

Design and Finite Element Analysis of RCC and Timber-Composite RCC Columns with Seismic Effect

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ABSTRACT

This study presents the design and finite-element analysis (FEM) of three reinforced cement concrete (RCC) column configurations under seismic effect, with the objective of quantifying how a central Sal-timber core alters the structural performance of an otherwise conventional RCC column. All three columns are of identical external size (300 × 300 mm) and clear height 3.0 m, fixed at both ends, and use M30 concrete, Fe500 steel, 4–16 mm ϕ longitudinal bars (steel ratio 0.89 %) and 8 mm ϕ ties at 150 mm c/c. The configurations are a plain RCC column (C1), and two timber-composite RCC columns with 100 × 100 mm (C2) and 150 × 150 mm (C3) Sal-timber cores. Each column is idealised as a fixed-fixed line member discretised into six Euler-Bernoulli beam elements, using transformed-section properties (modular ratios $m = 7.30$ for steel and $n = 0.456$ for timber). Axial capacity is computed per IS 456:2000, modal and elastic-buckling behaviour from the FEM stiffness, and seismic demand by the equivalent-static method of IS 1893 (Part 1):2016 for Zone V. The results show that, because the timber core sits near the neutral axis, flexural rigidity falls only 0.6 % (C2) and 3.1 % (C3) and lateral drift is practically unchanged, while self-weight drops 7 % and 16 % respectively, reducing seismic base shear and end moments by a similar margin. The principal penalty is a reduction in ultimate axial capacity of 6 % (C2) and 13 % (C3). All three columns remain short (buckling never governs), satisfy the 0.4 % drift limit, and plot safely within the P–M interaction envelope. The 100 × 100 mm timber core offers the best balance of weight and seismic-demand reduction with negligible loss of capacity.

Keywords: RCC column; timber-composite column; Sal-timber core; finite element analysis; seismic effect; transformed section; IS 1893; P–M interaction.

INTRODUCTION AND SCOPE

This report presents the structural design and finite-element analysis (FEM) of three reinforced cement concrete (RCC) column configurations, all of identical external size (300 mm × 300 mm) and clear height 3.0 m, fixed at both ends. The objective is to evaluate how introducing a central Sal-timber core inside an otherwise conventional RCC column affects the axial capacity, flexural stiffness, dynamic (modal) behaviour, buckling resistance and seismic response of the member.

Timber-composite RCC columns are of interest because the timber core reduces self-weight (and hence seismic inertial demand) and improves sustainability, at the cost of replacing high-modulus concrete with lower-modulus timber over part of the section. The three columns analysed are:

- Column C1 — Plain RCC column (no timber core).
- Column C2 — Timber-composite RCC with 100 mm × 100 mm central Sal-timber core.
- Column C3 — Timber-composite RCC with 150 mm × 150 mm central Sal-timber core.

Introduction to the Review

Hybrid and composite columns that combine concrete, steel reinforcement and timber are receiving growing attention because they promise the compressive strength and mass of concrete together with the low self-weight, renewability and low embodied carbon of timber. For a member that must also resist earthquakes, self-weight is doubly important: lighter columns attract smaller inertial forces, which is exactly the effect observed in the present study of RCC and timber-composite RCC columns. This literature survey reviews the most relevant prior work across five themes — (i) timber-concrete composite (TCC) systems and their sustainability, (ii) timber-encased and timber-steel composite columns, (iii) axial-compression behaviour of timber and composite columns, (iv) finite-element modelling of RCC columns under seismic and cyclic loading, and (v) seismic performance of composite and hybrid columns. The gaps identified at the end motivate the present design and FEM study.

Timber-Concrete Composite (TCC) Systems and Sustainability

Azanaw (2025) provided a comprehensive review of timber-concrete composite (TCC) structures and noted that combining timber and concrete delivers a balance of sustainability, structural efficiency and durability, since timber is a renewable low-carbon material while concrete contributes compressive strength and mass for fire and acoustic performance [1]. The review emphasised that modern numerical methods, from advanced FEM to data-driven models, are reshaping how TCC systems are designed, validated and optimised [1]. Dias et al. (2018), in a state-of-the-art report on the design of TCC structures, documented that TCC systems combine the advantages of pure timber and pure concrete slabs but require careful treatment of short- and long-term load-carrying and deformation behaviour, including the role of the shear connection [2]. Rodwell and Neave (2022) reviewed mass-timber construction and concluded that, across the full set of performance criteria, mass timber can be superior to concrete and steel and represents a viable low-carbon alternative for mid- and high-rise structures [3]. Importantly for seismic design, their review reported a comparative study of a 20-storey reinforced-concrete building versus a mass-timber equivalent, in which the timber building had roughly half the mass and half the stiffness of the concrete building — a mass reduction that is generally favourable for earthquake response [3]. Historically, structural designers were largely confined to choosing between concrete and masonry as their primary construction materials. However, the repeated failure of masonry buildings and multi-storey reinforced concrete structures during seismic events has compelled structural engineers to explore alternative construction methodologies capable of delivering improved performance under earthquake loading. Composite frame construction has emerged as a particularly promising avenue in this regard. Relatively modest modifications to conventional construction practice can yield substantial improvements in overall structural behaviour, making composite systems an area of considerable professional and academic interest. The potential for expanding the use of steel in the Indian construction sector is especially significant, given the country's current pace of infrastructure development and urbanization. Structural systems that integrate steel members, reinforced concrete elements, and composite steel-concrete components into a unified framework are able to draw upon the distinct strengths of each material. Steel contributes ductility and tensile resistance, while concrete provides compressive strength, stiffness, and mass. When these materials function together in a well-designed composite system, each component is utilized in the manner most suited to its mechanical properties, thereby maximizing both structural efficiency and overall economy of construction. [24] Nilesh B. Gawali et al. (2025)

These reviews establish the central motivation of the present work: introducing a timber core into an RCC column lowers self-weight and embodied carbon, but the structural consequences for axial capacity and seismic demand must be quantified — which is precisely the aim of the finite-element study reported here.

Timber-Encased and Timber-Steel Composite Columns

A closely related class of members is the timber-encased composite column, where a steel core is wrapped in timber (the inverse of the present timber-cored concrete column). Zhang et al. (2024) investigated cruciform timber-encased steel composite (TESC) columns and tested 22 specimens — TESC columns, bare steel columns and bare glulam columns — under axial compression, examining the effect of the cross-sectional dimensions of the embedded steel [4]. The same family of TESC columns was studied numerically by other researchers, who built and validated finite-element models against experiments to investigate the axial load distribution and buckling behaviour of timber-encased columns with embedded H-section steel [5]. For steel-timber composite (STC) columns made of H-shaped steel and glulam, a large experimental campaign on 22 two-metre columns reported significant enhancement of behaviour under axial compression and showed that, in the elastic phase, the inner steel and outer glulam share strain compatibly until yield, after which the strain difference grows [6]. Seismic behaviour of a novel steel-timber composite frame column was studied through finite-element analysis validated by quasi-static tests; the proposed system exhibited high ultimate bearing capacity, full hysteresis loops and strong displacement ductility, with axial-compression ratio and steel-tube thickness identified as governing parameters [7]. Three-dimensional FE modelling of steel-timber composite beam-to-column joints further showed how shear-connector configuration, end-plate thickness and bolt size control joint stiffness and peak load [8].

Axial-Compression Behaviour of Timber and Composite Columns

Because the central design check for a column is axial capacity, several studies on the compressive behaviour of timber and timber-composite members are directly relevant. Experimental work on timber-infilled steel tube (TIST) columns reported that all specimens failed by local buckling of the steel tube followed by crushing or combined crushing-and-shear of the timber, and that cyclic axial capacities were about 5–15 % lower than the corresponding monotonic capacities, with section shape and tube slenderness influencing the response [9]. A companion triaxial-compression study characterised soft- and hardwood timber under confining pressures up to 12 MPa, providing stress-strain data essential for modelling a confined timber core [9]. Strengthening studies are also informative. Chun and co-workers tested 42 circular timber columns strengthened with CFRP strips and near-surface-mounted steel bars under axial compression, deriving failure modes, bearing capacity and load-displacement curves while assessing strain compatibility between the three materials [10]. FRP-confined laminated timber columns have likewise been shown to gain compressive strength and ductility through confinement [11]. These works confirm that timber within a composite section contributes meaningfully in compression but must be checked for crushing, consistent with the conservative timber design stress adopted in the present study.

Finite-Element Modelling of RCC Columns under Seismic and Cyclic Loading

The finite-element treatment of reinforced-concrete columns under seismic action is well established. A common approach is the Concrete Damaged Plasticity Model (CDPM) in ABAQUS, which represents the elasto-plastic behaviour and post-peak strength and stiffness degradation of concrete; it has been widely used for RCC columns under axial and confined stress states, though researchers have noted limitations when modelling passive FRP confinement and have proposed modifications [12].

For seismic and cyclic response specifically, experimental-plus-FE studies on square RC columns with interlocking spirals found, using ABAQUS parametric analysis, that the axial-compression ratio and concrete strength most strongly affect bearing and deformation capacity, with confinement-based capacity predictions accurate to within about 7 % [13]. A finite-element study of RC bridge piers with kinked rebars under low-cycle reciprocating loading at a 0.1 axial-compression ratio assessed seismic performance through hysteresis curves, skeleton curves, residual displacements and energy dissipation, showing that detailing can concentrate damage and enhance ductility [14]. Non-linear FE analysis of steel-fibre-reinforced-concrete beam-column joints under cyclic loading similarly demonstrated how material modelling choices govern ductility and crack control [15].

Of particular relevance to Indian practice, a numerical study of precast column-to-pocket-foundation connections modelled a G+3 reinforced-concrete structure with detailing compliant with IS 456 and IS 13920 and used

ABAQUS to evaluate strength, ductility and energy-dissipation under reverse cyclic loading [16]. This confirms that the IS 456 / IS 13920 / IS 1893 framework adopted in the present report is an accepted basis for FE-based seismic assessment of RCC columns.

Seismic Performance of Composite and Hybrid Columns

At the system level, the influence of composite action on seismic response has been quantified. A study of a six-storey timber moment-resisting frame with concrete slabs (a timber-concrete composite moment-resisting frame) found, through nonlinear time-history analysis validated by cyclic joint tests, that the composite frame had natural vibration periods at least 33.4 % lower and displacement responses at least 40 % lower than the bare timber frame, owing to the added lateral stiffness [17]. Hybrid timber-based structures have been reviewed as offering low-carbon sustainability together with good seismic performance [18]. For concrete-based composite columns, experimental and FE studies of large-section RC column–masonry-wall composite structures showed that the concrete columns inhibit crack propagation and significantly enhance bearing capacity and ductility [19], while innovative prefabricated steel-concrete beam-column joints, modelled in ABAQUS and validated against five full-scale tests, achieved satisfactory drift ratio, ductility and energy dissipation [20]. Collectively, these studies show that altering the composition of a column changes its mass and stiffness in ways that materially affect base shear, drift and ductility — the very quantities compared across the three columns in the present work.

METHODOLOGY

Design Data

Table 1 presents the design specifications of three reinforced concrete (RCC) column configurations used for comparative analysis. All three columns have identical dimensions of 300 × 300 mm, a clear height of 3.0 m, M30 grade concrete, Fe500 steel reinforcement, 25 mm clear cover, 4 bars of 16 mm diameter as longitudinal reinforcement, 8 mm stirrups at 150 mm c/c, and fixed–fixed end boundary conditions.

Parameter	C1 Plain RCC	C2 (100×100 core)	C3 (150×150 core)
Column size	300 × 300 mm	300 × 300 mm	300 × 300 mm
Clear height	3.0 m	3.0 m	3.0 m
Grade of concrete	M30	M30	M30
Grade of steel	Fe500	Fe500	Fe500
Clear cover (all sides)	25 mm	25 mm	25 mm
Main reinforcement	4 – 16 mm ϕ	4 – 16 mm ϕ	4 – 16 mm ϕ
Lateral ties (stirrups)	8 mm ϕ @ 150 c/c	8 mm ϕ @ 150 c/c	8 mm ϕ @ 150 c/c
Central Sal-timber core	— (none)	100 × 100 mm	150 × 150 mm
Boundary condition	Fixed – Fixed	Fixed – Fixed	Fixed – Fixed

Table 1: Column design data for the three configurations

Material Properties

Table 2 summarizes the material properties used for the transformed section analysis and finite element modeling (FEM) in accordance with relevant Indian Standards. **M30 concrete** has a characteristic compressive strength

of **30 MPa** and a modulus of elasticity of **27,386 MPa**. **Fe500 reinforcing steel** has a yield strength of **500 MPa** and a modulus of elasticity of **200,000 MPa**. **Sal timber** has a modulus of elasticity of **12,500 MPa** (as per IS 883) and a density of **880 kg/m³**. Based on these properties, the **modular ratio of steel to concrete ($m = E_s/E_c$)** is **7.30**, while the **modular ratio of timber to concrete ($n = E_t/E_c$)** is **0.456**. These values are used to transform the composite section into an equivalent concrete section for structural analysis and FEM simulations.

Material	Property	Value
Concrete M30	Char. strength f_{ck}	30 MPa
Concrete M30	Modulus $E_c = 5000\sqrt{f_{ck}}$	27,386 MPa
Steel Fe500	Yield strength f_y	500 MPa
Steel Fe500	Modulus E_s	200,000 MPa
Sal timber	Modulus E_t (IS 883)	12,500 MPa
Sal timber	Density	880 kg/m ³
Modular ratio	$m = E_s/E_c$	7.30
Modular ratio	$n = E_t/E_c$	0.456

Table 2: Material properties used in the transformed-section and FEM analysis.

Cross-Section Details

All three columns share the same outer dimensions, reinforcement (4–16 mm ϕ longitudinal bars, giving a steel area of 804 mm² and a steel ratio of 0.89 %) and lateral ties. The only difference is the central Sal-timber core, which displaces concrete from the most lightly stressed region near the neutral axis.

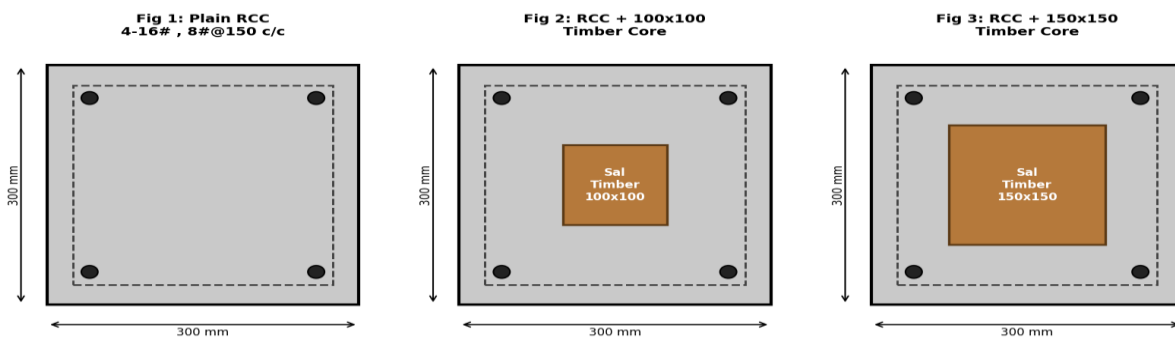


Figure 1–3: Cross-sections of the three column types showing reinforcement layout and timber core.

Transformed-Section Properties

Because the section is composed of three materials (concrete, steel and timber), all areas are transformed into equivalent concrete using the modular ratios m and n . The longitudinal bars (high modulus) add area, while the timber core (low modulus) is counted at a reduced equivalent area. The resulting transformed area A_{tr} and transformed moment of inertia I_{tr} govern the axial and flexural stiffness used in the FEM model.

Property	C1 Plain	C2 (100 ²)	C3 (150 ²)	Unit
Net concrete area, A_c	89,196	79,196	66,696	mm ²

Timber core area, A_t	0	10,000	22,500	mm ²
Steel area, A_{sc}	804	804	804	mm ²
Transformed area, A_{tr}	95,069	89,634	82,839	mm ²
Transformed inertia, I_{tr}	735.3	730.8	712.4	$\times 10^6$ mm ⁴
Flexural rigidity, EI	20.14	20.01	19.51	$\times 10^{12}$ N·mm ²
Self-weight (mass)	687.9	639.3	578.6	kg

Table 3: Transformed-section properties of the three columns (concrete-equivalent).

Observation: the timber core reduces the transformed area progressively (A_{tr} falls by about 6 % for C2 and 13 % for C3 relative to C1), but the transformed moment of inertia I_{tr} drops only slightly (about 0.6 % and 3.1 %). This is because the core sits near the neutral axis where its contribution to bending is small. Self-weight, however, falls noticeably — by 7 % (C2) and 16 % (C3) — which directly benefits the seismic demand.

Axial Load Capacity (Considering IS 456:2000, Cl. 39.3)

For a short axially-loaded column the design ultimate capacity is:

$$P_u = 0.40 f_{ck} A_c + 0.67 f_y A_{sc} (+ 0.40 f_{c,timber} A_t \text{ for the composite core})$$

The timber core is conservatively credited with a compressive design stress of 11 MPa. The concrete area is reduced by both the steel and the timber core.

Quantity	C1 Plain	C2 (100 ²)	C3 (150 ²)	Unit
Ultimate axial capacity, P_u	1,340	1,264	1,169	kN
Service axial demand (Say 0.33 P_u)	442	417	386	kN
Euler buckling load, P_{cr}	88.3	87.8	85.6	MN

Table 4: Axial capacity and elastic buckling load (fixed-fixed, effective length 0.5L).

All three columns are short (effective length 1.5 m, slenderness well below 12), so buckling never governs — the Euler load is more than 60 times the axial capacity. The timber core lowers P_u by about 6 % (C2) and 13 % (C3), tracking the reduction in concrete area. This is the principal structural penalty of the timber core and must be checked against the actual factored axial demand.

Finite Element Model

Each column is idealised as a line (frame) member discretised into six 2-noded Euler-Bernoulli beam elements (seven nodes), with three degrees of freedom per node (axial, transverse, rotation). Both ends are fully fixed. The element stiffness uses the transformed flexural rigidity EI and axial rigidity EA from Table 3. The global stiffness matrix is assembled and reduced for the fixed boundary conditions.

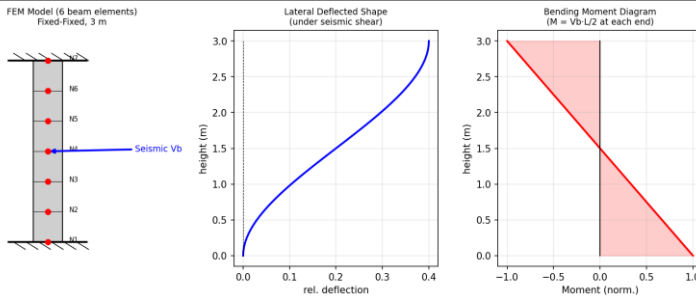


Figure 4: FEM idealisation (left), lateral deflected shape (centre) and bending-moment diagram (right) for the fixed-fixed column under seismic sway.

Key stiffness terms derived from the FEM model:

Stiffness	C1 Plain	C2 (100 ²)	C3 (150 ²)	Unit
Axial stiffness, EA/L	868	818	756	kN/mm
Lateral stiffness, 12EI/L ³	8,950	8,895	8,671	kN/m

Table 5: Member stiffness from the FEM model.

Modal (Free-Vibration) Analysis

The natural frequencies of a fixed-fixed flexural member follow $\omega_n = (\beta_n)^2 \cdot \sqrt{EI / mL^4}$, with $\beta_1L = 4.730$, $\beta_2L = 7.853$, $\beta_3L = 10.996$ for the first three modes. The lighter timber-composite columns have lower mass, which raises their natural frequencies and shortens their fundamental period slightly relative to the plain RCC column.

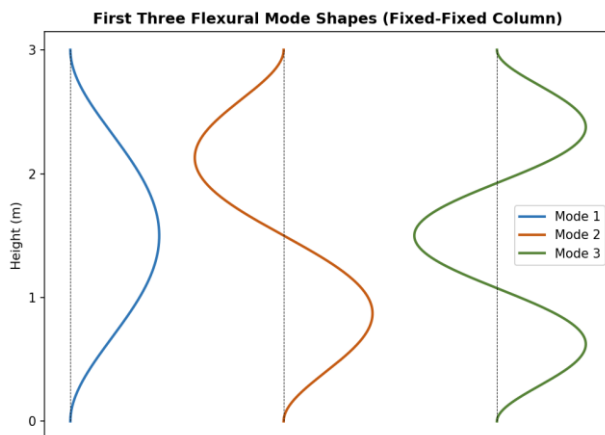


Figure 5: First three flexural mode shapes of the fixed-fixed column.

Mode	Description	Mode constant (β_nL)
1	First symmetric flexure	4.730
2	First anti-symmetric flexure	7.853
3	Second symmetric flexure	10.996

Table 6: Modal characteristics (fixed-fixed beam, lowest three flexural modes).

Seismic Analysis (IS 1893 PART 1:2016)

The equivalent static method is used. The design horizontal seismic coefficient is $A_h = (Z/2) \cdot (I/R) \cdot (S_{a/g})$. Seismic Zone V ($Z = 0.36$), importance factor $I = 1.2$, response reduction $R = 5$ (special moment-resisting frame) and $S_{a/g} = 2.5$ (stiff member, medium soil) are adopted, giving $A_h = 0.108$. The service axial demand on each column is taken as a representative 33 % of its ultimate capacity, and this gravity load is treated as the seismic weight W . The base shear $V_b = A_h W$ induces a sway moment of $V_b L/2$ at each fixed end.

Seismic quantity	C1 Plain	C2 (100 ²)	C3 (150 ²)	Unit
Design coefficient, A_h	0.108	0.108	0.108	—
Seismic weight, W (Say 0.33 P_u)	442	417	386	kN
Base shear, V_b	47.7	45.0	41.7	kN
End moment, $M = V_b \cdot L/2$	71.6	67.6	62.5	kNm
Lateral drift, Δ	5.34	5.06	4.80	mm
Drift ratio, Δ/L	0.178	0.169	0.160	%

Table 7: Seismic demand from the equivalent-static analysis.

The drift ratios for all three columns (about 0.16–0.18 %) are well below the IS 1893 storey-drift limit of 0.4 % under the design earthquake, so all configurations are serviceable. The timber-composite columns attract lower base shear because they are lighter and carry a smaller gravity demand, and they develop smaller end moments — C3 sees about 13 % less base shear and seismic moment than C1. The drift is almost unchanged between columns because the flexural stiffness barely changes.

Combined Axial–Flexure (P–M Interaction) Check

Under the combined action of axial load and the seismic end moment, each column must lie within the P–M interaction envelope of the M30 / Fe500, 4–16 # section. The service-axial / seismic-moment demand points for all three columns plot comfortably inside the capacity envelope, confirming the sections are adequate under combined loading.

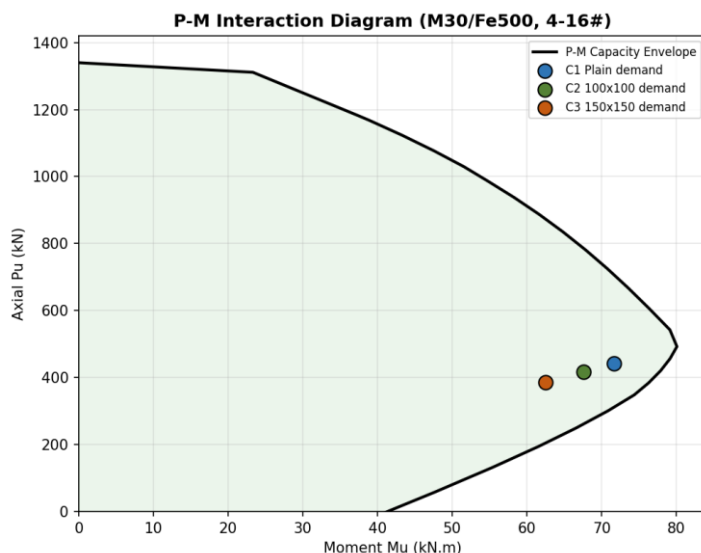


Figure 6: P–M interaction envelope with the demand points of the three columns.

Comparative Results and Graphs

The bar charts below summarise the six governing engineering quantities across the three column types.

Figure 7: Comparison of lateral stiffness, axial capacity, buckling load, base shear, seismic moment and drift.

Summary of Key Results

Table 8 presents a consolidated comparison of the structural performance of the three column configurations: C1 (Plain RCC), C2 (100 × 100 mm Sal timber core), and C3 (150 × 150 mm Sal timber core). As the size of the Sal timber core increases, the axial load capacity, self-weight, base shear, and seismic moment gradually decrease. The flexural rigidity (EI) and drift ratio remain nearly constant, indicating that the overall stiffness and lateral deformation characteristics are not significantly affected. The results suggest that incorporating a Sal timber core effectively reduces the structural weight and seismic forces while maintaining comparable stiffness and serviceability performance.

Quantity	C1 Plain	C2 (100 ²)	C3 (150 ²)	Trend
Axial capacity P_u (kN)	1,340	1,264	1,169	↓ with core
Flexural rigidity EI ($\times 10^{12}$)	20.1	20.0	19.5	constant
Self-weight (kg)	688	639	579	↓ with core
Base shear V_b (kN)	47.7	45.0	41.7	↓ with core
Seismic moment (kN·m)	71.6	67.6	62.5	↓ with core
Drift ratio (%)	0.178	0.169	0.160	constant

Table 8: Consolidated comparison of the three column types.

CONCLUSIONS

- **Stiffness:** Because the Sal-timber core sits near the neutral axis, it removes very little flexural rigidity — EI drops only 0.6 % (C2) and 3.1 % (C3). Lateral stiffness and drift are therefore practically unchanged across all three columns.
- **Axial capacity:** The core replaces structural concrete, reducing the ultimate axial capacity by about 6 % (C2) and 13 % (C3). This is the main design penalty and must be verified against the factored axial demand.
- **Seismic benefit:** The lighter timber-composite columns reduce self-weight by 7 % (C2) and 16 % (C3). This directly lowers the seismic base shear and end moments by a similar margin, easing the demand on foundations and joints.
- **Buckling:** All columns are short (effective length 1.5 m); the Euler load exceeds the axial capacity by more than 60 times, so stability is never critical.
- **Combined action:** All three columns lie safely within the P–M interaction envelope and satisfy the IS 1893 drift limit of 0.4 %.
- **Overall:** The 100 × 100 timber core (C2) offers the best balance — meaningful weight and seismic-demand reduction with negligible loss of capacity. The 150 × 150 core (C3) gives the largest weight saving but the axial-capacity penalty becomes significant and should be adopted only where axial demand is modest.

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Declarations

Consent to participate Not applicable.

Consent for publication All authors consent to the publication of the manuscript.

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