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Analysis of RCC and PSC Beam: A Comparative Research with Post-Tensioning Performance in Multistory Building under Seismic Zone III

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Abstract: The world is facing urban land shortages prompting engineers to design visually appealing high rise buildings, yet the under use of post tensioning techniques despite their advantages in material efficiency and structural integrity poses challenges in ensuring stability amid increasingly complex architectural demands. In this research work, to conduct an approach to use PSC in multistory buildings and its basic behaviour, a comprehensive review was carried out through various papers related to the PSC and its techniques have thoroughly and critically studied. Gap shows that none of the researchers conducted an analytical study on PSC beam by post tensioning using LRPC strand cables. Accurate simulations are conducted using an analysis software with various cases by considering a commercial building and replacing the PSC beams at different floor levels. These cases are then optimised as per its limiting values (OPSC-BP to OPSC-BR) and compared with general RCC rebars based general structure (RCC-B). To check the performance of commercial building, the output parameters such as deflection of beams, shear forces, bending moments in beam and base shear of the entire structure under seismic load has conducted with its suitable checks to observe the limiting values of the beam resistance are evaluated an compared. Observations in this research shows that for selected G+10 commercial apartment, there has a significant reduction in sizes when using the optimized PSC beam used and cross sectional area has reduced to minimum of 12.89% to maximum of 69.70% for different floor levels as conclusive part of this research work. At last, recommendations show that PSC allows in reduction of members that has directly proportioned with the cost and hence the economy has achieved.
Keywords: Multistorey building, Vertical elements, Beams, Shear wall, Post Tensioning, LRPC, Deflection in beams.

I. INTRODUCTION TO PRE STRESSED CONCRETE

In Prestressed Concrete (PSC), internal stresses are introduced deliberately prior to the application of external loads to resist anticipated tensile forces during service. This is accomplished by the tensioning of high-strength steel strands or tendons that are placed within the concrete. The tendons are either pre-tensioned before the concrete sets or post-tensioned after it has hardened. An increase in load-bearing capacity, a reduction in deflection, and the control of cracks are achieved through the process of prestressing. PSC is frequently adopted in the construction of bridges, high-rise buildings, and structures requiring long spans. Enhanced strength, improved durability, and better structural performance are delivered by PSC in such applications. Service life is extended and maintenance demands are reduced when PSC is used.

A. Types of PSC

Normally till date the main types of Prestressed Concrete (PSC) based on the method of prestressing are:

1. Pre-Tensioned Concrete
   a) In this method, the steel tendons are tensioned before the concrete is poured.
   b) The tension is transferred to the concrete after it hardens and bonds with the steel.
   c) Commonly used in precast elements like railway sleepers, slabs, and beams.

2. Post-Tensioned Concrete
   a) In this method, the concrete is cast first and allowed to harden.
   b) Steel tendons are then tensioned after the concrete has gained sufficient strength.
   c) Widely used in cast-in-place structures like bridges and multistory buildings.

II. RESEARCH OBJECTIVES

Compared to conventional RCC, greater efficiency is observed in pre stressed members. The use of PSC allows for more slender and longer structural elements. As a result, it is favored in projects demanding high performance and reliability. On keeping in mind the above problem statement outline for new research work is proposed in the form of conclusive outcomes given below :-

1) To create the various cases of PSC beams provided in the multistory building at different floor levels and comparing them by using Response Spectrum Method of dynamic analysis using Staad pro software.
2) To calculate force applied in PSC member and then applied all the cases.
3) To calculate the limiting values of deflection in beam member and then finding out the maximum deflection in beam member in the PSC provided level for different cases and check whether it will be sustaining the load or not with status of limiting values.
4) To calculate the limiting values of shear forces in beam member and then evaluation of maximum shear forces in beam member in the PSC provided level for different cases and check whether it will be sustaining the load or not. Then compare the shear generated using RCC and using PSC and finally the percentage reduction in shear has calculated.
5) To calculate the limiting values of bending moment in beam member and then evaluation of maximum bending moment in beam member in the PSC provided level for different cases and check whether it will be sustaining the load or not. Then compare the shear generated using RCC and using PSC and finally the percentage reduction in moment has calculated.
6) To determine maximum base shear of entire structure in X and Z horizontal direction and compare different cases to find the efficient configuration as per seismic analysis.
7) To find out the optimised size of PSC beam will replace with the area of PSC beam provided with reduction in area and its percentage reduction has the main part of the study.

The main and foremost objective is to determine the efficient case after comparison of various result parameters that will be PSC Post tensioning of beam recommendation for construction in the multistory building field.

III.PROCEDURE AND 3D MODELING OF THE STRUCTURE

The first phase of procedure and 3D modeling is data collection that refers to the process of systematically gathering information or evidence relevant to the research question or hypothesis. It can involve primary methods such as surveys and experiments or secondary sources such as existing datasets, literature and so on.

Table 1: LRPC strand wire sizes available in market

Sizes available in market		
9.3 mm	12.5 mm	15.24 mm
9.6 mm	12.7 mm	15.7 mm
11.3 mm	12.9 mm	16 mm

The building under consideration is a G+10 commercial structure constructed on medium soil, located in Seismic Zone III. The structural system consists of an ordinary shear wall integrated with a Special Moment Resisting Frame (SMRF) and a factor RF of 4 has adopted accordingly. As the building is commercial, an importance factor of 1.5 is used. The damping ratio is taken as 5%. The fundamental time period of vibration (Ta) is calculated using the empirical formula $Ta = 0.09*h/\sqrt{d}$, resulting in 0.8625 sec in the X & 0.7874 sec in the Z direction. The total height of the building is 47.92 m with a consistent floor to floor height of 3.66 m and the foundation depth is assumed to be 4 m. The plinth area of the building is 575 square meters. The structural framing includes a variety of beam sizes in reinforced concrete: 650 mm × 550 mm, 550 mm × 350 mm, and 450 mm × 300 mm. In the case of prestressed concrete (PSC) beams, sizes are modified based on load-carrying efficiency. The columns are sized at 750 mm × 650 mm. The slab thickness is 130 mm (0.130 m), while the shear wall and staircase waist slab have thicknesses of 140 mm (0.14 m) and 130 mm (0.130 m), respectively. For material properties, M30 grade concrete and Fe550 grade steel are adopted. Post-tensioning is achieved using a class-1 LRPC cable with a diameter of 12.7 mm, and one cable is used per prestressed member. The modulus of elasticity of steel is taken as 200 kN/mm² in accordance with IS 1343:2012 (Page 4, Clause 5.6.2.3), and the initial stress applied on the cable is 144.10 N/mm².

Table 2: Various cases for comparative analysis

S. No.	Abbreviation	Description of structure
1.	RCC-B	General Structure with RCC beam provided and interchanged at all floor levels
2.	OPSC-BP	General Structure with PSC beam provided and interchanged at plinth floor level
3.	OPSC-BI	General Structure with PSC beam provided and interchanged at first floor level
4.	OPSC-BII	with PSC beam provided and interchanged at second floor level
5.	OPSC-BIII	with PSC beam provided and interchanged at third floor level
6.	OPSC-BIV	with PSC beam provided and interchanged at fourth floor level
7.	OPSC-BV	with PSC beam provided and interchanged at fifth floor level
8.	OPSC-BVI	with PSC beam provided and interchanged at sixth floor level
9.	OPSC-BVII	with PSC beam provided and interchanged at seventh floor level
10.	OPSC-BVIII	with PSC beam provided and interchanged at eight floor level
11.	OPSC-BIX	with PSC beam provided and interchanged at ninth floor level
12.	OPSC-BX	with PSC beam provided and interchanged at tenth floor level
13.	OPSC-BR	with PSC beam provided and interchanged at roof level

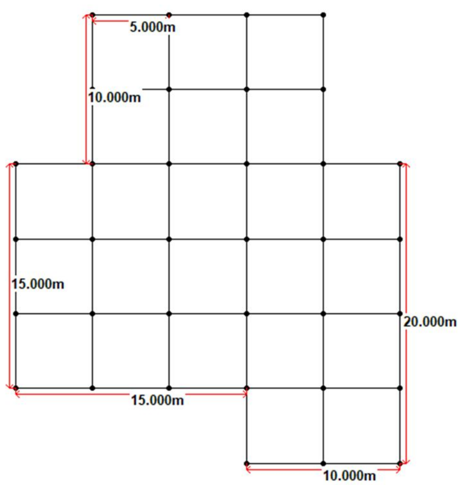


Fig. 1: Plan of all structural cases

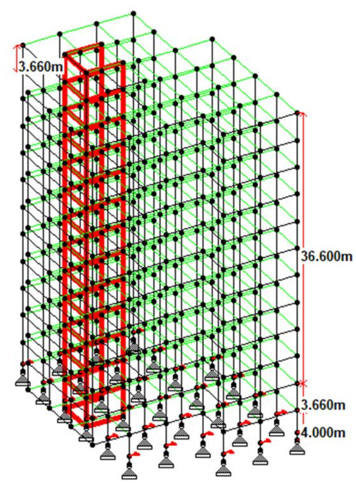


Fig. 2: 3- D view of all structural cases

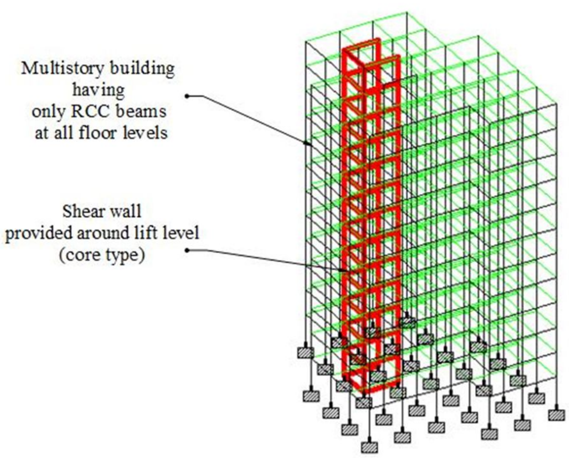


Fig. 3: Model RCC-B - General Structure with RCC beam provided and interchanged at all floor levels

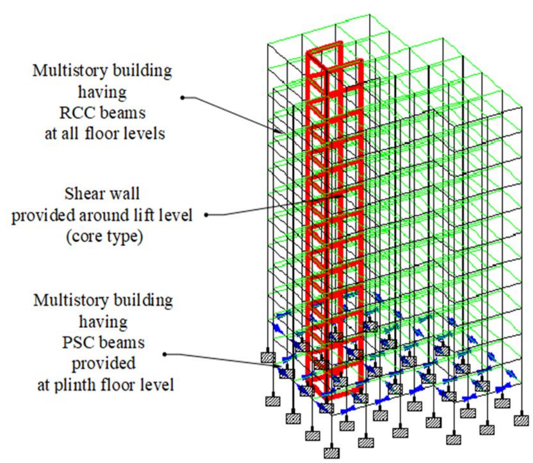


Fig. 4: Model OPSC-BP - General Structure with PSC beam provided and interchanged at plinth floor level

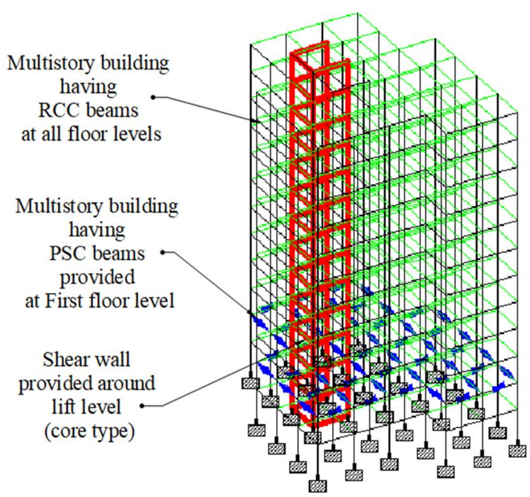


Fig. 5: Model OPSC-BI - General Structure with PSC beam provided and interchanged at first floor level

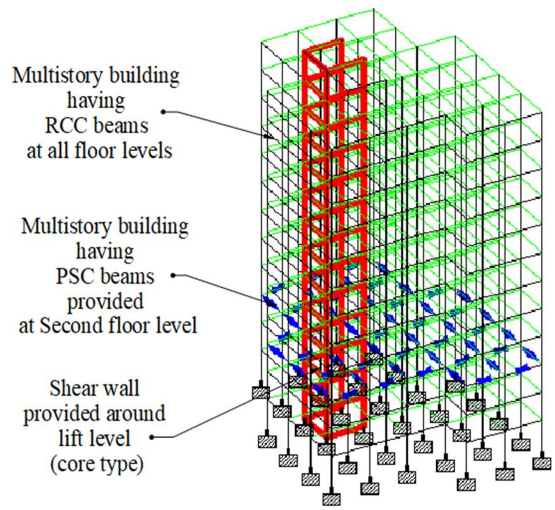


Fig. 6: Model OPSC-BII - General Structure with PSC beam provided and interchanged at second floor level

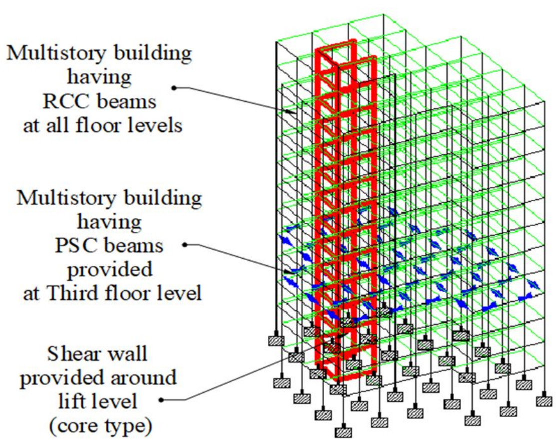


Fig. 7: Model OPSC-BIII - General Structure with PSC beam provided and interchanged at third floor level

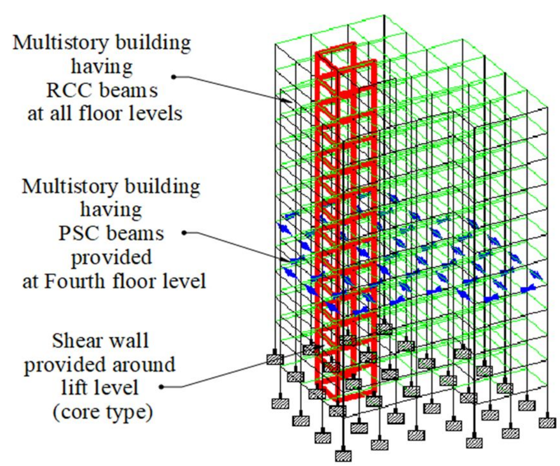


Fig. 8: Model OPSC-BIV - General Structure with PSC beam provided and interchanged at fourth floor level

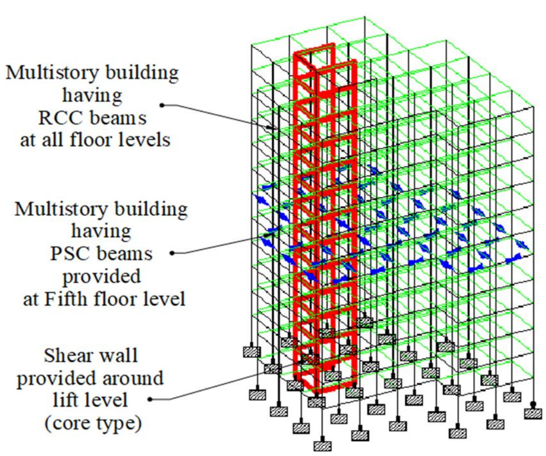


Fig. 9: Model OPSC-BV - General Structure with PSC beam provided and interchanged at fifth floor level

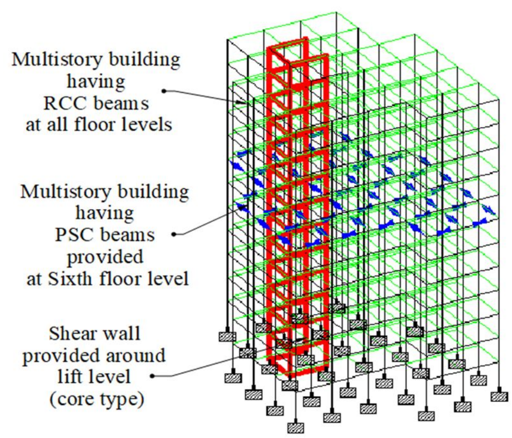


Fig. 10: Model OPSC-BVI - General Structure with PSC beam provided and interchanged at sixth floor

level

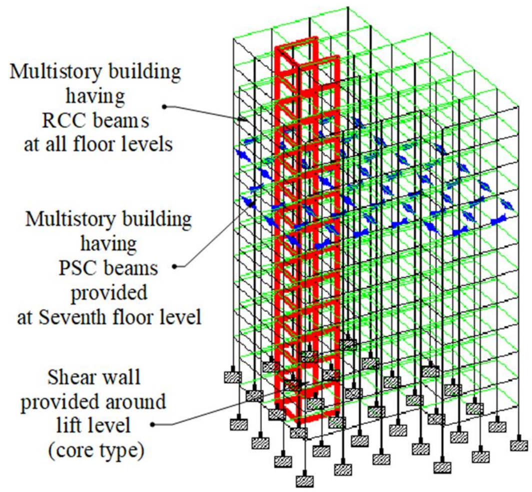


Fig. 11: Model OPSC-BVII - General Structure with PSC beam provided and interchanged at seventh floor level

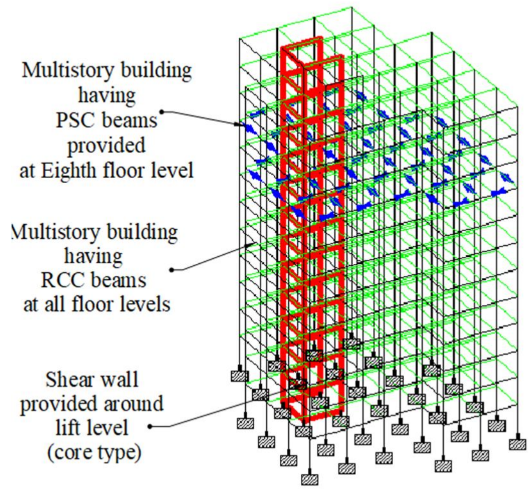


Fig. 12: Model OPSC-BVIII - General Structure with PSC beam provided and interchanged at eighth floor level

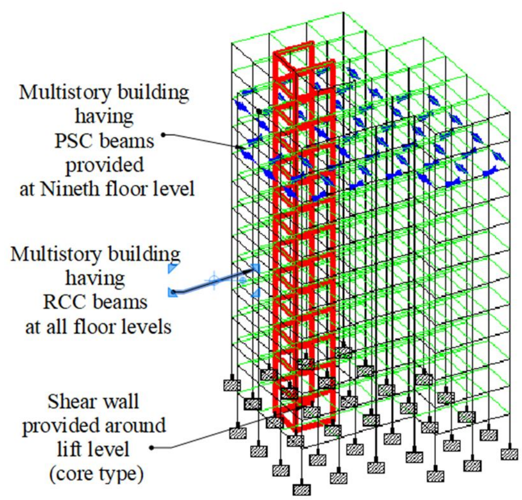


Fig. 13: Model OPSC-BIX - General Structure with PSC beam provided and interchanged at ninth floor level

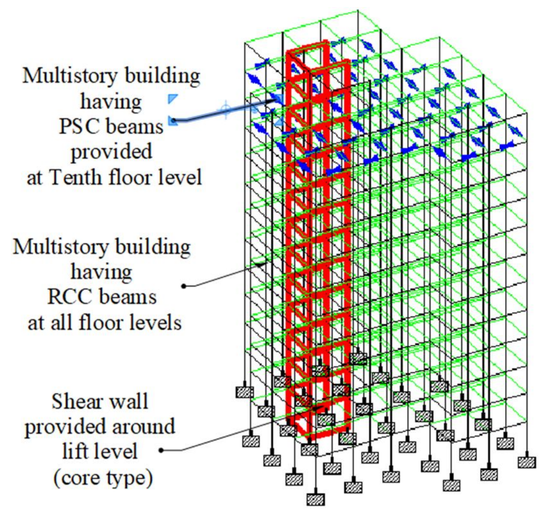


Fig. 14: Model OPSC-BX - General Structure with PSC beam provided and interchanged at tenth floor level

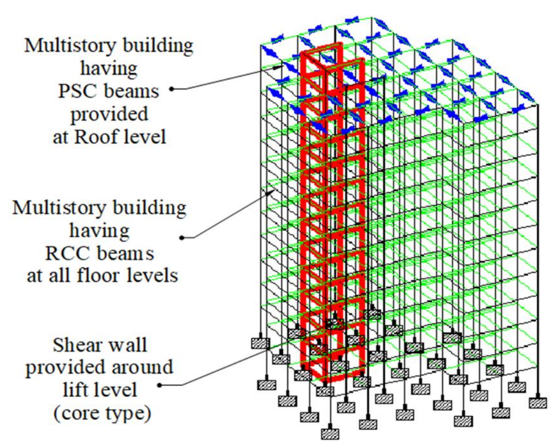


Fig. 15: Model OPSC-BR - General Structure with PSC beam provided and interchanged at roof level

IV. RESULTS AND DISCUSSION

Results are shown in tabular and in graphical form are as follows:

Table 3: Comparison of deflection in beam at different floor levels

Section Displacement											
Beam levels	RCC Beam size selected		Deflection Generated	Beam Number	Status of limiting values	Optimised PSC beam (mm)			Deflection Generated	Beam Number	Status of limiting values
	D	B	Δ (mm)			Case	D	B	Δ (mm)		
Roof	450	300	18.647	3113	passed under limiting value of 20mm	OPSC-BR	400	250	18.755	3113	passed under limiting value of 20mm
10th floor	450	300	19.013	3056		OPSC-BX	420	280	19.134	3056	
9th floor	550	350	18.566	2999		OPSC-BIX	480	320	18.91	2999	
8th floor	550	350	18.393	2942		OPSC-BVIII	480	320	18.721	2942	
7th floor	550	350	18.008	2885		OPSC-BVII	480	320	18.328	2885	
6th floor	550	350	17.27	2828		OPSC-BVI	480	290	17.645	2828	
5th floor	600	550	15.985	2771		OPSC-BV	480	320	16.818	2771	
4th floor	600	550	14.574	2714		OPSC-BIV	480	320	15.322	2714	
3rd floor	600	550	12.85	2657		OPSC-BIII	480	320	13.531	2657	
2nd floor	600	550	10.704	2600		OPSC-BII	480	320	10.953	2600	
1st floor	600	550	8.051	2543		OPSC-BI	450	300	8.659	2543	
GF/Plinth floor	600	550	4.575	107		OPSC-BP	400	250	7.127	107	

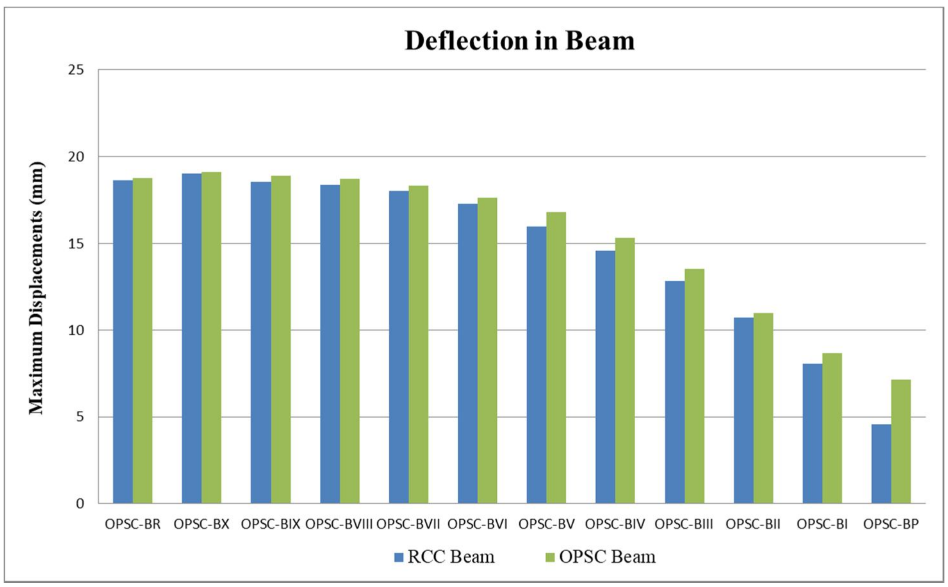


Fig. 16**:** Comparison of deflection in beam at different floor levels

Table 4: Comparison of shear forces in beam at different floor levels

Beam levels	RCC Beam size selected		Shear Generated	Optimised PSC beam (mm)			Shear Generated	Reduction in Shear
	D	B	Sy (kN)	Case	D	B	Sy (kN)	%
Roof	450	300	128.066	OPSC-BR	400	250	107.877	15.76
10th floor	450	300	141.336	OPSC-BX	420	280	129.471	8.39
9th floor	550	350	188.386	OPSC-BIX	480	320	148.764	21.03
8th floor	550	350	191.296	OPSC-BVIII	480	320	155.642	18.64
7th floor	550	350	200.048	OPSC-BVII	480	320	164.871	17.58
6th floor	550	350	205.421	OPSC-BVI	480	290	161.463	21.40
5th floor	600	550	297.555	OPSC-BV	480	320	174.814	41.25
4th floor	600	550	288.141	OPSC-BIV	480	320	173.715	39.71
3rd floor	600	550	290.04	OPSC-BIII	480	320	174.121	39.97
2nd floor	600	550	288.298	OPSC-BII	480	320	172.899	40.03
1st floor	600	550	279.937	OPSC-BI	450	300	152.057	45.68
GF/Plinth floor	600	550	253.648	OPSC-BP	400	250	116.99	53.88

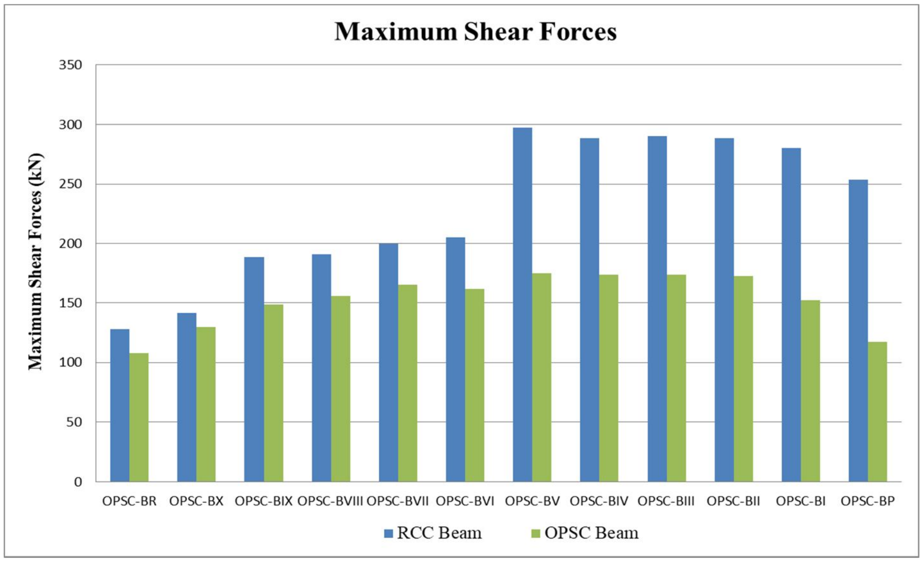


Fig. 17: Comparison of shear forces in beam at different floor levels

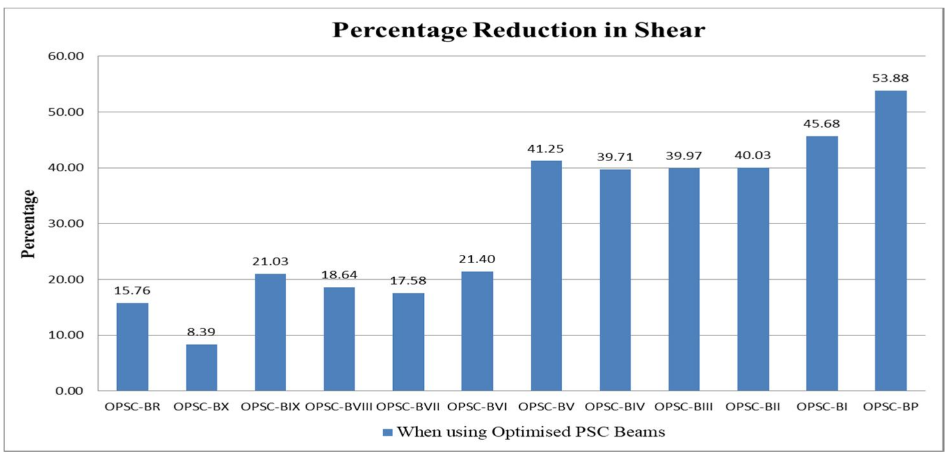


Fig. 18: Percentage reduction in shear forces in beam when using optimized PSC beams at different floor levels

Table 5**:** Comparison of bending moment in beam at different floor levels

Beam levels	RCC Beam size selected		Moment Generated	Optimised PSC beam (mm)			Moment Generated	Reduction in Moment
	D	B	Mu (kN)	Case	D	B	Mu (kN)	%
Roof	450	300	179.197	OPSC-R	400	250	136.351	23.91
10th floor	450	300	207.2	OPSC-BX	420	280	181.721	12.30
9th floor	550	350	356.32	OPSC-BIX	480	320	251.174	29.51
8th floor	550	350	362.806	OPSC-BVIII	480	320	257.069	29.14
7th floor	550	350	363.792	OPSC-BVII	480	320	272.76	25.02
6th floor	550	350	368.612	OPSC-BVI	480	290	266.512	27.70
5th floor	600	550	615.259	OPSC-BV	480	320	297.642	51.62
4th floor	600	550	579.787	OPSC-BIV	480	320	294.926	49.13
3rd floor	600	550	566.609	OPSC-BIII	480	320	296.02	47.76
2nd floor	600	550	562.106	OPSC-BII	480	320	293.969	47.70
1st floor	600	550	540.425	OPSC-BI	450	300	244.151	54.82
GF/Plinth floo	600	550	474.487	OPSC-BP	400	250	161.821	65.90

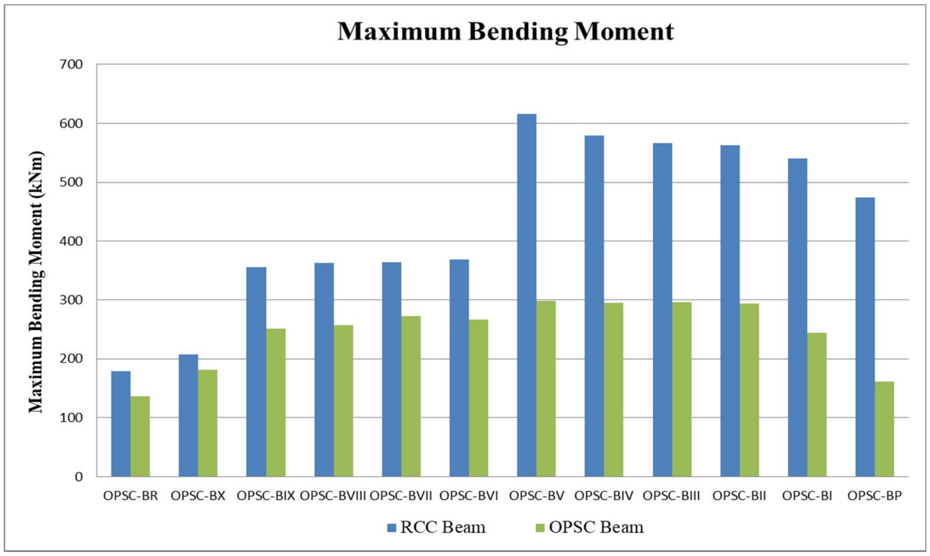


Fig. 19: Comparison of bending moment in beam at different floor levels

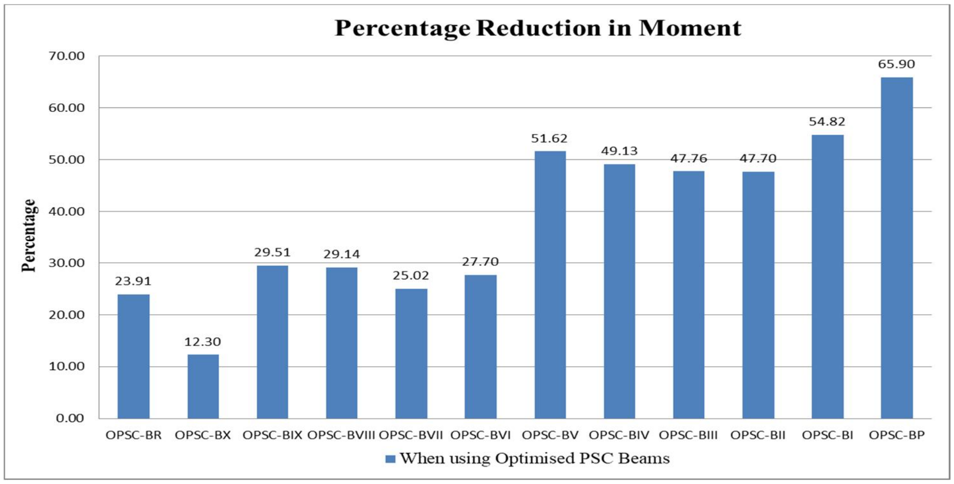
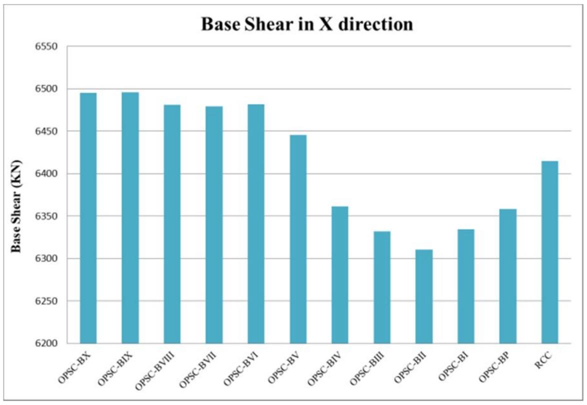


Fig. 20: Percentage reduction in bending moment in beam when using optimized PSC beams at different floor levels

Table 6: Comparison of base shear of structure when using optimized PSC beams at different floor levels

Base Shear		
Case	**Base shear X**	**Base shear Z**
OPSC-BR	6495.19	7174.51
OPSC-BX	6495.85	7170.75
OPSC-BIX	6480.93	7159.08
OPSC-BVIII	6479.35	7118.15
OPSC-BVII	6482.04	7098.33
OPSC-BVI	6445.32	7080.96
OPSC-BV	6361.56	7068.58
OPSC-BIV	6331.82	7078.37
OPSC-BIII	6310.71	6985.72
OPSC-BII	6334.71	6905
OPSC-BI	6358.48	6942.85
OPSC-BP	6415.08	7069.95
RCC	6502.29	7197.42



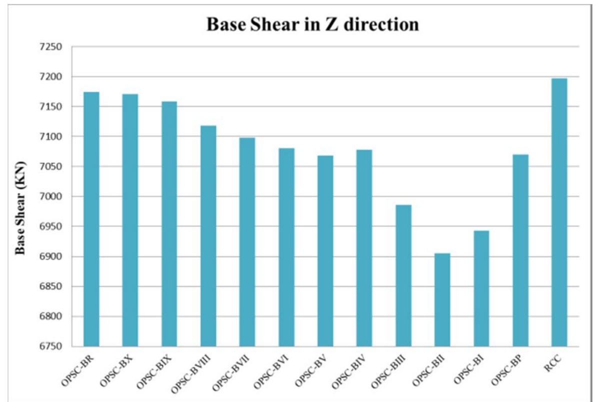


Fig. 21: Base Shear in X and Z direction when using optimized PSC beams at different floor levels

Table 7: Reduction in area of beam at different floor levels

Floor levels	RCC Beam size selected (mm)		Area (sq mm)	Optimised PSC beam provided (mm)		New Area (sq mm)	Reduction in Area (sq mm)	Reduction in Area (%)
	D	B		D	B			
Roof	450	300	135000	400	250	100000	35000	25.93
10th floor	450	300	135000	420	280	117600	17400	12.89
9th floor	550	350	192500	480	320	153600	38900	20.21
8th floor	550	350	192500	480	320	153600	38900	20.21
7th floor	550	350	192500	480	320	153600	38900	20.21
6th floor	550	350	192500	480	290	139200	53300	27.69
5th floor	600	550	330000	480	320	153600	176400	53.45
4th floor	600	550	330000	480	320	153600	176400	53.45
3rd floor	600	550	330000	480	320	153600	176400	53.45
2nd floor	600	550	330000	480	320	153600	176400	53.45
1st floor	600	550	330000	450	300	135000	195000	59.09
GF/Plinth floor	600	550	330000	400	250	100000	230000	69.70

V. CONCLUSION

The conclusion can be pointed out are as follows:-

1) The various cases of PSC beams provided in the multistory building at different floor levels has achieved. (details mentioned in Modelling Approach section)
2) The calculation of forces for applying the post tensioning effect has achieved. (details mentioned in Modelling Approach section)
3) The values of deflection generated in beam member has obtained and comparative analysis shows that selected PSC beams with reduced cross sectional area can generate same deflection are also under the limit. (details mentioned in result and discussion section).
4) The values of shear forces generated in beam member has obtained and comparative analysis shows that selected PSC beams with reduced cross sectional area can generate less shear forces significantly reduced to minimum 8.39% to maximum of 53.88% are also under the limit. (details mentioned in result and discussion section).
5) The values of bending moment generated in beam member has obtained and comparative analysis shows that selected PSC beams with reduced cross sectional area can generate less bending moment significantly reduced to minimum 12.30% to maximum of 65.60% are also under the limit. (details mentioned in result and discussion section).
6) The values of base shear generated for entire structure has obtained and comparative analysis shows that selected PSC beams with reduced cross sectional area can generate less base shear for both horizontal X and Z direction. (details mentioned in result and discussion section).
7) Optimised PSC beam generated by considering all result parameters significantly reduced to minimum 12.89% to maximum of 69.70%. (details mentioned in result and discussion section).

This project concluded that when comparing all the output result parameters, the structure where RCC beams provided and interchanges at different floor levels, this concept has proved to be efficient for interchanging of beams. The advantages of PSC Post-tensioning method allows the reduction in cross sectional area that ultimately will be suitable for multistory building field and hence should be recommended that when this type of construction procedure adopted, PSC Post tensioning beams will reduce the cost of the entire structure.

VI. ACKNOWLEDGEMENTS

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