



iJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** X **Month of publication:** October 2026

DOI: <https://doi.org/10.22214/ijraset.2026.85407>

www.ijraset.com

Call: ☎ 08813907089

E-mail ID: ijraset@gmail.com

Seismic Response of RC, Steel and Plan-Hybrid Steel-Concrete Frames

Finhasali Navsariwala¹, N. K. Solanki²

^{1,2}Applied Mechanics Department, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India

Abstract: Steel-concrete hybrid buildings are usually studied with the two materials stacked along the height, while frames that combine reinforced concrete (RC) and steel side by side in plan have received little attention. This paper compares the linear seismic response of six five-storey frames on an 18 m × 18 m plan: an all-RC frame, an all-steel frame and four plan-hybrid frames in which one to four of the five column lines are steel (steel grid ratio 0.2–0.8). Each layout is modelled with storey heights of 3 m and 5 m, designed to the Indian codes for seismic zone III without bracing or shear walls, and analysed in ETABS by the equivalent static method in both principal directions. Base shear, storey shear, roof displacement, inter-storey drift and secant lateral stiffness are compared. Replacing RC column lines with steel lowers the design base shear by up to 59%, because the frame becomes lighter, but it also lowers the lateral stiffness by up to 73%, so the roof displacement rises by up to 56%. The hybrid frames generally respond between the two single-material frames, and the frame with one steel line deflects slightly less than the RC frame while attracting 17% less base shear. The minor-axis orientation of the steel columns makes the hybrids 7–17% more flexible in the Y-direction. Raising the storey height from 3 m to 5 m increases the roof displacement 1.8–1.9 times and cuts the base shear by about 40%. All peak drifts stay below 0.09%, well inside the 0.4% limit of IS 1893 (Part 1):2016.

Keywords: steel-concrete hybrid structure, plan hybrid frame, steel grid ratio, storey drift, base shear, storey height, equivalent static analysis

I. INTRODUCTION

A hybrid structure uses reinforced concrete and structural steel as separate members of one lateral system, rather than fusing them inside a single cross-section as composite members do. Designers adopt the arrangement to put each material where it works best: concrete for mass, stiffness and fire resistance, steel for long spans, speed of erection and low self-weight. Coordinated research in the United States and Japan on frames with RC columns and steel beams (RCS) produced the first systematic design guidance for such systems [1], and later reviews describe a steady growth of steel-concrete hybrid and composite forms in practice [2].

Most seismic studies of hybrid buildings treat systems in which the materials are separated along the height or between the core and the frame. A shaking-table test on a scaled 25-storey building, combining a steel frame with a concrete core tube, gave early experimental evidence of how such mixed systems respond to strong shaking [3]. Because steel and concrete dissipate energy differently, the damping of such buildings cannot be taken as that of either material alone, and equivalent modal damping ratios have been proposed for them [4]. Fanaie and Shamlou [5] analysed 5-, 9- and 15-storey mixed frames under a large set of records and showed that their behaviour differs from that of RC or steel frames of the same height. Irregular RC-steel hybrid frames have been evaluated before and after strengthening [6], and fragility curves have been derived for vertical hybrid frames under mainshock-aftershock sequences [7]. Askouni studied RC-lower, steel-upper buildings under sequential near-fault excitations [8] and, in a three-way comparison with conventional RC and steel buildings, found fewer drift exceedances in the hybrid buildings [9]. The same concept appears in heavy industry, where a tall mixed structure supporting a refinery reactor has been examined by pushover and time-history analysis [10].

A second family of hybrids mixes the materials within each joint. Pushover studies of RCS special moment frames have quantified the influence of joint flexibility on their seismic performance [11], and an RCS frame has been compared with an equivalent RC frame by pushover analysis [12]. Storey height is a further parameter that shifts the period, the seismic weight and hence the design forces of moment frames designed to the Indian code [13]. Nonlinear static procedures are widely used to assess such frames, although their limits relative to dynamic analysis are well documented [14], [15].

The arrangement studied here has received far less attention: RC and steel frames placed side by side in plan, so that every storey contains both materials. The layout arises when a building is extended horizontally with a different material, or when one part of a plan needs column-free steel bays.

Its seismic response is not obvious. Steel bays reduce the seismic weight but also the stiffness, and wide-flange steel columns are much weaker about their minor axis, so the two plan directions need not respond alike. A preliminary study [16] examined such frames mainly through response reduction factors. The present paper sets that factor aside and compares the basic design-level seismic parameters (base shear, storey shear, storey displacement, inter-storey drift and lateral stiffness) of RC, steel and plan-hybrid frames without bracing. The effect of the steel grid ratio and of the storey height on each parameter is quantified in both principal directions.

II. METHODOLOGY

A. Building Models

Twelve regular moment-resisting frames were modelled: six plan layouts, each with a uniform storey height of 3 m or 5 m. The plan is 18 m $\times$ 18 m, with four bays of 4.5 m in each direction, giving five column lines (A–E) along X. The steel grid ratio is the number of steel column lines divided by five. The all-RC frame (5-RC) has a ratio of 0, the all-steel frame (5-S) a ratio of 1, and the hybrids 4RC_S1, 3RC_S2, 2RC_S3 and 1RC_S4 have ratios of 0.2 to 0.8. In each hybrid the RC lines occupy the left of the plan and the steel lines the right (Fig. 1). Table I lists the models.

TABLE I
Plan Layouts and Steel Grid Ratios (Each Layout Modelled with 3 m and 5 m Storeys)

Model	Steel Grid Ratio	RC Column Lines	Steel Column Lines
5-RC	0	A–E	–
4RC_S1	0.2	A–D	E
3RC_S2	0.4	A–C	D–E
2RC_S3	0.6	A–B	C–E
1RC_S4	0.8	A	B–E
5-S	1.0	–	A–E

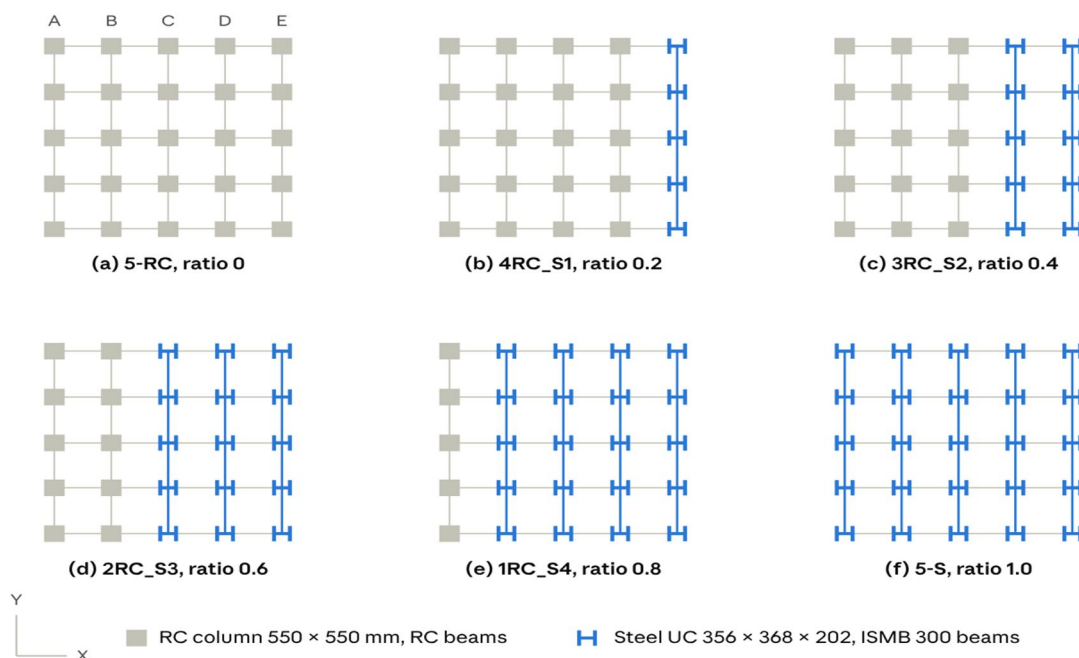


Fig. 1 Plan layouts of the RC, steel and plan-hybrid frames (steel grid ratio 0 to 1.0). The steel columns bend about their major axis in X and their minor axis in Y.

Each building has five storeys above the plinth beam and a further storey between the foundation and the plinth, so six storey levels are counted from the base. The total height is 18 m for the 3 m frames and 30 m for the 5 m frames. A 120 mm slab acts as a rigid diaphragm at every level, and the columns are fixed at the base. Fig. 2 shows the 3RC_S2 model.

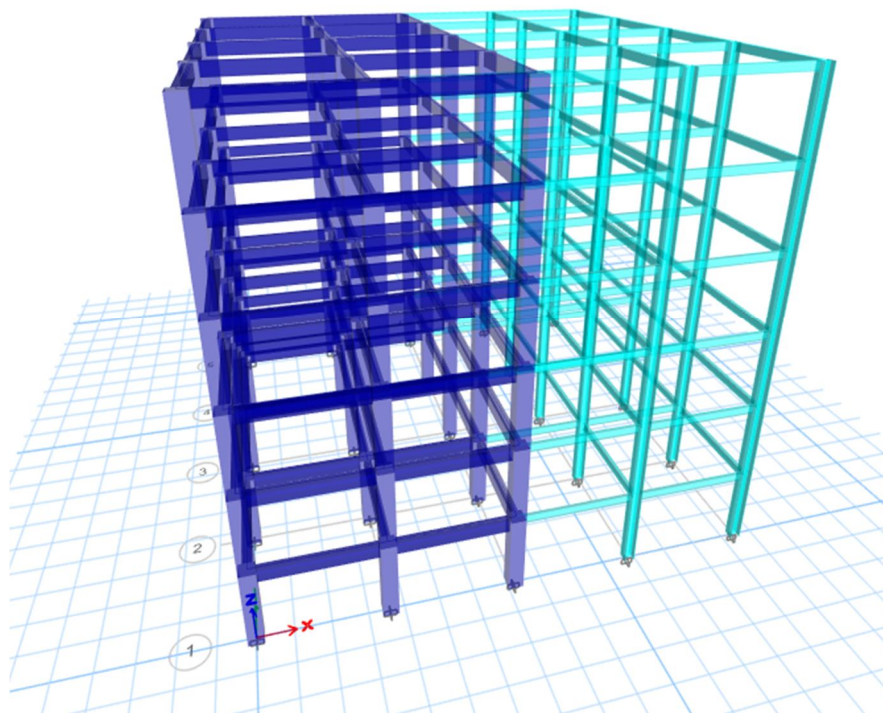


Fig. 2 Three-dimensional view of the 3RC_S2 plan-hybrid model in ETABS: RC grids (dark) and steel grids (light).

B. Members, Materials and Loads

The same member sizes are used in all twelve models (Table II), so that the material in each column line is the only variable. Steel columns are Jindal universal columns UC 356 × 368 × 202; Indian standard wide-flange sections failed the slenderness check for the 5 m storeys. They are oriented with the major axis resisting bending in X, so the minor axis resists bending in Y. RC members were designed to IS 456:2000 [17] and steel members to IS 800:2007 [18]. The seismic weight comprises the dead load plus 25% of the floor live load; no live load is taken on the roof [19]. Wind loads were taken from IS 875 (Part 3):2015 [20] for member design, but only the seismic response is reported here.

TABLE II
MEMBER SIZES, MATERIALS AND DESIGN DATA

Item	Value
RC column / RC beam	550 mm × 550 mm / 300 mm × 450 mm
Steel column / steel beam	UC 356 × 368 × 202 / ISMB 300
Slab thickness	120 mm
Concrete / reinforcement / structural steel	M30 / Fe 415 / Fe 250
Floor finish; live load (floor / roof)	1.0 kN/m ² ; 3.0 / 1.5 kN/m ²
Seismic zone, Z; soil type	III, 0.16; medium (type II)
Importance factor <i>I</i> ; response reduction factor <i>R</i>	1.2; 5 (special moment-resisting frame)
Basic wind speed; terrain category	44 m/s; 2

C. Analysis and Response Parameters

All models were analysed in ETABS by the equivalent static (seismic coefficient) method of IS 1893 (Part 1):2016 [19], separately in X and Y. The design base shear is given by (1):

$$V_B = A_h W, \quad A_h = (Z/2)(I/R)(S_a/g) \quad (1)$$

where W is the seismic weight and S_a/g is the spectral acceleration coefficient for medium soil, equal to $1.36/T$ for periods between 0.55 s and 4.0 s. The code gives the approximate period as $T_a = 0.075 h^{0.75}$ for RC frames and $0.085 h^{0.75}$ for steel frames, h being the height in metres. The base shear is distributed over the height in proportion to $W_i h_i^2$.

The inter-storey drift ratio of storey i is computed from the storey displacements u_i by (2):

$$\theta_i = (u_i - u_{i-1}) / h_i \quad (2)$$

It is checked against the IS 1893 limit of 0.004. A secant lateral stiffness $K = V_B/u_{\text{roof}}$ is also used to compare the overall stiffness of the frames. Base shear, storey shear, storey displacement, drift and K are reported for both directions and both storey heights.

III. RESULTS AND DISCUSSION

Table III summarises the peak response of all twelve frames in both directions. The sections below examine each parameter in turn, then the effects of storey height and loading direction.

TABLE III
PEAK SEISMIC RESPONSE UNDER THE EQUIVALENT STATIC DESIGN LOADS

Model	h (m)	$V_{B,X}$ (kN)	$V_{B,Y}$ (kN)	$u_{\text{roof},X}$ (mm)	$u_{\text{roof},Y}$ (mm)	$\theta_{\text{max},X}$ (%)	$\theta_{\text{max},Y}$ (%)	K_X (kN/mm)	K_Y (kN/mm)
5-RC	3	511.8	511.8	6.55	6.55	0.048	0.048	78.1	78.1
4RC_S1	3	422.5	415.6	6.42	6.92	0.047	0.051	65.8	60.0
3RC_S2	3	364.0	348.2	6.86	7.85	0.050	0.061	53.1	49.3
2RC_S3	3	303.5	280.8	7.54	8.85	0.055	0.065	40.3	31.7
1RC_S4	3	237.5	237.5	8.77	9.64	0.063	0.071	27.1	24.6
5-S	3	248.0	217.7	9.41	10.23	0.068	0.075	26.3	21.3
5-RC	5	304.1	304.1	12.35	12.35	0.054	0.054	24.6	24.6
4RC_S1	5	252.1	249.2	12.12	12.99	0.053	0.057	20.8	19.2
3RC_S2	5	216.4	206.5	12.84	14.59	0.057	0.064	16.9	14.2
2RC_S3	5	179.7	167.7	13.93	16.26	0.061	0.071	12.9	10.3
1RC_S4	5	139.9	135.7	15.90	17.62	0.070	0.077	8.8	7.7
5-S	5	143.6	123.8	16.73	18.66	0.074	0.081	8.6	6.6

A. Base Shear and Storey Shear

The design base shear falls steadily as RC column lines are replaced by steel (Table III). With 3 m storeys it drops from 511.8 kN for 5-RC to 237.5 kN for 1RC_S4 in X, a reduction of 54%. The cause is the loss of seismic weight. An RC column of 550 mm $\times$ 550 mm weighs about 7.6 kN/m and an RC beam about 3.4 kN/m, against about 2.0 kN/m for the UC column and 0.4 kN/m for the ISMB 300 beam. The all-steel frame attracts slightly more base shear than 1RC_S4 in X (248.0 kN against 237.5 kN at 3 m, and 143.6 kN against 139.9 kN at 5 m). The weight change alone does not explain this reversal of about 3–4%; it is probably linked to the different period used for the all-steel frame.

The storey shear profiles in Fig. 3 have the same shape for every layout. The shear grows quickly over the upper storeys and changes little between the plinth storey and the one above it, because the parabolic distribution assigns little force to the low plinth level. The roof storey carries 34–37% of the base shear in all frames, so the steel grid ratio changes the magnitude of the storey shears but not their distribution over the height.

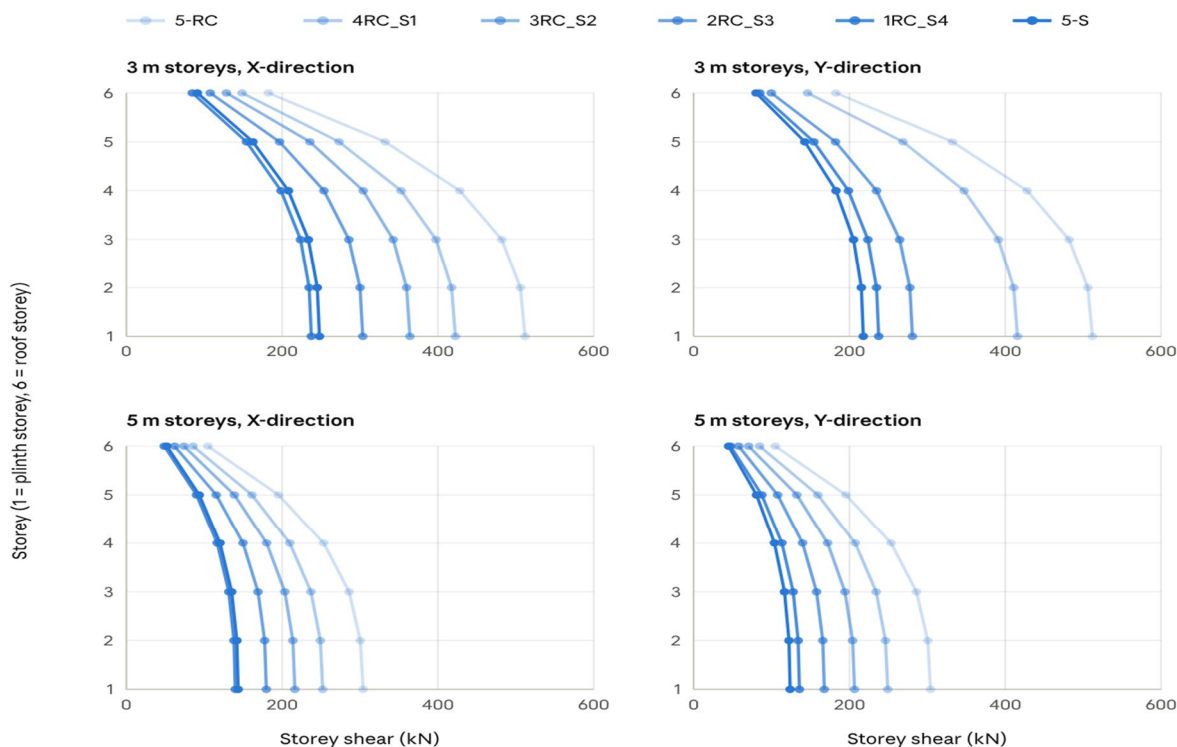


Fig. 3 Storey shear profiles of the six layouts under the design earthquake load: (a) 3 m storeys, X; (b) 3 m storeys, Y; (c) 5 m storeys, X; (d) 5 m storeys, Y. The 3RC_S2 curve is omitted from (b).

B. Lateral Stiffness and Roof Displacement

The secant lateral stiffness falls faster than the base shear (Fig. 4). With 3 m storeys, K drops by 66% in X (78.1 to 26.3 kN/mm) and by 73% in Y (78.1 to 21.3 kN/mm) between 5-RC and 5-S, while the base shear drops by 52% and 57%. The roof displacement therefore grows with the steel grid ratio, by up to 44% in X and 56% in Y.

The frame with one steel line is the exception. In X, 4RC_S1 loses 17% of the base shear and only 16% of the stiffness, so its roof displacement is 2% smaller than that of the RC frame at both storey heights. A small steel fraction thus lightens the frame without any loss of X-direction displacement performance. From a ratio of 0.4 upwards the loss of stiffness dominates.

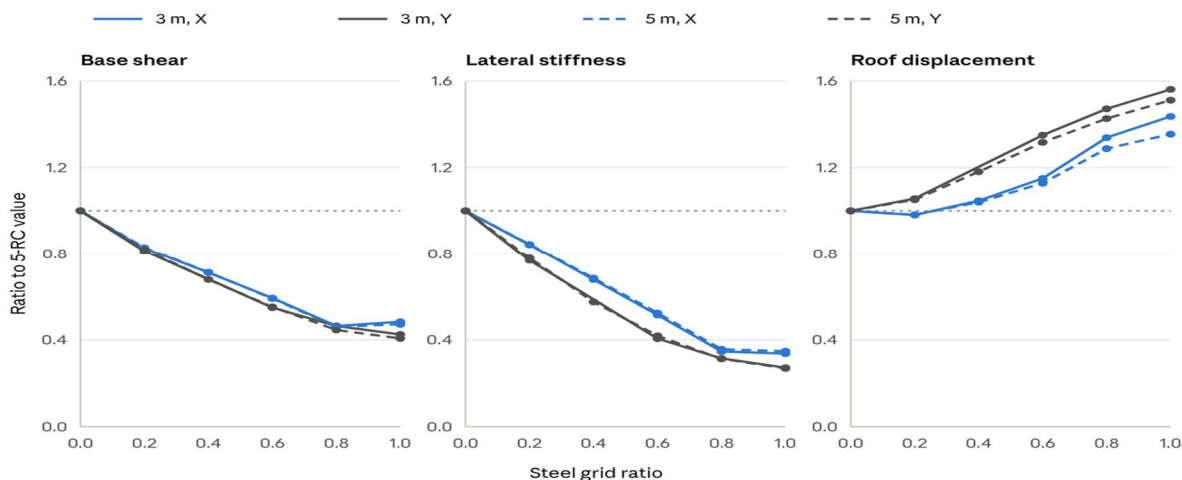


Fig. 4 Base shear, secant lateral stiffness and roof displacement of each frame relative to the all-RC frame, plotted against the steel grid ratio. The 3 m, Y series has no point at a ratio of 0.4.

C. Storey Displacement

The displacement profiles (Fig. 5) show the shear-type deformation of moment frames: the displacement grows almost linearly over the lower storeys and flattens towards the roof. The profiles of the hybrid frames lie between those of 5-RC and 5-S, ordered by steel grid ratio, except that 4RC_S1 in X lies on the RC curve. The spread between the frames widens with height, because the stiffness differences add up storey by storey. The largest roof displacement, 18.66 mm, occurs for the all-steel frame with 5 m storeys in Y.

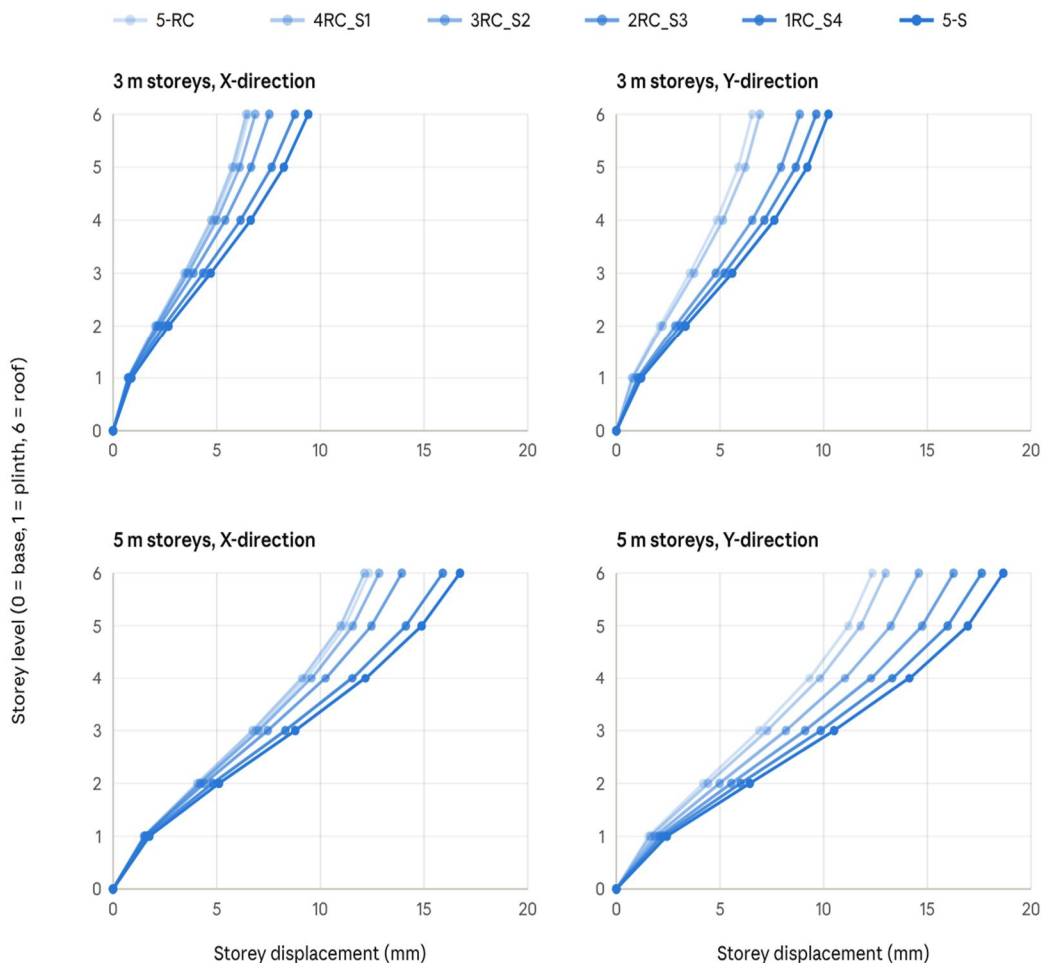


Fig. 5 Storey displacement profiles under the design earthquake load: (a) 3 m storeys, X; (b) 3 m storeys, Y; (c) 5 m storeys, X; (d) 5 m storeys, Y. The 3RC_S2 curve is omitted from (b).

D. Inter-Storey Drift

The drift peaks in storey 3, the second storey above the plinth, in every frame and both directions (Fig. 6). The two end storeys, the plinth storey and the roof storey, drift least. The peak drift rises with the steel grid ratio, from 0.048% to 0.068% in X and from 0.048% to 0.075% in Y with 3 m storeys. The highest value, 0.081% for 5-S with 5 m storeys in Y, is about one fifth of the IS 1893 limit of 0.4% [19]. None of the unbraced frames therefore needs bracing to satisfy the drift criterion at this hazard level. Drift is unlikely to govern the choice of steel grid ratio for low-rise frames in zone III.

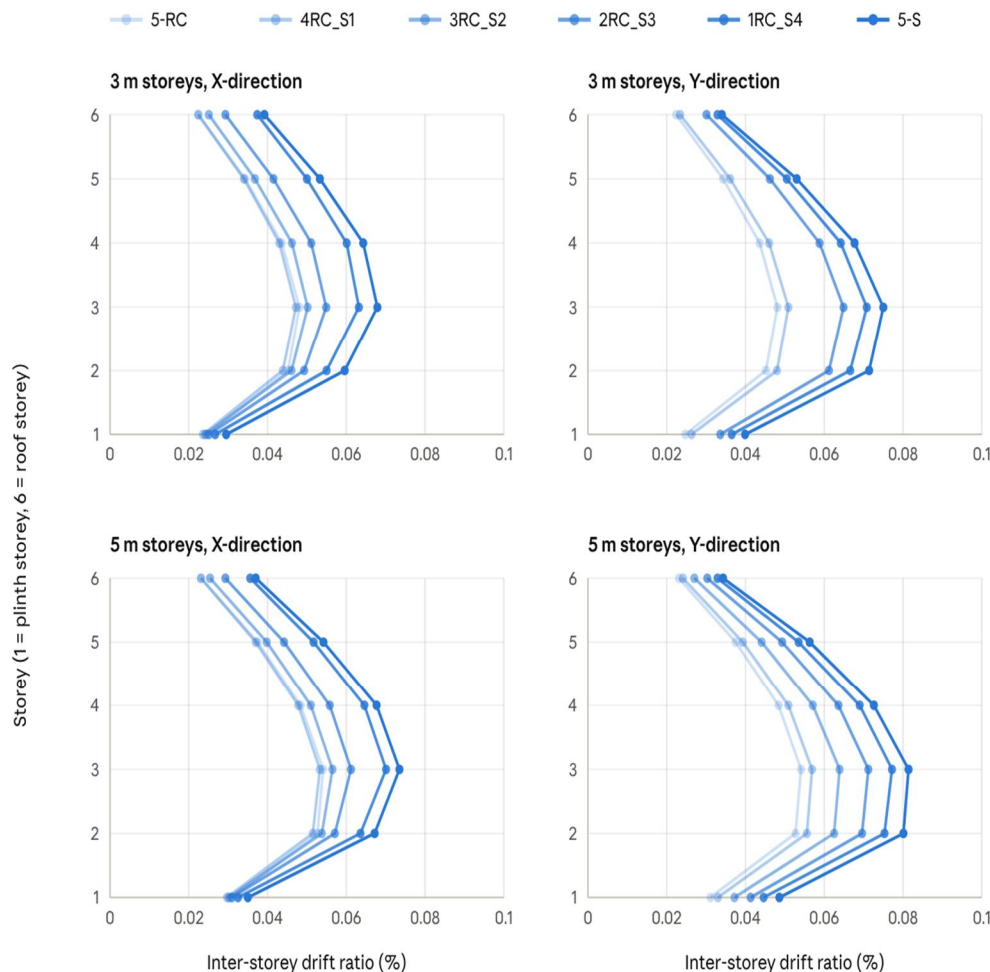


Fig. 6 Inter-storey drift ratio profiles under the design earthquake load: (a) 3 m storeys, X; (b) 3 m storeys, Y; (c) 5 m storeys, X; (d) 5 m storeys, Y. The 3RC_S2 curve is omitted from (b).

E. Effect of Storey Height

Increasing the storey height from 3 m to 5 m increases the roof displacement 1.78–1.89 times and the peak drift ratio only 1.08–1.13 times (Table III). The drift is a ratio to the storey height, so most of the extra displacement is absorbed by the taller storeys. The base shear falls to 57–60% of its 3 m value, because the longer period of the taller frames lowers the spectral acceleration. The stiffness falls to about one third, from 78.1 to 24.6 kN/mm for 5-RC. The ordering of the six layouts is the same at both heights, so the trends of Sections III-A to III-D do not depend on storey height.

F. Directional Behaviour

The RC frame responds identically in X and Y, since its square columns are equally stiff in both directions. Every frame containing steel is more flexible in Y. For 5-S the Y/X roof displacement ratio is 1.09 at 3 m and 1.12 at 5 m, which reflects the minor-axis bending of the UC columns. In the hybrids the ratio peaks at 1.17 for 2RC_S3, above the all-steel value.

Loading direction also explains this peak. Under X loading every X-direction frame contains the same mix of RC and steel columns, so the stiffness is symmetric and the floors translate without twisting. Under Y loading the RC column lines are much stiffer than the steel lines, which moves the centre of stiffness towards the RC side of the plan. The extra Y displacement of the hybrids is consistent with the torsion this eccentricity causes, and the effect is largest when the two materials share the plan most evenly. Designers of plan-hybrid frames should therefore check torsional irregularity in the direction normal to the material boundary.

IV. CONCLUSIONS

Twelve unbraced five-storey RC, steel and plan-hybrid frames, with storey heights of 3 m and 5 m, were compared under the equivalent static design loads of IS 1893 (Part 1):2016. The main conclusions are as follows.

- 1) Replacing RC column lines with steel lowers the design base shear almost in proportion to the steel grid ratio, by 54–55% at a ratio of 0.8, because the frame becomes lighter. The all-steel frame attracts 3–4% more base shear than the 1RC_S4 frame in X.
- 2) The lateral stiffness falls faster than the base shear, by 65–73% for the all-steel frame. The roof displacement therefore rises with the steel grid ratio, by up to 44% in X and 56% in Y.
- 3) The frame with one steel line (4RC_S1) is the best compromise in this set. It attracts about 17% less base shear than the RC frame, deflects about 2% less in X and only 5–6% more in Y.
- 4) The drift peaks in the second storey above the plinth in every frame. Its largest value, 0.081%, is about one fifth of the 0.4% limit, so drift does not govern the design of these low-rise unbraced frames in zone III.
- 5) Raising the storey height from 3 m to 5 m multiplies the roof displacement by 1.8–1.9 and the peak drift ratio by 1.08–1.13. It lowers the base shear to 57–60% and the stiffness to about one third. The ranking of the six layouts is the same at both heights.
- 6) Every frame containing steel is more flexible in Y, where the steel columns bend about their minor axis. The Y/X displacement ratio of the hybrids reaches 1.17, above the 1.09–1.12 of the all-steel frame, which is consistent with torsion from the stiffness eccentricity of the mixed plan. Torsional irregularity should therefore be checked in the direction normal to the RC–steel boundary.

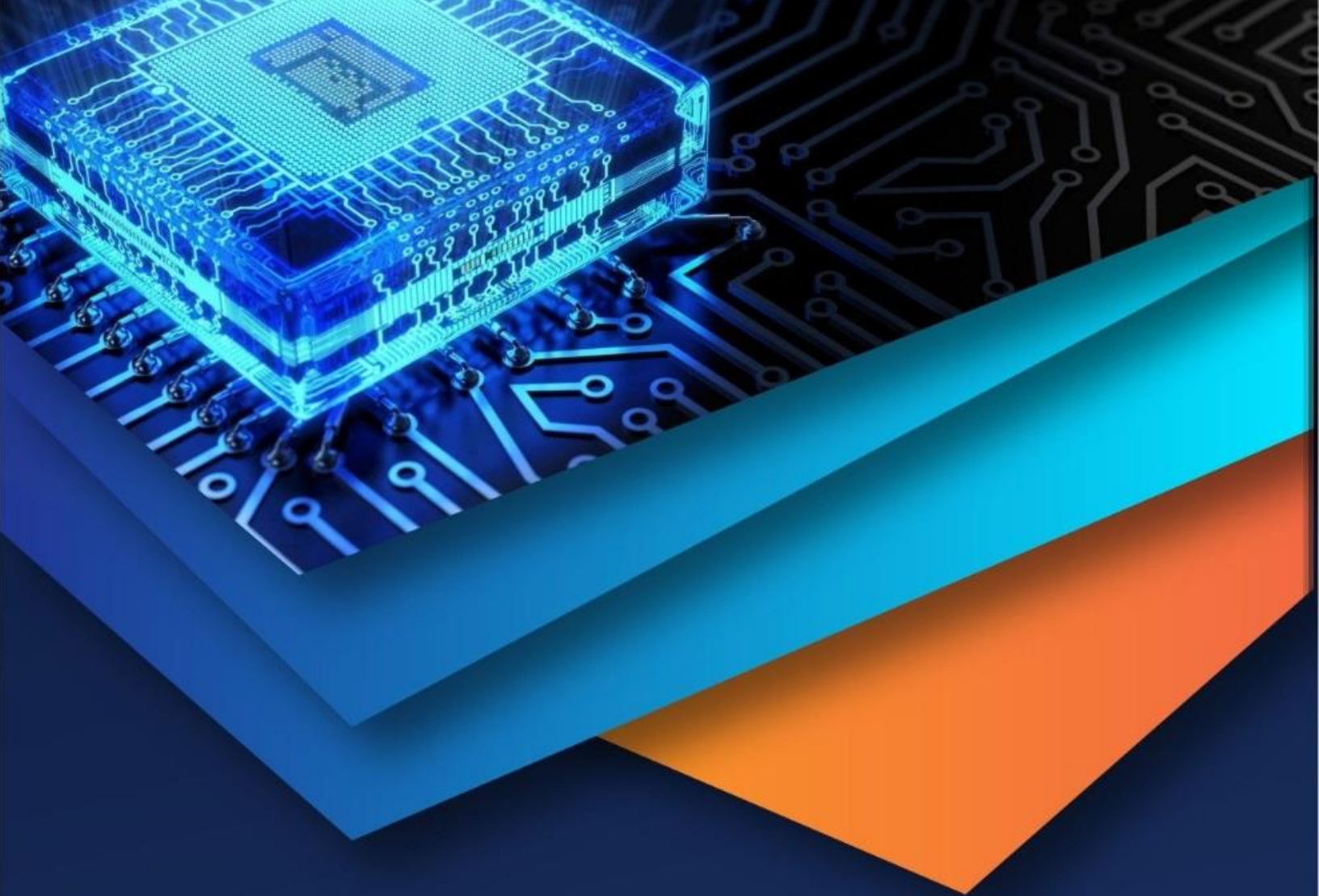
The study is limited to linear static analysis of regular low-rise frames. Nonlinear static and time-history analyses, a direct measure of the torsional response, and the detailing of the RC–steel interface are needed before the trends can be generalised to taller or irregular plan-hybrid buildings.

REFERENCES

- [1] G. G. Deierlein and H. Noguchi, "Overview of US–Japan research on the seismic design of composite reinforced concrete and steel moment frame structures," *J. Struct. Eng.*, vol. 130, no. 2, pp. 361–367, 2004, doi: 10.1061/(ASCE)0733-9445(2004)130:2(361).
- [2] J. Nie, J. Wang, S. Gou, Y. Zhu, and J. Fan, "Technological development and engineering applications of novel steel–concrete composite structures," *Front. Struct. Civ. Eng.*, vol. 13, no. 1, pp. 1–14, 2019, doi: 10.1007/s11709-019-0514-x.
- [3] X. Zhou and G. Li, "Shaking table model test of a steel–concrete composite high-rise building," *J. Earthq. Eng.*, vol. 14, no. 4, pp. 601–625, 2010, doi: 10.1080/13632460903193949.
- [4] A. V. Papageorgiou and C. J. Gantes, "Equivalent modal damping ratios for concrete/steel mixed structures," *Comput. Struct.*, vol. 88, no. 19–20, pp. 1124–1136, 2010, doi: 10.1016/j.compstruc.2010.06.014.
- [5] N. Fanaie and S. O. Shamlou, "Response modification factor of mixed structures," *Steel Compos. Struct.*, vol. 19, no. 6, pp. 1449–1466, 2015, doi: 10.12989/scs.2015.19.6.1449.
- [6] X. Ren, S. Gong, and Y. Lu, "Performance evaluation of seismic strengthened irregular RC–steel hybrid frames," *J. Perform. Constr. Facil.*, vol. 33, no. 1, 2019, doi: 10.1061/(ASCE)CF.1943-5509.0001242.
- [7] B. Ghanbari, M. Fathi, and A. H. Akhaveissy, "Fragility curves for reinforced concrete (RC)/steel vertical hybrid frame structure under mainshock–aftershock sequences," *J. Struct. Integr. Maint.*, vol. 8, no. 3, pp. 179–187, 2023, doi: 10.1080/24705314.2023.2220946.
- [8] P. K. Askouni, "The behavior of hybrid reinforced concrete–steel buildings under sequential ground excitations," *Computation*, vol. 11, no. 5, Art. no. 102, 2023, doi: 10.3390/computation11050102.
- [9] P. K. Askouni, "Seismic comparison of hybrid steel–reinforced concrete and conventional frames," *Appl. Sci.*, vol. 15, no. 7, Art. no. 3772, 2025, doi: 10.3390/app15073772.
- [10] S. Radaoui, K. Skalomenos, and G. Papagiannopoulos, "Seismic behaviour and design of a tall mixed reinforced concrete–steel structure supporting an oil refinery reactor," *Bull. Earthq. Eng.*, vol. 22, no. 14, pp. 7047–7083, 2024, doi: 10.1007/s10518-024-02001-z.
- [11] B. F. Azar, H. Ghaffarzadeh, and N. Talebian, "Seismic performance of composite RCS special moment frames," *KSCE J. Civ. Eng.*, vol. 17, no. 2, pp. 450–457, 2013, doi: 10.1007/s12205-013-1431-5.
- [12] M. Singh Oinam and S. S. Ningthoukhongjam, "Comparison of seismic performance of composite (RCS) frame with RC frame using pushover analysis," in *Advances in Structural Engineering*, ser. Lecture Notes in Civil Engineering, vol. 81. Springer, 2021, pp. 31–44, doi: 10.1007/978-981-15-5235-9_3.
- [13] P. P. V. Rao and L. M. Gupta, "Effect of seismic zone and story height on response reduction factor for SMRF designed according to IS 1893(Part-1):2002," *J. Inst. Eng. India Ser. A*, vol. 97, no. 4, pp. 367–383, 2016, doi: 10.1007/s40030-016-0183-x.
- [14] H. Krawinkler and G. D. P. K. Seneviratna, "Pros and cons of a pushover analysis of seismic performance evaluation," *Eng. Struct.*, vol. 20, no. 4–6, pp. 452–464, 1998, doi: 10.1016/S0141-0296(97)00092-8.
- [15] A. M. Mwafy and A. S. Elnashai, "Static pushover versus dynamic collapse analysis of RC buildings," *Eng. Struct.*, vol. 23, no. 5, pp. 407–424, 2001, doi: 10.1016/S0141-0296(00)00068-7.
- [16] K. K. Rana, "Assessment of seismic performance of structures hybrid in plan," M.E. thesis, Faculty of Technology and Engineering, The Maharaja Sayajirao Univ. of Baroda, Vadodra, India, 2023.
- [17] Plain and Reinforced Concrete — Code of Practice, IS 456:2000, Bureau of Indian Standards, New Delhi, India, 2000.
- [18] General Construction in Steel — Code of Practice, IS 800:2007, Bureau of Indian Standards, New Delhi, India, 2007.



- [19] Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings, IS 1893 (Part 1):2016, Bureau of Indian Standards, New Delhi, India, 2016.
- [20] Design Loads (Other than Earthquake) for Buildings and Structures — Code of Practice, Part 3: Wind Loads, IS 875 (Part 3):2015, Bureau of Indian Standards, New Delhi, India, 2015.



10.22214/IJRASET



45.98



IMPACT FACTOR:
7.129



IMPACT FACTOR:
7.429



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089  (24*7 Support on Whatsapp)