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Comparative Analysis & Performance of PT Beams vs. RCC Deep Beams in Multistory Buildings Under Dynamic Loading

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Abstract

As the demand for multistory buildings rises, so do the need for structural systems that can withstand dynamic loads like earthquakes, wind, and vibration. Reinforced Cement Concrete (RCC) deep beams and Post-Tensioned (PT) deep beams are among the structural members that have received widespread interest for their unique structural properties and performance benefits. This review paper compares the performance of RCC deep beam structure with PT beam structure of multistory buildings under dynamic loading condition. The basic characteristics of both beam systems, different dynamic loads applied to buildings and important performance parameters as the load carrying capacity, deflection, stiffness, ductility, energy dissipation, crack control, serviceability and durability are discussed. The extensive study of the latest literature has shown that the PT beams have a higher load carrying capacity, less deflection, better crack resistance and high structural efficiency, whereas the RCC deep beams are high in stiffness, shear resistance and simpler to construct. The study summarizes the benefits, drawbacks and practical use of both systems and suggests possible future research to enhance structural performance and resilience under dynamic loading.

Keywords; Post-Tensioned Beams (PT Beams), RCC Deep Beams, Dynamic Loading, Multistory Buildings, Structural Performance Evaluation.

INTRODUCTION

Rapid urbanization, population growth, and the need to make use of the limited land area have led to a significant rise in the construction of multistoried buildings over the past few decades. The continuing rise of building heights requires structural components to be able to deal with, apart from their static load, dynamic loads which are caused by earth quakes, wind forces, vibrations caused by machines and any other transient action. In reinforced concrete structures, beams are one of the most important structural elements, as they are used to distribute the load from the slabs to the columns and provide overall stability and safety to the structure [1]. Thus, it is necessary to select a beam system that is appropriate for optimal performance under dynamic loading conditions. In the modern construction, there are two commonly used beam systems, one is Reinforced Cement Concrete (RCC) deep beam and Post-Tensioned (PT) beam. The small span to depth ratio of RCC deep beams allows them to support a heavy load and transfer stresses efficiently [2]. They are usually used on transfer girders, the foundation system and in highly loaded areas of structure. PT beams, on the other hand, have high strength steel tendons tensioned after concrete setting, creating compression stresses which enhance load carrying capacity, minimize cracking and allow for longer spans, with reduced structural depth [3]. The difference in the dynamic loading behavior of these beam systems is greatly affected by their stiffness, ductility, energy dissipation and crack control properties. It is important for engineers and designers to understand these differences, if they want to enhance the performance and resilience of multistory buildings [4].

The review paper compares the structural behavior, dynamic response, strength characteristics, serviceability performance, and suitability for modern multi-story construction of PT beams and RCC deep beams. The goal of the study is to come together with the existing research results and to find the pros, cons and future potential of each beam system in a dynamic loading environment.

Overview of RCC Deep Beams

Deep beams are structural members with a relatively low span to depth ratio, typically below 2 for simply supported deep beams, and below 2.5 for continuous deep beams. Deep beams are not assumed to have linear strain distribution across the depth as for traditional beams. This results in the load being mainly transferred in the member by compression struts and tension ties, causing a nonlinear stress distribution in the member [5]. Deep beams are frequently employed in multi-story structures where there are heavy concentrated loads to be carried across short spans. Common uses include transfer girders, shear walls, foundation caps and areas around openings. They are also quite deep with high shear resistance and load carrying capabilities, thus they can be used for structures with high vertical loads and lateral loads [6].

RCC deep beams have high stiffness and strength under dynamic load conditions like earthquake loads and wind loads. But, cracking patterns, shear failures and stress concentrations around supports and loading points can often affect their behavior. Therefore, proper reinforcement detailing is an essential requirement to improve ductility and to perform safely under cyclic loading conditions [7]. The design of RCC deep beam is typically designed based on the Strut-and-Tie Model (STM) that has been shown to capture the internal force transfer mechanism. Despite their growing popularity in structural design codes, RCC deep beams remain a vital solution for multistory building construction for their strength, ease of construction and acceptance [8].

Overview of Post-Tensioned (PT) Beams

The Post-Tensioned (PT) beam is an advanced structural form that is produced with the use of high strength steel tendons in the concrete within a duct. Once the concrete is strong enough, the tendons are stretched and tied to the concrete, putting stresses in compression into the beam. This prestressing action is able to resist tensile stresses induced under service loading and greatly improves the structural performance [9]. The use of PT beams has become widely popular in multi-storey buildings because of the ability to span longer distances, provide shallower beam depths and increase the span efficiency. The induced compression force

reduces cracking and deflection, and produces a higher serviceability than expected for standard reinforced concrete members. PT beams are therefore commonly used in commercial complexes, large span floor systems, parking structures and high-rise buildings [10].

PT beams exhibit superior stiffness, crack resistance and energy absorption under dynamic loading conditions. The prestressing force further reduces the stress concentrations of tension and restricts the propagation of cracks under the seismic and wind excitations, maintaining the integrity of the structure. Also, PT structures have reduced self-weight which reduces the seismic forces to which the building will be subjected [11]. While PT beams offer several benefits, they are not suitable for all situations and require specialized construction methods, expertise, and monitoring during installation and maintenance. In addition, factors like prestress losses, corrosion of the tendons, and the performance of the anchorages must be considered in order to achieve long-lasting durability. However, in the context of dynamic loading conditions, the high strength, excellent serviceability and efficient use of material makes PT beams an attractive solution for modern multi-storey structures [12], [13].

Dynamic Loading in Multistory Buildings

Dynamic loading is defined as the loading which changes with time in terms of magnitude, location, direction, or duration. Dynamic loads produce vibrations, accelerations and inertial forces that are significant in the behavior of multistory buildings, but are relatively constant loads. Dynamic loading effects must be taken into account in the design and analysis of modern high-rise structures, in order to guarantee their safety, serviceability and long-term structural behavior. Earthquake loads, wind loads, impact loads, machine-induced loads, blast loads and traffic induced vibrations are the major dynamic loads imposed on multistory buildings [14].

- i. **Earthquake Loads:** Earthquakes generate ground motions that induce horizontal and vertical forces in buildings. These forces create vibrations and inertial effects that can lead to structural damage if not properly considered in design.
- ii. **Wind Loads:** Wind exerts pressure on building surfaces, producing lateral forces and vibrations. Tall buildings are particularly susceptible to wind-induced oscillations and sway.

- iii. **Impact Loads:** Impact loads occur when objects or vehicles strike structural elements. These loads act over a short duration but generate high stresses and localized damage.
- iv. **Machine-Induced Loads:** Mechanical equipment such as generators, pumps, and elevators produce repetitive vibrations that may affect structural performance, especially when resonance occurs.
- v. **Blast Loads:** Explosions create sudden pressure waves that impose extremely high forces on structures within a very short time, potentially causing severe damage.
- vi. **Traffic-Induced Vibrations:** Vibrations generated by road traffic, railways, and metro systems can be transmitted through the ground and affect nearby buildings.

Among these dynamic loads, earthquake and wind loads are the most critical for multistory buildings because they directly influence the overall structural response and safety of the structure.

Structural Performance Parameters for Beam Evaluation

There are a number of structural parameters which can be used to assess the performance of RCC deep beam and Post-Tensioned (PT) beams under dynamic loading. These parameters are used to study the strength, stability, serviceability and behavior of beam systems in multistory buildings over a period of time [15].

i. Load-Carrying Capacity

The load carrying capacity of a beam is the greatest weight a beam can hold without breaking. One of the most significant performance indicators of structure. A load carrying capacity that is higher can withstand higher dead load, live load and dynamic load. The prestressing force normally gives a higher capacity to carry load to PT beams, and the large depth with efficient load transfer mechanism gives high strength to RCC deep beams.

ii. Deflection Characteristics

Deflection is the amount of movement of a beam when it is loaded. Over deflection may impact structural integrity, comfort of occupants and serviceability. Due to the effect of prestressing, the deflections found in PT beams tend to be lower than those found in other types of beams. The good

deflection resistance is achieved by the deep beams of RCC as they are stiffer and deeper.

iii. Stiffness and Ductility

Stiffness is a resistance of the beam to deformation when the load is applied on it while ductility is the capability of the beam to change its shape considerably before it fails. High stiffness reduces structural movement and vibration, and adequate ductility will provide energy absorption during dynamic events like earthquakes. Generally, the stiffness of the RCC deep beam is high, while that of the PT beam can be high or moderate, depending on the level of prestressing and reinforcement.

iv. Energy Dissipation Capacity

Energy dissipation capacity is the beam's capacity to dissipate and absorb energy produced by dynamic loads. This is especially relevant in earthquake events when a large number of loading cycles are imposed. Structural damage and overall stability can be minimized with beams having greater energy dissipation capability. In RCC and PT beam systems, this parameter is greatly affected by reinforcement detailing and material properties.

v. Crack Formation and Propagation

The formation of cracks is caused by tensile stresses in concrete that are greater than the tensile strength of the concrete. Cracks can be formed and may develop during service, leading to a loss of structural strength, stiffness and durability. When heavy loading occurs, visible cracking is more likely to form in RCC deep beams, while PT beams will experience less cracking because of the compression of the prestressing. The control of cracks increases structural safety and service life.

vi. Serviceability and Durability Considerations

Serviceability is the ability of a beam to satisfy the serviceability requirements under usual service conditions, namely, to deflect with limited deflection, vibrate to the limit of vibration and not crack under normal service conditions. Durability is the ability of the beam to resist the effects of moisture, corrosion, temperature changes and chemicals over time. Usually, PT beams have better durability since the cracks are minimal thereby reducing the entrance of harmful substances. When properly designed and maintained, deep beams made of RCC can offer a high level of durability. Serviceability and durability are both important to provide

long-term performance and reliability of multistory building structures.

Table 1: Structural Performance Parameters for Beam Evaluation

S. No.	Performance Parameter	Description	Importance in Dynamic Loading
1	Load-Carrying Capacity	Maximum load that a beam can support safely before failure.	Determines the ability of the beam to resist dead, live, seismic, and wind loads.
2	Deflection Characteristics	Measure of beam displacement under applied loads.	Controls structural stability, serviceability, and occupant comfort.
3	Stiffness	Resistance of a beam to deformation under loading.	Reduces excessive movement, vibration, and structural sway.
4	Ductility	Ability of a beam to undergo deformation before failure.	Enhances safety by providing warning before collapse, especially during earthquakes.
5	Energy Dissipation Capacity	Ability to absorb and dissipate energy generated by dynamic forces.	Reduces structural damage and improves seismic performance.
6	Crack Formation	Initiation of cracks due to tensile stresses exceeding concrete strength.	Influences structural integrity, durability, and maintenance requirements.
7	Crack Propagation	Growth and spread of existing cracks under repeated loading.	Affects long-term performance and potential structural failure.
8	Serviceability	Ability to perform satisfactorily under normal operating conditions.	Ensures acceptable levels of deflection, vibration, and cracking.
9	Durability	Resistance to environmental deterioration such as corrosion and weathering.	Determines the lifespan and maintenance needs of the structure.
10	Vibration Response	Structural reaction to dynamic forces and oscillations.	Critical for occupant comfort and structural safety in multistory buildings.
11	Strength-to-Weight Ratio	Relationship between structural strength and self-weight.	Influences efficiency and seismic performance of the building.
12	Structural Stability	Ability to maintain equilibrium under various loading conditions.	Prevents excessive deformation, buckling, or collapse during dynamic events.

LITERATURE REVIEW

(Jancy et al., 2023) [16] Present a novel approach to modeling post-tensioned beams that involves calibrating the FE model to experimental results until the load capacity and post-critical state are achieved. We conducted an analysis of "two post-tensioned beams" with distinct nonlinear tendon configurations. Prior to the experimental testing of the columns, material testing was conducted for the reinforcing steel, concrete, and prestressing steel. The Hypermesh program was employed to establish the spatial arrangement of the finite elements of the beams geometrically. The Abaqus/Explicit solver was utilized for numerical analysis. The concrete damage plasticity model was employed to characterize the behavior of concrete in terms of the various laws of elastic–plastic stress–strain evolution for tension and compression. Elastic-hardening plastic constitutive models were utilized to describe the behaviour of steel components. An effective approach to simulating the load was established, backed by the application of "Rayleigh mass damping" in an explicit procedure. A satisfactory convergence between numerical and experimental results is guaranteed by the model approach that has been presented.

The fracture patterns formed in concrete represent the real behaviour of structural members at every loading stage. Random flaws observed during experimental research on the findings of numerical analysis were also explored.

(Kahar et al., 2024) [17] These days, the post-tensioning method is becoming more and more popular because of its use. The most cost-effective and secure design may be created by employing the post-tensioning technique. More safety measures for the slabs' shear and deflection standards must be taken while employing this technique. The comparable frame approach and load balancing may be used to construct post-tensioned flat slabs. An office building is used as a case study for the implementation of the design process. The office building's (G+4) layout is taken into account. This building is created by examining four cases with different floor systems. The amounts of concrete, pressurizing steel, and reinforcing steel needed for the slab, beam, and column are computed and displayed in tabular form. In addition, the building's overall cost per square meter is determined, and the costs of the four cases are compared.

(Patel & Kodwani, 2024) [18] Following the comparison analysis, numerical values and structural stability were examined. The model was designed and analyzed using ETABS programming in the elastic domain, and the models for the arrangement of columns and beams came last. In this study, a G+13 tall building frame with three distinct conditions—deep beam, deep beam with secondary beams, and post-tensioned beams—is taken into consideration. Using the response spectrum approach and the I.S. 1893-I codal provisions, we are doing dynamic analysis in this work. We are using ETABS, an integrated building design program, for analysis and design.

(Dhamija et al., 2024) [19] ETABS software is used to study the structural response of reinforced concrete (RCC) and post-tensioned (PT) slabs under lateral loading. This study studies RCC and PT slabs' behavior by utilizing finite element analysis to calculate bending moments, shear pressures, and storey drift. Prestressed slabs exhibit lower bending moments and shear pressures than RCC slabs, illustrating the efficiency of prestressing in decreasing structural needs. A reduction in storey drift also shows increased resilience to lateral deformations in PT slabs. PT slabs are an appealing option since they provide potential advantages for building layouts and construction in terms of structural performance and cost-effectiveness.

(Chaturvedi & Singh, 2025) [20] conduct an approach to the usage of PSC in multistory buildings and its fundamental behavior, a complete review was conducted through a variety of articles pertaining to the PSC and its methods that have been carefully and critically examined. The gap indicates that none of the studies used LRPC strand cables to post-tension PSC beams in an analytical investigation. A commercial building is taken into consideration and the PSC beams are replaced at different floor levels in order to do accurate simulations utilizing an analytical program with varied cases. After that, these cases are optimized according to their limiting values (OPSC-BP to OPSC-BR) and contrasted with a generic construction based on RCC rebars (RCC-B). The output parameters, such as beam deflection, shear forces, bending moments in beams, and base shear of the entire structure under seismic load, have been carried out with the appropriate checks to observe the limiting values of the beam resistance are evaluated and compared in order to assess the performance of commercial buildings. The research's conclusive findings indicate that, for a subset of G+10 commercial apartments, the optimized PSC beam significantly reduces sizes, and the cross sectional area decreases to a minimum of 12.89% and a maximum of

69.70% for various floor levels. Finally, suggestions demonstrate that PSC permits a member reduction that is precisely proportionate to the cost, hence achieving economic success.

(Tahmasebinia et al., 2023) [21] Examine how "post-tensioned concrete flat slabs" with various shapes and damping ratios behave dynamically. The AS3600 standard was followed in the construction of four groups of models with varying lengths, widths, thicknesses, and damping ratios. These were utilized to compare the control variable technique with the reference model in order to ascertain the impact of each parameter on the vibration serviceability. "Natural frequency, peak acceleration, and response factor" were the vibration evaluation criteria. The impact of various geometries and damping ratios on vibration is ascertained using both "the Strand7 finite element analysis (FEA) method and the SCI/CSTR43 standard" theoretical calculations approach. By comparing the mistakes of the two approaches, the viability of the Strand7 FEA technique for vibration analysis is also evaluated. The Strand7 FEA approach is quite accurate and practical, according to the paper's conclusion. The natural frequency is greatly influenced by the span in both directions, and improving the vibration serviceability may be achieved by increasing the damping ratio and the thickness of the slab. Upon the findings of this paper, suggestions are offered for the future design of vibration in post-tensioned concrete slabs.

(Antony & LAL, 2023) [22] The compressive stresses are typically absorbed by the concrete in the "case of RCC (Reinforced cement concrete)" beams, while the tensile stresses are absorbed by the steel. We are not taking into account the concrete mixture that is set below the neutral axis due to its fragile character in terms of tension resistance. In spite of the steel that is present to withstand the tensile stress, the tension zone concrete will develop a few minute fractures. After a lot of study, it is found out that this problem may be removed by stressing both the steel and concrete, however this should be carried out before the load application. We can conclude internal prestressing in two distinct ways: the pretensioning process and the posttensioning process. Tendons must be tensioned between hard anchor blocks cast during the pre-tensioning process before concrete is cast using molds. This can be done on the floor, pre-tensioning bed, or in columns. Concrete is tensioned following casting in post-tensioning. Concrete slabs are cast by integrating ducts to accommodate the tendons. The high-tensile wires are tensioned and affixed by wedges after the concrete has reached a sufficient strength.

A brace is then connected to the end face of the member. After this procedure, some space will remain, which may be filled with grout. The ETABS 2017 has been employed to evaluate the effect of PT beams and RC beams in multi-story

buildings subjected to seismic activity. Additionally, the bracings' impact on the PT beam structure has been examined.

Table 2: Summary of Literature Review on PT Beams and RCC Deep Beams

Author(s) & Year	Objective/Focus	Key Findings
More & Gudadappanavar (2022) [23]	Comparative evaluation of RCC deep beams and PT beam-slab systems in multistory buildings under seismic loading using ETABS.	PT systems improve load-carrying capacity, economy, structural behavior, and aesthetics compared to conventional RCC structures.
Verma & Bandewar (2020) [24]	Investigation of RCC deep beam behavior under seismic loading and the influence of shear reinforcement.	Shear reinforcement significantly affects shear strength. Diagonal cracks were the first failure indicators, and load-deflection behavior was evaluated.
Divshikar & Patil (2021) [25]	Review of flexural behavior of post-tensioned beams.	Post-tensioning enhances structural performance and is widely used in building, hydraulic, highway, marine, and nuclear structures.
Singh et al. (2018) [26]	Study of prestressed concrete technology and anchorage systems.	Prestressing through pre-tensioning and post-tensioning improves structural efficiency, with anchorage systems playing a vital role in performance.

CONCLUSION

The behavior of beam systems is an important factor in guaranteeing a building's safety, stability and serviceability when subjected to dynamic loading conditions in a multistory building. This review discussed the structural behaviour and performance attributes of RCC deep beams and Post-Tensioned (PT) beams subjected to earthquake, wind and other dynamic loadings. Deep beams are well suited for heavy load applications as they offer good shear properties, stiffness and load transfer characteristics with RCC. These tend to crack, though, and may need thicker members. PT beams, on the other hand, are used to increase the load carrying capacity, decrease deflection, control crack formation and increase structural efficiency through the use of prestressing forces. The examined studies have shown that PT beams overall demonstrate excellent performance in terms of serviceability, durability, vibration control, and seismic response. Further, the lighter weight and longer span of PT beams are economically and architecturally advantageous. However, specialized construction skills and maintenance are required to successfully implement them. In summary, both types of beams have their respective merits, and the choice of the beam system should take into account the project requirements, the loading, the economy, and the required structural performance. Further research should be conducted to advance analytical techniques and novel materials that further enhance the behavior of the beam under dynamic loading.

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