating column systems should be carefully analysed considering the beam of transfer interaction with the supporting columns. Various studies have highlighted the fact that precise modelling methods, such as finite element analysis (FEA), should be used to determine the behaviour of these systems under various loading conditions, such as dead loads, live loads, and seismic forces. The findings of these tests are helpful in establishing the best strategies to be applied to the prestressing systems and design of the transfer beams to ensure that the floating-column system is stable and efficient in its service life.

### 4.1. Introduction to Floating Column Systems

Floating column systems are a new architectural design type that is mostly implemented in recent buildings to fill large open areas, usually in multi-storey buildings. These systems consist of columns which are suspended overhead such that the beams are not directly held by the ground floor, thereby creating column-free spaces in the lower floors. Floating columns are flexible, particularly in commercial buildings where large spans are required to accommodate open floor plans, such as shopping centres, auditoria, and exhibition halls. A floating column is a column that places the load of higher levels on a beam, which then places the weight on the columns or structural components of higher levels.

Columns are typically placed in areas where the structural load must be passed to lower levels by the upper levels, and the building does not interfere with the open-plan structure of the lower levels of the building. Nevertheless, the introduction of floating columns usually causes some difficulties, especially in the complexity of structural analysis and construction. This is because the lack of direct foundation support may lead to further stress with consequent stability issues.

From a design perspective, floating columns require special consideration to ensure that they can transfer loads safely without affecting the overall structural integrity of the building. Any beams attached to floating columns, such as transfer beams, must be designed to accommodate the high bending moments and shear forces introduced by the unconventional load path of the floating columns. The problems associated with the distribution of vertical and lateral loads and the possible torsional effects, which may be caused by the position of the floating columns and the overall behaviour of the structure, also require special attention. Floating column systems are typically adopted in high-rise buildings, where space control and aesthetics are key issues. They allow designers the freedom to design open and continuous areas in such applications and enable them to handle the increased load of the upper floors in the structure. Although floating column systems have many advantages, they should be constructed with a keen attention to load balance and stability requirements, particularly in areas that tend to experience seismic activities.

### 4.2. Significance of Transfer Beams

Floating column systems with transfer beams are essential for the performance of high-rise structures and complex architectural designs deployed in modern buildings. These beams ensure that the loads of higher levels are transferred to the lower columns, particularly in buildings where the columns that support the loads are not straight owing to architectural limitations, such as open floor plans or huge interiors. The importance of transfer beams is due to the fact that they provide stability and load distribution of a structure through vertical load transfer across non-aligned column locations. The main role of a transfer beam is to fill the gap between the columns that hold the building and thus redistribute the loads applied to the supporting columns or foundation. This aids in preserving the integrity of the building and eliminating structural failure. The construction of the transfer beams in the floating column systems requires a thorough examination of many factors, including the intensity of the loads, strength of the material used in these constructions, and the structural size, as they should be able to endure the weight of the columns above them and the sideways forces, such as wind and seismic forces. In addition, the use of transfer beams is critical for optimising the space and operation of buildings. For example, in a commercial building or parking structure, the transfer beams provide the option of creating open spaces in the lower story and are not necessarily blocked by columns to provide flexibility in the design. As such, the functioning of transfer beams in floating column structures has a direct impact on the general safety, functionality, and cost-effectiveness of a structure. More detailed methods of analysis, such as finite element analysis, are frequently utilised to assess the transfer beam under various load conditions to ensure that the design satisfies safety requirements and is best maintained during the life of a building.

## 4.3. Prestressing Techniques in Beams

The tendon profile type, tendon eccentricity, magnitude of the prestressing force, tendon layout configuration, and depth optimisation are all factors that affect the performance of prestressed transfer beams in floating column systems. These different tendon profiles, such as straight, parabolic, and draped, have a significant impact on both bending resistance and load balancing, particularly with regard to the benefits of parabolic or draped tendon profiles in providing high resistance to the bending moments created by concentrated loads originating from floating columns. The role of tendon eccentricity in creating a resisting moment is also critical; as the amount of eccentricity increases, so does the moment capacity, which ultimately creates lower tensile stress on that tendon. However, excessive eccentricity can create stress concentrations and construction difficulties. The level of prestressing force used also affects performance; therefore, it needs to be optimised. An insufficient prestressing force will not adequately control deflection and cracking, whereas an excessive prestressing force will create overstressing conditions, in addition to cambering and/or local crushing of concrete. The layout configuration (single layer vs. multiple layers) of the tendons in relation to each other also affects the overall efficiency of the structure by affecting how the total stress is distributed throughout the structure, as well as affecting the deflection behaviour of the system. Finally, beam depth optimisation is very important in determining beam performance; the depth of the beam can affect both stiffness and deflection, whereas excessive beam depth results in increased self-weight and construction cost. Conversely, insufficient depth ultimately leads to compromised serviceability of the structure. Thus, all these variables must be considered when designing assemblages with prestressed concrete transfer beams within floating column systems.

### 4.4. Load Distribution in Floating Columns

Floating columns in high-rise buildings have become a popular structural system for conceptualising spaces to fit large open areas such as lobbies, parking, and commercial spaces. Floating columns refer to columns which do not directly depend on the foundation but share their loads with another lower floor slab which in turn shares the loads with the foundation using other supporting structures such as beams or shear walls. The distribution of loads within the floating column is one of the most important aspects that directly influence the structural stability and performance of the building. In conventional construction, load transfer occurs between the columns and foundation, which balances the load evenly. Nevertheless, in floating column configurations, the load of the floating column is passed on to the surrounding structural members, such as beams, slabs, and other columnar members. These components are designed to support the additional weight transferred by the floating columns. Predictably, increased bending and shear forces can result in bending moments that the overall structure must accommodate. Several studies have established that improper loads on floating-column systems can lead to structural collapse. Floating columns typically transfer their loads to reinforced concrete beams, transfer beams, or both. The transfer beams are designed to provide additional moment and shear force owing to the loading from the floating columns. Consequently, engineers must pay special attention to transfer beams under such redistributed loading conditions because they are subjected to increased loading (stress), as opposed to traditional beams. Prestressed transfer beams can also be used to reduce deflection and improve overall structural stability. The loads on floating columns are influenced by various factors, such as the building layout, number of floating columns, span of the transfer beam, and characteristics of the materials composing the structural members. Engineering analysis using methods such as finite element analysis (FEA) and nonlinear analysis are highly developed analytical control techniques that are used regularly to model and evaluate load transfer and overall structural impact.

### 4.5. Behavior Under Seismic and Wind Loads

The prestressed transfer beam structural performance of floating column systems under seismic and wind loads has attracted considerable attention owing to the distinct behaviour of high-rise buildings. The use of transfer beams, which are typically involved in redistributing the loads of the upper floors to the lower structural frameworks, is critical in maintaining the stability and integrity of the entire structure, particularly in buildings with floating columns that do not have direct vertical loading paths.

Transfer beam prestressing assists in elevating the strength and stiffening of the transfer beam, thereby increasing the ability to resist outside forces, such as seismic and wind loads. Prestressed transfer beams show high resistance to seismic loading because of their precompression which is beneficial in controlling cracking and deflection in order to be able to effectively absorb and dissipate energy. It has been discovered that flexibility of the floating column system influences the distribution of seismic forces since beams to be used are prone to bending, shear and torsional forces during an earthquake. The behaviour of the transfer beam under seismic forces may be affected by the level of prestressing, beam geometry, and actions of other structural components.

## 4.6. Material Selection for Prestressed Beams

The choice of prestressed beam in floating-column systems requires critical consideration to achieve structural integrity, performance, and durability of the structures under different loading conditions. Prestressed concrete beams are typically employed in structures in which the strength and deflection are minimal, such as floating column structures. These systems usually entail the use of beams that are highly bent and sheared under the influence of the eccentric load distribution caused by the floating columns. Therefore, the materials must not only offer the necessary strength but also help enhance the long-term durability and resistance of the beam to environmental factors. Concrete is the main material used in prestressed beams owing to its compressive properties and heavy-weight resistance. High-strength concrete: High-strength concrete with a compressive strength of usually more than 50 Mpa is required because of the better load-carrying capacity of concrete and the reduction in the cross-section size of the beam, thereby minimising the dead load of the structure. High-strength steel tendons or cables are also critical because they help the beam to withstand tensile stresses and provide a balance between strength and ductility. The prestressing process is usually performed using steel tendons because of their high tensile strength, which enables the beam to sustain the required forces with minimal elongation and breakage.

## 4.7. Performance Analysis through Finite Element Modeling (FEM)

At present, FEM is essential for evaluating prestressed transfer beams used in floating column applications. Floating columns are often used in high-rise open-space buildings and experience complex reactions to applied loads. FEM has been shown to be an adequate modelling tool for demonstrating the structural behaviour of transfer beams under various loading situations.

For prestressed transfer beams, FEM is a good representation for modelling the complete geometry of the beam (i.e. its boundary conditions and materials), thus producing accurate predictions of stress distribution, deformation, and failure mode. The main advantage of FEM is its capability to manage the non-linearities of prestressed systems, that is, the interaction between the prestressing force and the beam response. Prestressing increases the beam capacity to sustain external forces, thus minimising deflections and cracks, which is essential for the structural integrity of floating column systems. FEM simulations can enable a proper estimation of several parameters, such as load transfer, stress concentration, where support is introduced, and the effects of various prestressing methods. With the help of the model being enhanced with different levels of prestress and beam designs, engineers should be able to make the transfer beam design optimal to achieve maximum functionality and safety. In addition, FEM can be used to test the seismic performance because it can simulate dynamic loads and forecast the behaviour of the transfer beam during an earthquake or any other dynamic phenomenon. The ability to use the Finite Element Method (FEM) along with today's software applications has significantly enhanced our ability to analyse complicated structural systems, such as floating columns supported by prestressed transfer beams. This analytical method can help ensure that high-rise buildings and other unique architectural designs are structurally sound, durable, and efficient over time. The analysis of any FEM design will include the tendon profile, eccentricity of the tendon, variation in the prestressing force, and depth of the beam as the four key parameters in the design process.

### 4.8. Influence of L/D Ratio, Depth Variation and Ultimate Load Capacity

The L/D ratio, depth variation, and ultimate load capacity of prestressed transfer beams in floating-column systems are essential design parameters for assessing the performance of structures. The L/D ratio indicates the extent to which a beam spans in relation to its effective depth. For instance, a slender beam (higher L/D ratio) subjected to a concentrated floating column load will typically experience excessive deflection, high tensile stress levels, and lower stiffness than a beam with a lower L/D ratio, which can be more effective than providing greater stiffness, deflection control, and cracking control. Although the effect of depth variation on the transfer beam structural behaviour is direct (i.e. the greater the depth of the beam, the greater the flexural stiffness, moment resistance, shear capacity, and ultimate load capacity), if a beam is excessively deep, it will also be heavier, thus increasing the amount of material used, increasing the cost, and decreasing the amount of usable building area.

Therefore, the transfer beam should be optimally designed for its required functions, as opposed to having an excessive depth added to the beam. The ultimate load capacity of a prestressed transfer beam is also affected by its depth, tendon profile, eccentricity, and amount of prestressing force. Therefore, when the optimum depth and L/D ratio of the transfer beam are achieved, the transfer beam will transfer the load more efficiently, reduce the risk of serviceability problems, and increase the safety of the transfer structure. Thus, the L/D ratio, depth variation, and ultimate capacity are integral to the proper functioning of a prestressed transfer structure in a floating column design.

## 4.9. Design Challenges and Structural Failures

The layout of prestressed transfer beams in floating column systems poses several singular problems that may considerably affect the overall structural performance. Achieving proper load distribution is one of the major challenges. Floating columns also produce an uneven distribution of vertical loads, which are shifted to higher levels of transfer beams. These beams should be built to carry concentrated loads that are not necessarily directly held at intermediate levels and hence may have high bending moments and shear loads. These forces should be considered in the design; otherwise, overworking and cracking of the beams or, in the worst-case scenario, structural failure may occur. The other difficulty is the use of the prestressing forces. The prestressing tendons should be installed and stressed properly to ensure that the forces are well balanced on the transfer beam. Poor tensioning or even poor positioning of the tendons may result in an uneven distribution of force, which will result in deflection, cracking, and even failure of the transfer beam during the service loads. In addition, the connection of the transfer beam to the floating columns must be strong and stable. Poor detailing at such connections can cause local failures, particularly under seismic or wind loading conditions. Failures in the structure of such a system are usually associated with incorrect calculations of the load, ineffective detailing, and the inability of the transfer beam to resist forces that exceed the anticipated ones. Such failures are normally described as those that have noticeable cracking, excessive deflections, and, in some cases, total collapse. Such failures can be avoided through proper design and practicality of serviceability, safety, and application of superior methods for analysing information. Inspection and maintenance are also essential done at regular intervals to ensure that any problems are identified early enough such that they do not cause any serious damage.

### 4.10. Recent Advances and Research in Prestressed Beams

As far as recent technological advancements in designing and examining pre-stressed transfer beams for floating column applications are concerned, these technologies have helped improve the efficiency and performance of transfer beams significantly. Owing to their use in tall buildings and other complex structures, pre-stressed beams have become more common owing to their ability to support long spans and heavy dead loads. Transfer beams transfer loads from floating columns to either the floor slabs below them (when no walls are present) or directly to the foundation of the building. Modern studies have focused on optimising the design of prestressed transfer beams with the introduction of advanced materials such as ultra-high-performance concrete (UHPC) and fibre-reinforced polymers (FRPs), which enhance the strength and durability of such beams. More specifically, UHPC has excellent mechanical characteristics, allowing for the construction of thinner beams and the use of less material with the same load-bearing capacity. Meanwhile, FRPs are applied to augment the shear strength and corrosion resistance of beams under stress to provide better long-term service, particularly in severe conditions. In addition, greater modelling accuracy and efficiency have been achieved through further increases in computational capabilities, including the use of finite element analysis (FEA) and multi-objective optimisation methods, permitting more precise modelling of prestressed beams in different load scenarios. This will help explain the complicated behaviour of prestressed transfer beams in floating column systems, particularly how they react to dynamic loads such as wind and seismic loads. In addition, sustainability has been shifted to the application of recycled aggregates, environmentally friendly prestressing methods, and design methods that consume less energy. These inventions help lower the carbon footprint of high-rise buildings and ensure the structural integrity of prestressed transfer beams. Current studies and technological advancements are still in the process of enhancing the functionality, economy, and durability of prestressed transfer beams to guarantee their centrality in the contemporary building industry.

## 5. DISCUSSION

Floating column systems (FCS) is a system that is gaining popularity in the modern high rise buildings because it allows huge open spaces on the lower levels, which is usually used as parking or commercial spaces. However, these systems present great difficulty in terms of structural design, particularly in load distribution.

The fact that the columns are not built all the way to the foundation and the roof makes the columns dependent on transfer beams that redirect the loads through other structural elements, which may be higher columns. The main application of transfer beams is to control the bending moments, shear forces, and loads of floating columns. The design of these beams should be such that they can withstand these complex loading conditions to guarantee the overall stability and safety of the structure. Prestressed concrete is commonly used in these transfer beams because it increases their resistance to bending, shear, and deflection. The prestressing process provides an internal force that opposes the tension induced by external loads, thus improving the beam performance and increasing its ability to carry loads. In floating column systems, transfer beams are influenced not only by the vertical loads of the columns above but also by lateral loads, such as wind and earthquakes. Conventional structural analysis may not adequately model this complexity; as a result, advanced technology such as Finite Element Analysis (FEA) is used to predict structural behaviour under various loading conditions, including how stresses are concentrated, how deflection occurs, and how each structure may fail. In addition, at the time of a seismic event, the forces applied to the transfer beams can increase significantly owing to dynamic effects; thus, effective design methodologies must be employed. Recent studies have focused on the inclusion of high-performance concrete (HPC) and fibre-reinforced polymers (FRP) in transfer beam construction to improve the strength, durability, and performance of beams under dynamic environments, including earthquakes [20].

Load distribution is a major problem in floating-column systems. In traditional building systems, the load is placed on the columns which directly pass to the foundation, making it evenly distributed. Nevertheless, in floating columns, the transfer is performed using transfer beams, which can result in an uneven distribution of forces. This nonuniform load path must be considered when designing the transfer beams and supporting columns. Other stresses are present on these beams, which may lead to bending and shear forces that are higher than those observed in conventional designs. It has been observed that transfer beams can be strengthened to enhance their performance in such circumstances to minimise cracking and reduce deflections. Prestressed concrete decreases the overall size of the beam and the material used in construction, but at the same time, it provides the beam with enough strength to support the increased load in the floating column system. In addition, dynamic forces, particularly seismic activity, can introduce large stress levels and possible failure in the transfer beams.

In response, researchers have used the latest modelling tools, such as dynamic analysis and response spectrum techniques, to comprehend the behaviour of transfer beams subjected to seismic loads. As an illustration of this, a study by Pang et al. (2024) concluded that high-performance concrete and L-shaped steel are highly effective in enhancing the seismic strength of concrete joints, and this is the same case with the floating column system. Similarly, E.N. Thejesh et al. (2020) demonstrated that various transfer beam models, both prestressed and non-prestressed, can significantly affect the building in its response to seismic forces. The results of this study highlight the importance of designing transfer beams to support not only static loads but also to operate optimally in a dynamic environment. Finally, a combination of the stability and safety of floating column systems is necessary.

## 6. CONCLUSION

A review of the concept of prestressed transfer beams in floating column buildings reveals that the principle of floating column buildings is critical for achieving the structural stability and performance of contemporary high-rise buildings. Although floating column systems provide a high proportion of open space on lower stories, they are difficult to implement because of the discontinuous nature of the columns, and necessitate the use of transfer beams to redistribute loads effectively. The capability to support additional weight means that pre-stressed concrete transfer beams can withstand more bending and shearing forces than regular transfer beams when supporting floating columns; when subjected to the added weight of floating columns (i.e. immense lateral and vertical bending moments), the transfer beam will tend to deflect more, hence improving its ability to resist cracking. The ability to accurately represent the load distribution patterns of floating column systems through analytical models, such as finite element analysis (FEA), has added to the documentation regarding the effectiveness of using transfer beams for supporting floating columns, since accurate predictions can then improve any design decisions made to the transfer beam itself and the floating column system as a whole. In addition, incorporating high-performance concrete (HPC) and fibre-reinforced polymers (FRP) in transfer beam designs has improved the overall strength and ductility of transfer beams, particularly for loads induced by earthquakes or other dynamic forces. Furthermore, by properly designing the load-distribution systems of floating column structures with accurate loading predictions, designers can achieve improved safety and performance of floating column structures.

Given that floating column systems are becoming increasingly commonplace in the construction of new buildings, it is essential that designers continue to utilise advanced analytical methods and new materials to maximise the safety, stability, and cost efficiency of these new structures as they evolve.

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