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Comparative Seismic Performance of RCC Beam with Rebar and Post Tensioned PSC Beam Using LRPC Strands with M35 Grade on Hard Soil

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Abstract: India has been identified among the most densely populated countries in the world, as per recent statistics. A severe shortage of urban land has been experienced due to this high population density. To ensure maximum spatial efficiency, buildings with aesthetic appeal have been engineered using RCC technology. In recent constructions, the advantages of Prestressed Concrete (PSC)—including lower material usage and higher structural strength—have not been fully considered. The substitution of RCC with PSC, while maintaining stability, has been regarded as the principal challenge. A systematic review of literature focusing on PSC implementation and techniques was undertaken in this dissertation. The gap in the research field was noted, as no analytical study has been reported involving post tensioned PSC beams with LRPC strand cables. Multiple simulation cases were performed using advanced structural analysis software for a commercial building model. Different structural cases with PSC beams at various floor levels were analyzed and later optimized into categories ranging from PSC-LRPC-B to PSC-LRPC-M. These optimized cases were subsequently compared against a standard RCC structure labeled RCC-REBAR-A. Key performance indicators such as beam deflection, shear force, bending moment, and total base shear under seismic effects were carefully assessed. Limiting capacities of beam resistance were investigated using these parameters and thoroughly examined. In a G+10 residential building scenario, considerable reductions in beam size were achieved using optimized PSC members. Cross sectional areas of beams were reduced by a minimum of 11.11% and a maximum of 78.79%, depending on the floor level. Finally, economic benefits were realized, as the reduction in member sizes due to PSC implementation was found to correlate with overall cost savings.
Keywords: Prestressed Concrete (PSC), Post Tensioning, LRPC Strand Cables, Seismic Performance, Structural Optimization

I. INTRODUCTION TO PRE STRESSED CONCRETE

Prestressed Concrete (PSC) systems are strategically engineered by introducing predetermined internal compressive stresses before subjecting the structure to any external loading. To achieve this, high-tensile steel tendons or strands are tensioned and anchored within the concrete matrix. Depending on the sequencing, the tendons are either pre-tensioned prior to casting or post-tensioned subsequent to concrete hardening. Through such controlled prestressing, the system exhibits improved flexural capacity, enhanced crack mitigation, and reduced service deflections. Utilization of PSC is prevalent in large-span bridge decks, high-rise towers, and advanced infrastructure where performance efficiency is paramount. In these applications, structural behavior is significantly optimized by enhanced material properties and geometric adaptability. Ultimately, this method contributes to increased durability, extended design life, and minimized lifecycle maintenance.

A. Types of Prestressed Concrete

The classification of PSC is primarily defined by the method adopted to apply the prestress force, leading to two dominant techniques:

1. Pre-Tensioned Concrete

- Prior to the concrete pour, steel tendons are tensioned against external abutments to introduce stress into the formwork.
- Upon concrete curing, the prestress is transferred as the steel bonds integrally with the hardened concrete mass.
- Typically, this method is standardized for factory-produced elements such as prestressed sleepers, lintels, and pretensioned beams.

2. Post-Tensioned Concrete
- Initially, the structural concrete is poured and allowed to achieve a requisite level of strength.
- Following adequate strength gain, the enclosed ducts are used to tension steel tendons and apply anchorage at the ends.
- This system is extensively applied in monolithic or cast-in-place structures like continuous-span bridges and floor slabs in high-rise buildings.

II. RESEARCH OBJECTIVES

On keeping in mind the above problem statement objectives of the study are as follows:-
1) Multiple design cases of prestressed concrete (PSC) beams are to be developed at various floor levels within a multistory structure, with a comparative evaluation carried out through the Response Spectrum Method using STAAD Pro software.
2) Calculation of internal forces in the PSC members will be performed initially, after which these forces will be applied across all structural configurations.
3) Deflection limits for PSC beam members will be determined, followed by analysis of maximum deflection in each case to assess whether the values lie within acceptable serviceability criteria.
4) Shear force thresholds in the beams will be evaluated and compared across PSC levels in different cases, and the percentage reduction in shear force due to PSC over RCC will be calculated at the end.
5) Bending moment capacity will be examined by determining the peak moment in each PSC beam case and verifying whether the structure resists the applied load, concluding with a comparative percentage reduction against RCC systems.
6) Base shear analysis of the structure will be undertaken in both X and Z horizontal directions, and the most efficient case will be selected based on the performance under seismic conditions.
7) Optimized beam dimensions will be explored by replacing conventional PSC beams with reduced-size alternatives, and the percentage reduction in beam area will be determined as a key contribution.

The overall objective centres on identifying the most efficient post-tensioned PSC beam configuration after assessing all cases, leading to practical recommendations for residential building applications.

III. PROCEDURE AND 3D MODELING OF THE STRUCTURE

The initial phase in procedural workflow and 3D modeling comprises systematic data acquisition, which is integral to aligning inputs with the research objectives or theoretical framework. This phase encompasses both primary data collection methodologies, including controlled experiments, field observations, and structured surveys. In addition, secondary data sources such as validated datasets, scholarly publications, and archival records are also utilized to enrich the evidence base. By combining these approaches, a comprehensive and multi-dimensional dataset is constructed. Methodological rigor during this stage ensures accuracy, reproducibility, and analytical depth. Ultimately, the credibility and validity of the 3D modeling output are deeply influenced by the quality of this foundational dataset.

For the structural analysis, a set of standardized input parameters was assumed uniformly across all cases. The structure was considered to be situated on hard soil, falling under Seismic Zone III. An ordinary shear wall system with Special Moment Resisting Frame (SMRF) was adopted, corresponding to a response reduction factor of 4. The building was classified as a commercial facility, and hence an importance factor of 1.5 was applied. A damping ratio of 5% was considered throughout the dynamic analysis. The fundamental time period of vibration (Ta) was calculated using the empirical formula Ta = 0.09*h/(d)^0.5, yielding values of 0.8625 seconds in the X-direction and 0.7874 seconds in the Z-direction.

In terms of material properties, M35 grade concrete and Fe550 grade steel were used. For prestressing, a class 1 Low Relaxation Prestressed Concrete (LRPC) cable with a diameter of 12.7 mm was employed, with a single post-tensioning cable used per beam. The modulus of elasticity of steel was taken as 200 kN/mm², as per IS 1343:2012 (Page 4, Clause 5.6.2.3). An initial cable stress of 144.10 N/mm² was applied in accordance with design standards.

The structure featured a plinth area of 575 square meters and was configured as a G+10 residential apartment with a total height of 47.92 meters. Each storey maintained a uniform floor-to-floor height of 3.66 meters, with the foundation extending to a depth of 4 meters. RCC beam dimensions were categorized into three sizes: 600 mm × 550 mm, 550 mm × 350 mm, and 450 mm × 300 mm. For prestressed concrete (PSC) beams, dimensions were modified based on load-carrying efficiency. The columns were designed with a cross-section of 700 mm × 600 mm. The slab thickness was maintained at 135 mm, while the shear wall and stair waist slab were designed with thicknesses of 140 mm and 135 mm respectively.

Table 1: Various cases for comparative analysis with abbreviations

S. No.	Abbreviation	Description of structure
1.	RCC-REBAR-A	Residential Apartment with RCC beam provided and checked at all floor levels
2.	PSC-LRPC-B	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at plinth level
3.	PSC-LRPC-C	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at ground floor level
4.	PSC-LRPC-D	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at I floor level
5.	PSC-LRPC-E	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at II floor level
6.	PSC-LRPC-F	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at III floor level
7.	PSC-LRPC-G	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at IV floor level
8.	PSC-LRPC-H	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at V floor level
9.	PSC-LRPC-I	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at VI floor level
10.	PSC-LRPC-J	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at VII floor level
11.	PSC-LRPC-K	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at VIII floor level
12.	PSC-LRPC-L	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at IX floor level
13.	PSC-LRPC-M	Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at X floor level
	Here,	
	RCC	Reinforced Cement Concrete
	PSC	Prestressed Concrete
	LRPC	Low Relaxation Prestressed Concrete

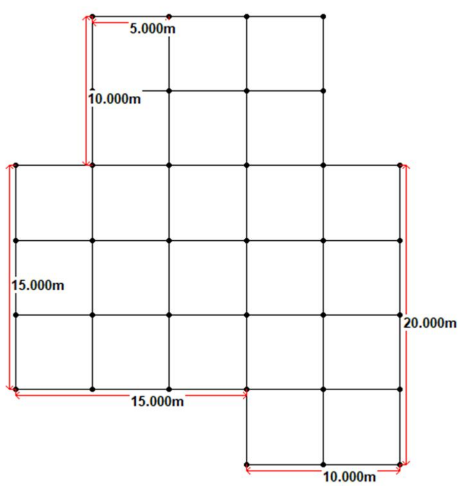

Fig. 1: Plan of all residential apartment buildings

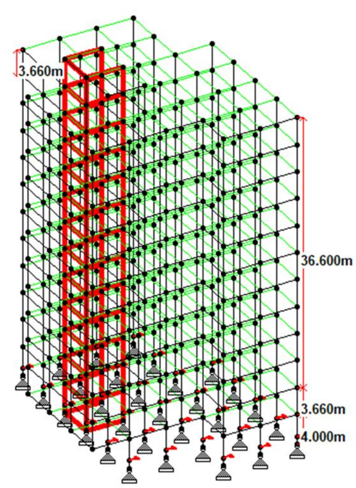

Fig. 2: 3- D view of all residential apartment buildings

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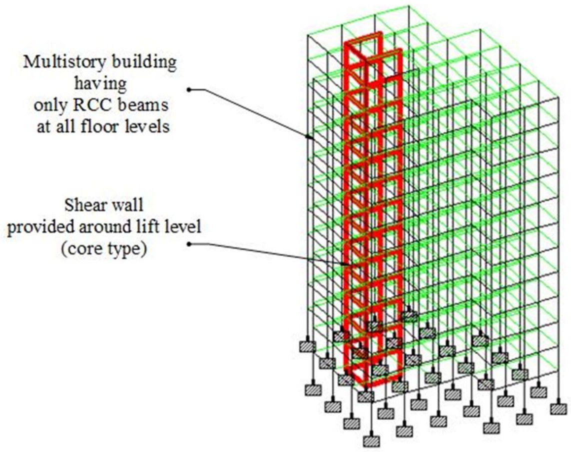

Fig. 3: Model RCC-REBAR-A - Residential Apartment with RCC beam provided and checked at all floor levels

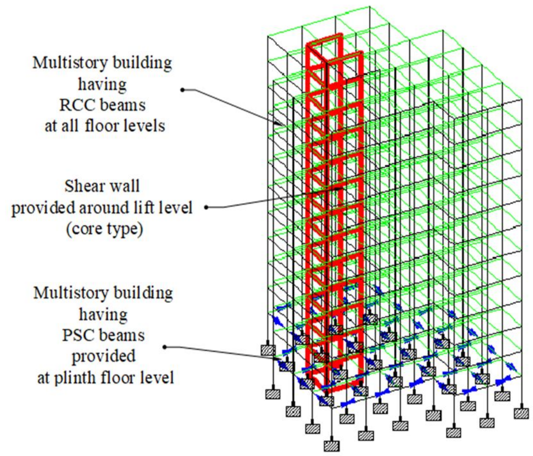

Fig. 4: PSC-LRPC-B - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at plinth level

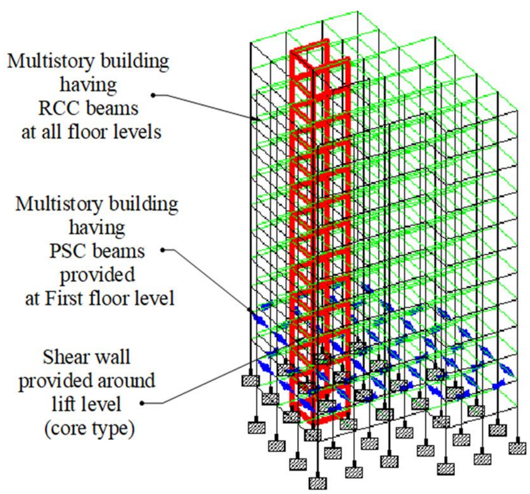

Fig. 5: PSC-LRPC-C - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at ground floor level

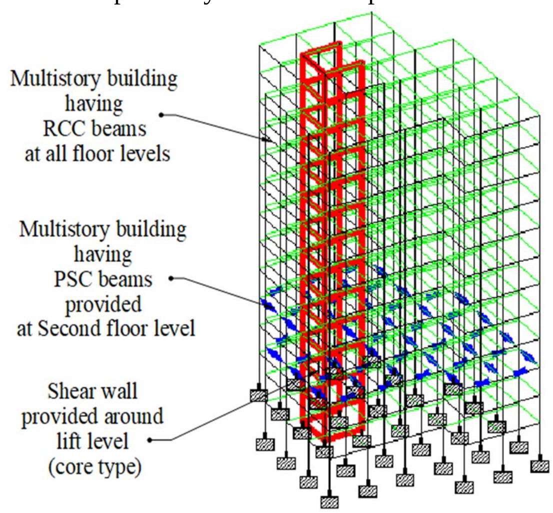

Fig. 6: PSC-LRPC-D - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at II floor level

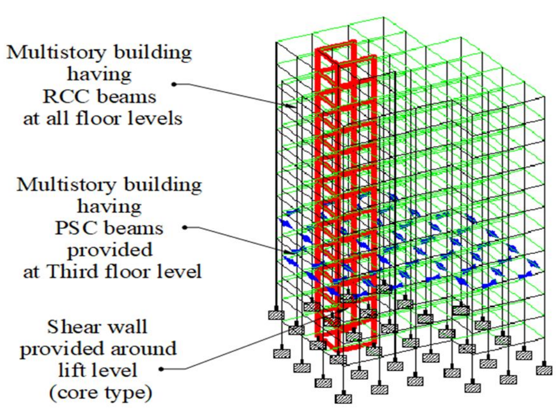

Fig. 7: PSC-LRPC-E - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at III floor level

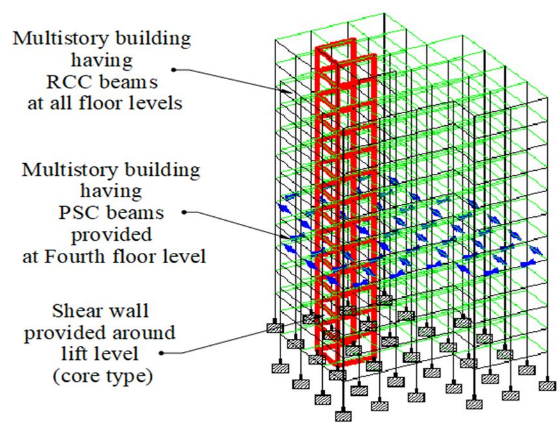

Fig. 8: PSC-LRPC-F - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at IV floor level

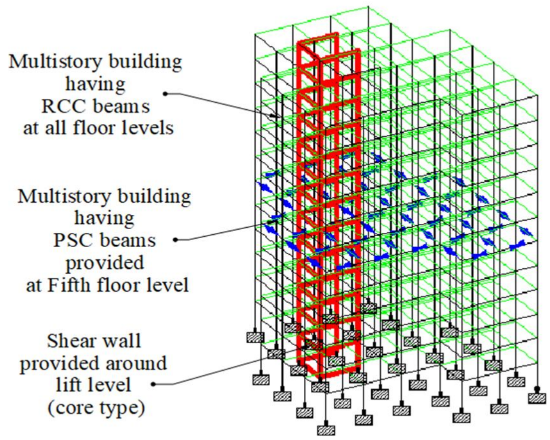

Fig. 9: PSC-LRPC-G - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at V floor level

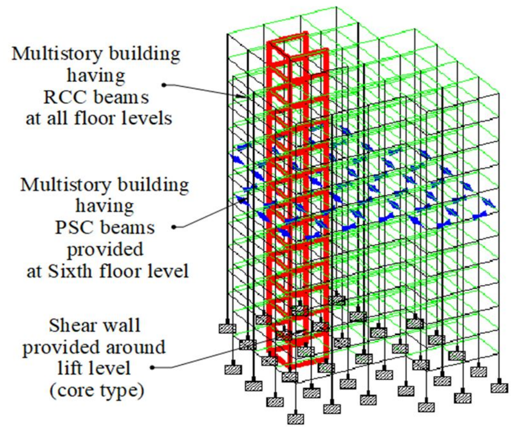

Fig. 10: PSC-LRPC-H - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at VI floor level

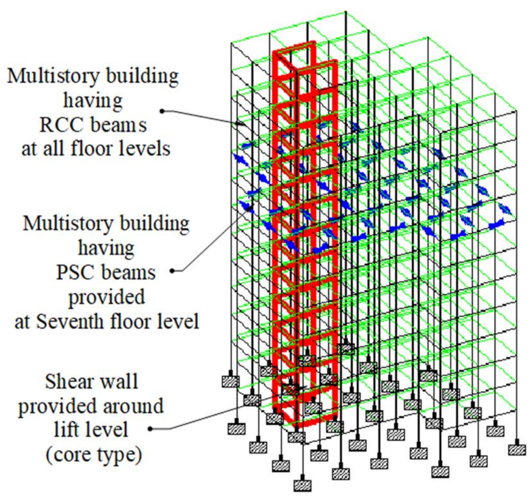

Fig. 11: PSC-LRPC-I - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at VII floor level

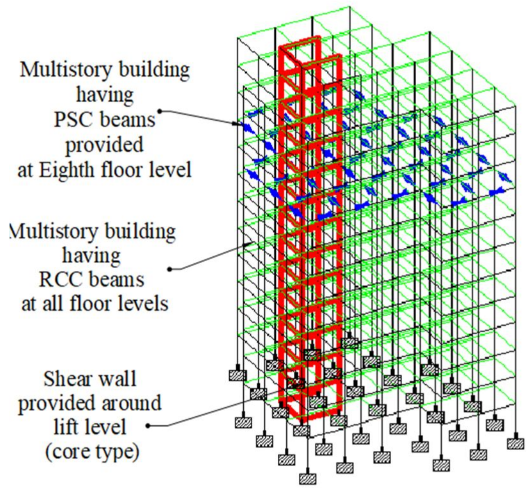

Fig. 12: PSC-LRPC-J - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at VIII floor level

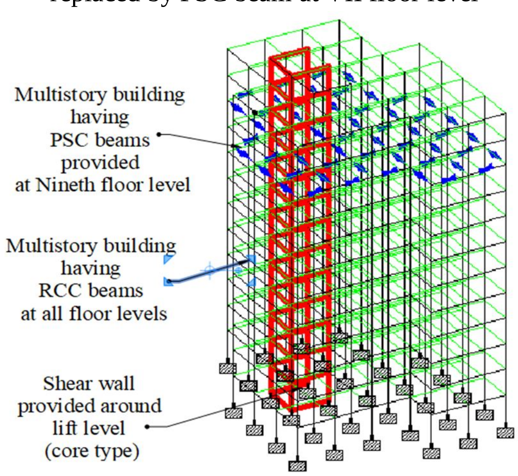

Fig. 13: PSC-LRPC-K - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at IX floor level

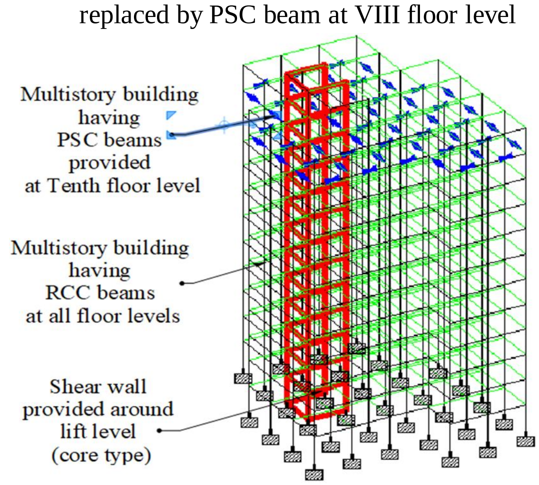

Fig. 14: PSC-LRPC-L - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at X floor level

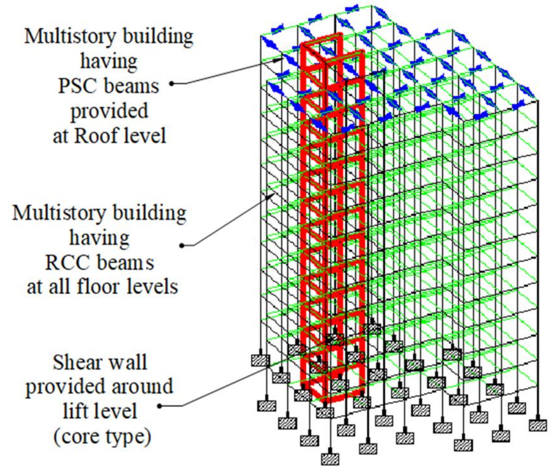

Fig. 15: PSC-LRPC-M - Residential Apartment with RCC beam provided and checked at all floor levels replaced by PSC beam at roof floor level

IV. RESULTS AND DISCUSSION

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

Table 2: Deflection comparison in beams 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	16.601	3113	passed under limiting value of 20mm	PSC-LRPC-M	400	300	17.583	3113	passed under limiting value of 20mm
10th floor	450	300	17.174	3056		PSC-LRPC-L	400	300	18.585	3056	
9th floor	550	350	16.027	2999		PSC-LRPC-K	450	300	17.534	2999	
8th floor	550	350	15.791	2942		PSC-LRPC-J	450	300	17.385	2942	
7th floor	550	350	15.382	2885		PSC-LRPC-I	450	300	17.032	2885	
6th floor	550	350	14.687	2828		PSC-LRPC-H	450	300	16.411	2828	
5th floor	600	550	13.725	2771		PSC-LRPC-G	480	320	15.198	2771	
4th floor	600	550	12.488	2714		PSC-LRPC-F	480	320	13.959	2714	
3rd floor	600	550	10.98	2657		PSC-LRPC-E	480	320	12.371	2657	
2nd floor	600	550	9.128	2600		PSC-LRPC-D	480	320	10.393	2600	
1st floor	600	550	6.705	2543		PSC-LRPC-C	480	320	7.991	2543	
GF/Plinth floo	600	550	4.004	107		PSC-LRPC-B	350	200	4.259	107	

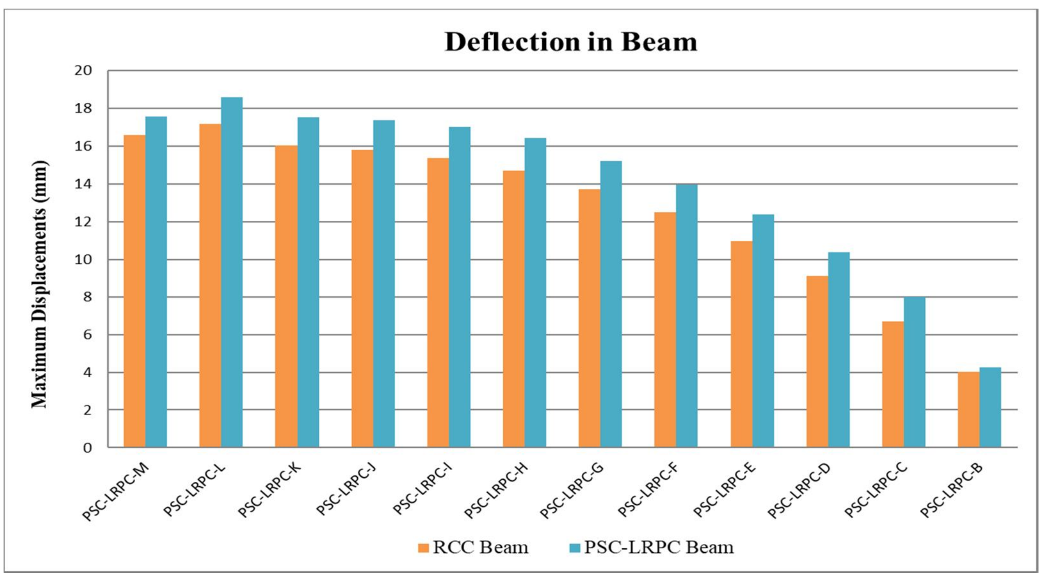

Fig. 16: Deflection comparison in beams at different floor levels

Table 3: Shear Forces comparison in beams 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	118.642	PSC-LRPC-M	400	300	114.089	3.84
10th floor	450	300	136.527	PSC-LRPC-L	400	300	129.628	5.05
9th floor	550	350	167.438	PSC-LRPC-K	450	300	130.368	22.14
8th floor	550	350	170.31	PSC-LRPC-J	450	300	134.864	20.81
7th floor	550	350	175.942	PSC-LRPC-I	450	300	142.355	19.09
6th floor	550	350	179.984	PSC-LRPC-H	450	300	147.553	18.02
5th floor	600	550	255.16	PSC-LRPC-G	480	320	168.095	34.12
4th floor	600	550	246.801	PSC-LRPC-F	480	320	170.317	30.99
3rd floor	600	550	247.82	PSC-LRPC-E	480	320	171.135	30.94
2nd floor	600	550	246.017	PSC-LRPC-D	480	320	169.749	31.00
1st floor	600	550	239.232	PSC-LRPC-C	480	320	165.593	30.78
GF/Plinth floor	600	550	218.938	PSC-LRPC-B	350	200	98.026	55.23

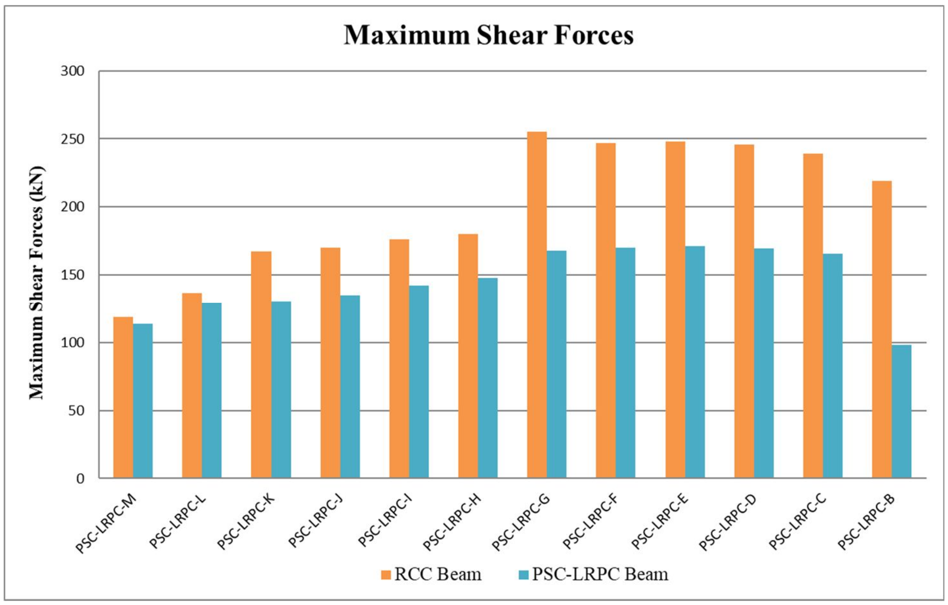

Fig. 17: Shear Forces comparison in beams at different floor levels

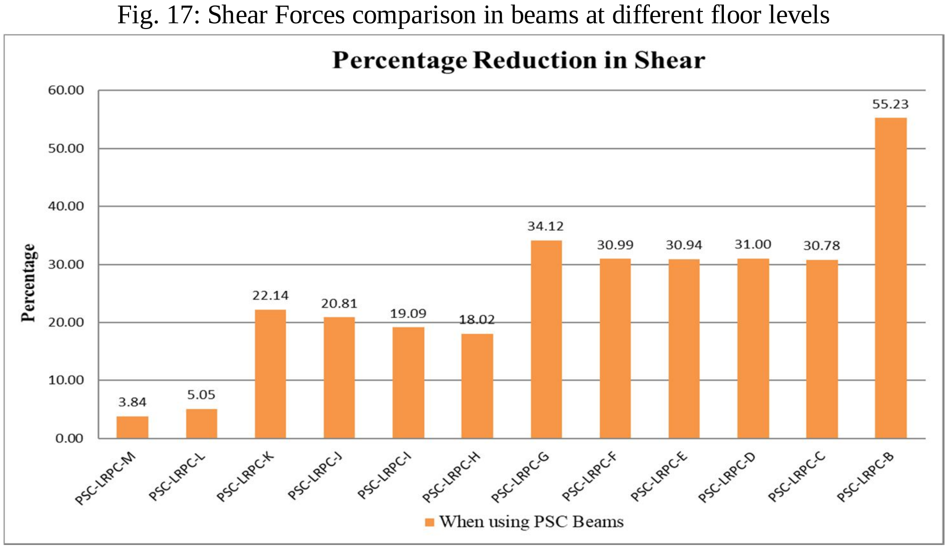

Fig. 18: Percentage reduction in shear forces in beam

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Table 4: Bending moment comparison in beams 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	154.026	PSC-LRPC-M	400	300	147.657	4.14
10th floor	450	300	187.599	PSC-LRPC-L	400	300	174.518	6.97
9th floor	550	350	296.256	PSC-LRPC-K	450	300	198.171	33.11
8th floor	550	350	301.198	PSC-LRPC-J	450	300	201.384	33.14
7th floor	550	350	303.37	PSC-LRPC-I	450	300	217.106	28.44
6th floor	550	350	303.417	PSC-LRPC-H	450	300	230.198	24.13
5th floor	600	550	499.75	PSC-LRPC-G	480	320	279.498	44.07
4th floor	600	550	471.988	PSC-LRPC-F	480	320	285.053	39.61
3rd floor	600	550	454.42	PSC-LRPC-E	480	320	287.175	36.80
2nd floor	600	550	499.808	PSC-LRPC-D	480	320	283.613	43.26
1st floor	600	550	432.296	PSC-LRPC-C	480	320	273.425	36.75
GF/Plinth floor	600	550	381.256	PSC-LRPC-B	350	200	115.46	69.72

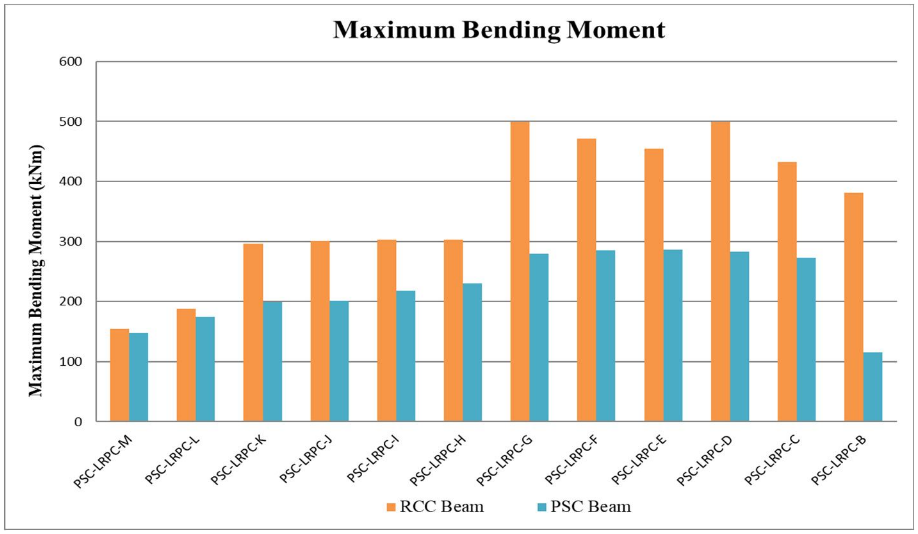

Fig. 19: Bending moment comparison in beams at different floor levels

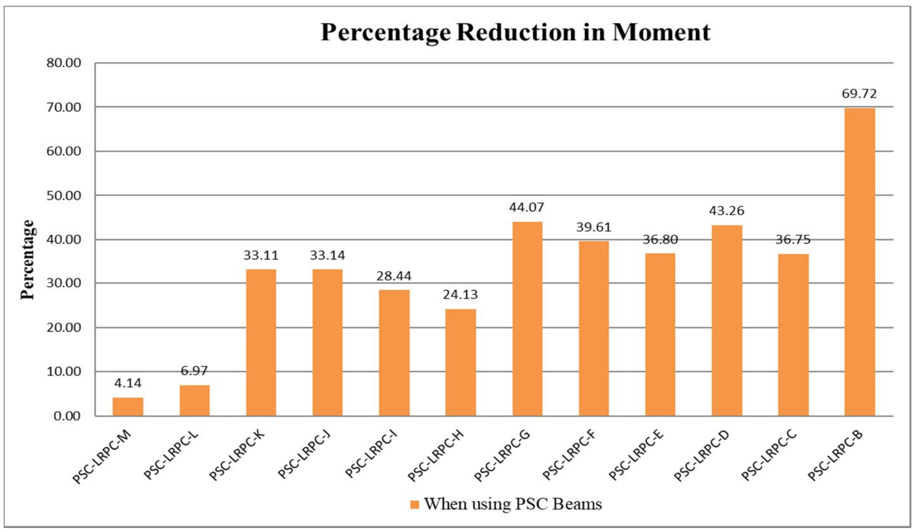

Fig. 20: Percentage reduction in bending moment in beam

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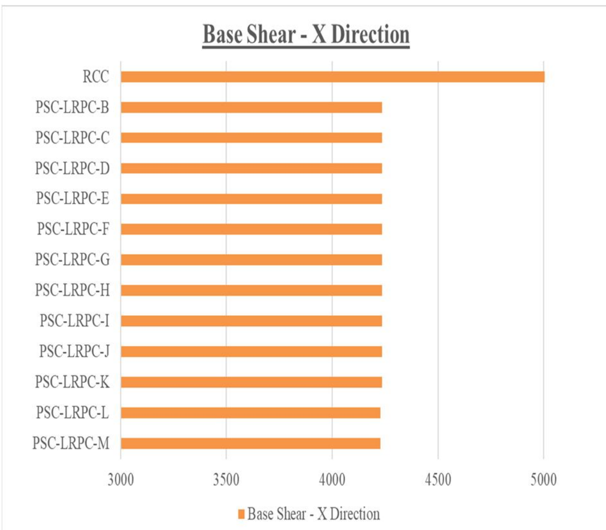
Table 5: Base shear Comparison

Base Shear		
Case	Base shear X	Base shear Z
PSC-LRPC-M	4228.59	4609.97
PSC-LRPC-L	4228.59	4609.97
PSC-LRPC-K	4236.1	4624.33
PSC-LRPC-J	4236.1	4624.33
PSC-LRPC-I	4236.1	4624.33
PSC-LRPC-H	4236.1	4624.33
PSC-LRPC-G	4236.1	4624.33
PSC-LRPC-F	4236.1	4624.33
PSC-LRPC-E	4236.1	4624.33
PSC-LRPC-D	4236.1	4624.33
PSC-LRPC-C	4236.1	4624.33
PSC-LRPC-B	4236.1	4624.33
RCC	5003.74	5445.43



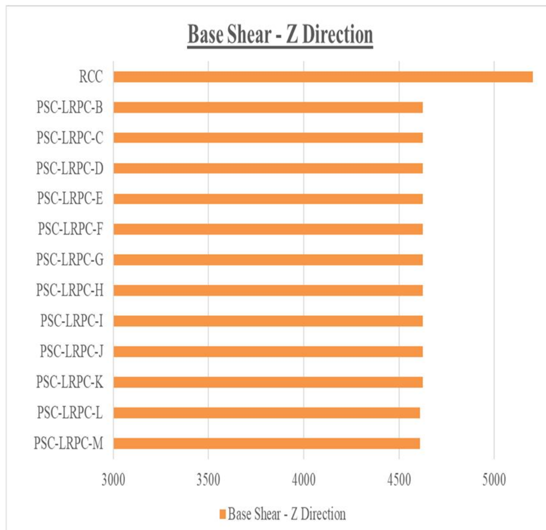


Fig. 21: Base Shear in X and Z direction

Table 6: Improved area with reduction in % area of residential apartment

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	300	120000	15000	11.11
10th floor	450	300	135000	400	300	120000	15000	11.11
9th floor	550	350	192500	450	300	135000	57500	29.87
8th floor	550	350	192500	450	300	135000	57500	29.87
7th floor	550	350	192500	450	300	135000	57500	29.87
6th floor	550	350	192500	450	300	135000	57500	29.87
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	480	320	153600	176400	53.45
GF/Plinth floor	600	550	330000	350	200	70000	260000	78.79

V. CONCLUSION

The conclusion can be pointed out are as follows:-

1) The modelling of various PSC beam cases at multiple floor levels in a residential apartment has successfully completed over hard soil.

2) The application forces necessary for inducing post tensioning effects have accurately calculated and implemented.
3) Deflection values within the beam elements were recorded and it has found through comparative analysis that optimized PSC beams with reduced cross sectional areas produced deflections within permissible limits, maintaining structural performance.
4) Shear force values in beam members were computed and the study revealed that PSC beams showed a significant reduction ranging from 3.84 % to 55.23 %, all within permissible range.
5) Bending moment values obtained from analysis demonstrated that optimized PSC beams led to reductions from 4.14 % up to 69.72 %, without exceeding the permissible range.
6) Base shear responses for the entire building in both horizontal directions (X and Z) have analysed and a consistent decrease has observed when PSC beams have used.
7) Overall, when RCC section replaced by PSC section resulted in a reduction of cross sectional area ranging from 11.11 % to 78.79 %, confirming the efficiency of the proposed design approach over hard soil.

Concluding the research, the comparison of all structural performance parameters indicated that replacing RCC beams with PSC beams at selected floor levels improves efficiency. The post tensioning method in apartments not only ensures structural adequacy but also facilitates a substantial reduction in beam cross sectional area, thereby decreasing the total material consumption. As a result, this approach is highly recommended for adoption in residential apartments, where living is a priority, offers both cost efficiency and structural performance advantages.

VI. ACKNOWLEDGEMENTS

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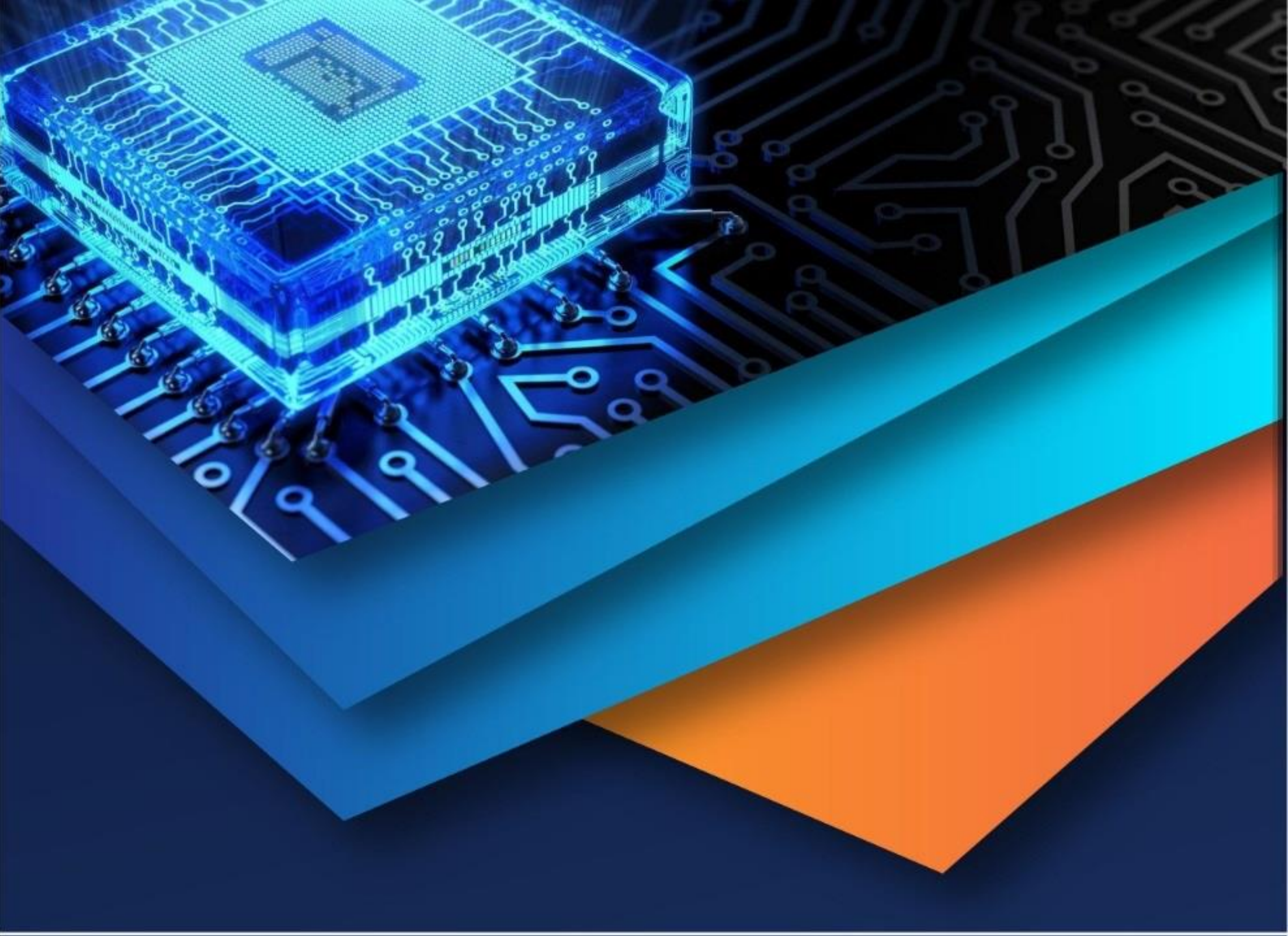

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