

PERFORMANCE EVALUATION OF HIGH-STRENGTH CONCRETE AND ULTRA-HIGH-PERFORMANCE CONCRETE (UHPC) IN HIGH-RISE RC BUILDINGS UNDER SEISMIC LOADING

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Abstract - The selection of concrete grade affects the stiffness, mass, member dimensions, and earthquake response of tall reinforced-concrete (RC) buildings. This study compares conventional M30 concrete, high-strength concrete (HSC, M60), and ultra-high-performance concrete (UHPC, M130) in a controlled analytical investigation of a G+13 special moment-resisting RC frame. Three ETABS models with the same plan, height, loading, and seismic input were analysed by linear modal time-history analysis using the El Centro 1940 record in the two principal directions. The models differed in concrete properties and the member sizes developed for the respective grades. Peak base shear in the X direction decreased from 700.04 kN for M30 to 678.11 kN for M60 and 621.20 kN for M130; corresponding reductions in the Y direction were from 670.09 kN to 649.62 kN and 595.70 kN. Roof displacement and peak drift were also lower for the high-performance alternatives. The M60 model had the shortest fundamental period and smallest displacement, whereas the M130 model produced the smallest base shear and overturning moment, reflecting the interaction of material stiffness, density, and section reduction. All models remained within the applicable drift criterion. The results indicate that UHPC can reduce global seismic demand in the studied configuration, but conclusions are limited to linear modelling, one regular frame, and one earthquake record. Nonlinear, multi-record, and cost-informed studies are required before broad design recommendations are made.

Key Words: High-strength concrete; ultra-high-performance concrete; seismic response; time-history analysis; ETABS; high-rise reinforced concrete; base shear; storey drift.

1. INTRODUCTION

Rapid urbanisation and the limited availability of land have accelerated vertical development in Indian cities and elsewhere. Reinforced concrete remains the dominant material for these buildings because its constituents are widely available and its design and construction practices are well established. As height increases, however, lateral actions become a primary design concern. Earthquake loading is particularly consequential in regions where growing urban centres coincide with moderate or severe seismic hazard. In this setting, material choice cannot be treated only as a strength or cost decision: it influences the

mass and stiffness matrices that govern the dynamic response of the entire building.

Conventional M30 concrete is commonly adopted for structural framing, but its strength can require comparatively large columns and beams at lower levels. Larger sections increase self-weight and consume usable floor area. HSC offers higher compressive strength and elastic modulus, permitting more compact members for a similar gravity-load capacity. UHPC is a denser, fibre-reinforced cementitious composite with very high compressive strength, high elastic modulus, improved durability, and post-cracking tensile resistance. These characteristics make it attractive for critical members, but they do not by themselves establish how a complete high-rise frame will behave under earthquake excitation.

At building scale, a higher concrete grade may increase stiffness, while the smaller sections it enables may reduce seismic mass. The resulting shift in natural period can either increase or reduce response depending on the input motion. Therefore, direct system-level comparison is needed rather than inference from material properties alone. Existing research has extensively examined high-strength concrete columns, confinement, cyclic behaviour, and UHPC components, but relatively few studies compare conventional concrete, HSC, and UHPC in the same high-rise building configuration under the same ground motion.

This paper reports a comparative ETABS study intended to address that gap. It evaluates the effect of replacing M30 concrete with M60 HSC and M130 UHPC on natural period, storey shear, base shear, overturning moment, displacement, drift, and representative column forces. The focus is on a controlled analytical comparison, not on experimental qualification of a particular UHPC mix or on a prescriptive code design of UHPC buildings.

2. BACKGROUND AND RESEARCH NEED

The seismic response of a multistorey RC building depends on the interaction of inertia, stiffness, damping, geometry, and ground-motion frequency content. A simplified relation, T proportional to the square root of mass divided by stiffness, is useful for interpreting the influence of concrete grade. Increasing elastic modulus tends to reduce the natural

period for a fixed geometry, while the reduced member dimensions feasible with stronger concrete alter both stiffness and mass. A reliable assessment must therefore consider the whole structural model, including the member sizes selected for each material.

HSC has been studied extensively in seismic members because higher-strength concrete may exhibit different confinement and cyclic-response characteristics than normal-strength concrete. Research has shown the importance of transverse reinforcement and ductile detailing in preserving performance under load reversals. UHPC research similarly demonstrates substantial material strength, matrix compactness, and fibre-related crack bridging, but many applications remain bridges, precast joints, overlays, and specialised structural elements. Its adoption in ordinary high-rise frames, particularly in India, requires evidence that links material selection to global response and practical design trade-offs.

The present comparison deliberately uses a regular building plan and a pure special moment-resisting frame. This removes plan irregularity, shear-wall variation, and changes in load pattern as competing explanations for response differences. The research question is: under identical gravity loads and the same time-history input, how do M30, M60, and M130 material systems affect the seismic response of a G+13 RC frame when their sections are sized for the relevant grade?

3. METHODOLOGY

3.1 Building configuration and controlled models

A regular rectangular RC building with eleven bays in the global X direction (35 m overall) and eight bays in the global Y direction (26.25 m overall) was selected. The building has a ground floor plus thirteen upper floors, a uniform 3.0 m storey height, and a total height of 42 m. The lateral system is a special moment-resisting frame without shear walls. Slabs are 150 mm thick and were idealised as rigid diaphragms. The symmetric plan was chosen to avoid torsional effects caused by geometric asymmetry and to concentrate the comparison on the framing material.

Three models were developed in ETABS version 22.5. Model 1 used M30 concrete, Model 2 used M60 HSC, and Model 3 used M130 UHPC for beams and columns. Reinforcing steel was Fe500 in all models. Member sections were developed by iterative preliminary sizing and verification for each concrete grade; the final representative beam/column sizes were 300 x 600 mm and 750 x 750 mm for M30, 300 x 500 mm and 700 x 700 mm for M60, and 300 x 450 mm and 650 x 650 mm for M130. This approach reflects a realistic use of stronger materials: the models are not merely identical geometries with different elastic moduli.

3.2 Material and loading assumptions

For M30 and M60, the elastic modulus was calculated using $E_c = 5000 \sqrt{f_{ck}}$, giving approximately 27,386 MPa and 38,730 MPa, respectively. A literature-based value of 45,000 MPa was used for M130 UHPC because the IS 456 empirical expression is not intended for that strength range. Unit weights of 25 kN/m³ for M30 and M60 and 26 kN/m³ for UHPC were adopted, while Poisson's ratio was 0.20 for all concretes. The fibre contribution and nonlinear tensile response of UHPC were not independently represented in the linear elastic model.

Self-weight was computed automatically from member geometry and material density. Superimposed floor finish load was 1.25 kN/m², typical-floor live load was 3 kN/m², and roof live load was 2 kN/m². Seismic parameters followed the stated Indian-code framework: Zone III, zone factor 0.16, importance factor 1.2, response-reduction factor 5.0, 5% damping, and medium soil (Type II). The foundation was idealised as fixed, and soil-structure interaction, P-delta effects, material cracking, and geometric nonlinearity were excluded consistently from all models.

3.3 Dynamic analysis and response measures

Each model was first subjected to modal analysis to establish its periods, followed by linear modal time-history analysis using the El Centro 1940 accelerogram. The record was applied independently in the global X and Y directions, producing six analysis runs. The response measures extracted for comparison were storey/base shear, natural period, maximum storey displacement, storey overturning moment, storey acceleration, inter-storey drift, and forces in a representative column. HSC and UHPC responses were interpreted relative to the M30 baseline. This framework permits material-induced differences to be observed while holding layout, imposed loading, and earthquake input constant.

4. RESULTS

4.1 Dynamic characteristics

The first-mode periods were 0.926 s for M30, 0.879 s for M60, and 0.895 s for M130. Thus, the M60 frame had a 5.08% shorter fundamental period than the M30 frame, while M130 was 3.35% shorter. This ordering is important: the UHPC model was not automatically the stiffest global system despite having the highest assigned modulus. Its more aggressive section reduction and slightly higher unit weight changed the stiffness-to-mass balance. The result illustrates why structural response should not be inferred from compressive strength alone.

4.2 Base shear and force distribution

Under EX, storey shear increased from the upper floors to a maximum near GF+12 and reduced slightly at the top floor. The peak values were 700.04 kN for M30, 678.11 kN for M60, and 621.20 kN for M130. At the peak, M60 reduced the response by 3.13% and M130 by 11.26% relative to M30. The same pattern was observed in EY, where peak values were 670.09, 649.62, and 595.70 kN, equivalent to reductions of 3.05% and 11.10% for M60 and M130. The consistently lower force profile for M130 suggests that smaller high-performance sections can reduce the seismic force demand in this particular regular frame.

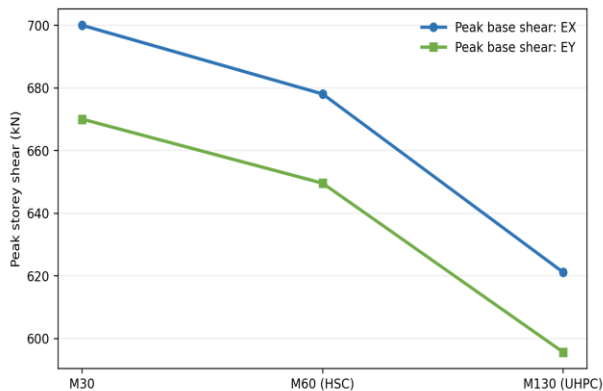


Figure 1. Peak storey shear comparison under El Centro loading. Values are the reported maxima near GF+12 in each principal direction.

4.3 Displacement, drift, and overturning moment

Maximum storey displacement increased with height in every model. In EX, roof displacement was 10.860 mm for M30, 10.311 mm for M60, and 10.490 mm for M130. The corresponding reductions from M30 were 5.06% and 3.41%. In EY, the roof values were 11.422, 10.825, and 10.998 mm, respectively, which represents reductions of 5.23% for M60 and 3.71% for M130. The displacement results track the fundamental periods: M60 showed the strongest global stiffness effect, with UHPC intermediate because of the smaller members used in that model.

Peak EX storey drift occurred near GF+3 and was 0.000344 for M30, 0.000329 for M60, and 0.000335 for M130. The M60 and M130 models therefore reduced peak drift by 4.36% and 2.62%, respectively. All results are well below the stated IS 1893 limit of 0.004 times storey height. The peak base overturning-moment magnitudes were 128,216.41 kNm for M30, 124,332.34 kNm for M60, and 114,155.60 kNm for M130. Relative to M30, the reductions were 3.03% and 10.97%. This is an important foundation-level outcome because lower overturning demand can influence foundation sizing and the distribution of axial forces in perimeter columns.

Table 1. Comparison based on the reported ETABS results. Percentage change is relative to the M30 model.

Response measure	M30	M60 (HSC)	M130 (UHPC)	Interpretation
Fundamental period (s)	0.926	0.879	0.895	M60 shortest
Peak base shear, EX (kN)	700.04	678.11	621.20	M130: -11.26%
Peak base shear, EY (kN)	670.09	649.62	595.70	M130: -11.10%
Roof displacement, EX (mm)	10.860	10.311	10.490	M60: -5.06%
Roof displacement, EY (mm)	11.422	10.825	10.998	M60: -5.23%
Peak drift, EX	0.000344	0.000329	0.000335	All within limit
Base overturning moment (kNm)	128216.41	124332.34	114155.60	M130: -10.97%

4.4 Column-force response

Representative C-1 column results under the selected load combination also showed lower demands with the high-performance materials. At GF+5, the reported axial-force magnitude reduced from 1,423.74 kN in Model 1 to 1,276.92 kN in Model 2 and 1,159.70 kN in Model 3. The associated shear and moment values were likewise generally lower in the HSC and UHPC cases. Because the selected column is one response location rather than a complete capacity design audit, these values should be read as a comparative indicator. They are nevertheless consistent with the reduced global shear and overturning demands observed for the M130 model.

5. DISCUSSION

The results reveal a useful distinction between two performance objectives. If the objective is to minimise period, roof displacement, and peak drift in the studied frame, M60 HSC performed best. Its increased modulus,

combined with a moderate section reduction, yielded the most favourable stiffness-to-mass balance. If the objective is to reduce peak base shear and overturning moment, M130 UHPC performed best. The latter outcome is associated with the substantially smaller structural sections permitted by the material and the resulting decrease in structural mass and force demand, despite UHPC's slightly larger unit weight. This distinction is practically relevant. A higher material grade does not guarantee a monotonic improvement in every global response quantity. The structural designer must choose member proportions, reinforcement detailing, connection behaviour, damping assumptions, and ground-motion suite as part of an integrated design. Treating UHPC merely as a stronger form of conventional concrete would miss its material-specific behaviour and may also overstate conclusions from a linear elastic model. In the present analysis, the fibre-driven tensile and post-cracking behaviour that is a major reason to select UHPC was not modelled; consequently, the paper assesses elastic global demand rather than nonlinear energy dissipation or damage control.

The base-shear reductions are encouraging, but they should not be interpreted as a universal seismic benefit of UHPC. Time-history demand is sensitive to record frequency content, scaling, damping, modal combination, and the change in natural period. A different suite of spectrum-compatible or site-specific records could produce a different ranking. Similarly, fixed-base and rigid-diaphragm idealisations are appropriate for the controlled comparison but do not include soil-structure interaction, diaphragm flexibility, or construction-stage effects. The regularity of the selected building also limits direct transfer of the results to buildings with setbacks, soft storeys, shear walls, outriggers, or torsional irregularity.

From an implementation perspective, the structural efficiency of UHPC must be balanced against material cost, supply chain, placement procedures, curing, quality control, and design-code coverage. HSC may offer a more readily deployable route to reduced member sizes and improved drift control where normal high-rise construction practices are available. UHPC may be most attractive in critical zones, heavily loaded lower-storey columns, transfer elements, joints, or other locations where its strength and durability justify its additional complexity. A hybrid material strategy could therefore be more realistic than an all-UHPC frame, but it would require a separate optimisation study.

5.1 Engineering implications for material selection

The comparison has direct implications for preliminary material selection in tall RC frames. In a conventional strength-based process, material grade is often selected after a building form and framing layout have been fixed. The present results suggest that material selection should instead be considered early, together with member

proportions and target seismic performance. A change from M30 to M60 allowed reductions in beam depth and column size while producing a lower period, lower displacement, and lower drift. In a project where serviceability, facade movement, or occupant comfort are controlling concerns, this HSC response could be valuable even if its reduction in base shear is relatively modest.

The UHPC model emphasises a different potential advantage. Its M130 strength supported the largest reduction in beam and column sections and the lowest base-shear and overturning-demand measures. For an urban high-rise, smaller vertical members can also improve usable floor area, reduce concrete volume, and facilitate architectural planning. These benefits must be weighed against the often higher binder content, fibre dosage, and production control required for UHPC. The question is therefore not whether UHPC is universally superior; it is whether the locations and performance goals that benefit from it justify the material and execution requirements.

A rational design response may be zoned material use. Lower storeys and highly stressed transfer regions carry large axial and lateral demands and are natural candidates for HSC or UHPC, while upper-storey framing could use lower-strength concrete where demand is less severe. Such a strategy can preserve the mass and space benefits of high-performance material where they matter most without requiring an all-UHPC superstructure. It would, however, introduce construction interfaces and a more complicated analytical model. The controlled three-model comparison in this paper intentionally did not investigate that option.

5.2 Interpretation of the response measures

Base shear, displacement, drift, and overturning moment should be interpreted together. Base shear represents the aggregate lateral force mobilised in the analysed building, but it does not alone describe deformation capacity or damage. Storey drift relates more directly to likely nonstructural damage and to member deformation demand. Overturning moment reflects the foundation-level couple needed to balance height-wise lateral forces. The M130 model was most favourable for force and overturning indicators, while M60 was most favourable for the displacement and drift indicators. This difference is mechanically credible because elastic modulus is only one contributor to the global stiffness of a frame; member geometry and mass change at the same time.

The finding that M60 had a shorter period than M130 merits particular attention. If all member dimensions had been held constant, the higher modulus assigned to UHPC would normally be expected to increase stiffness further. In this study, however, the UHPC framing was sized more slenderly, so the reduction in section inertia moderated the material-stiffness benefit. This outcome supports the study design

decision to allow independently sized sections. It also shows why comparison studies must report both material properties and geometry rather than treating the concrete grade as a single isolated number.

The response profiles did not show a contradiction between the lower period of the HSC model and the lower base shear of the UHPC model. A time-history response depends on the frequency content of the input record and on the participating mass and mode shapes, not simply on period. The small but systematic reduction in upper-level shear and base overturning for M130 is consistent with the lower structural demand reported by the ETABS models. It should nevertheless be treated as a result for the selected El Centro record, not as a code-level reduction factor for UHPC frames.

5.3 Model verification and scope boundaries

The reliability of a comparative analysis depends principally on maintaining a common modelling basis. The three ETABS models used the same plan grid, storey elevations, slab thickness, diaphragm idealisation, gravity loads, seismic parameters, steel grade, and fixed-base condition. The concrete grade and the sections sized for that grade were the intended differences. Modal periods, height-wise response distributions, and code drift checks were reviewed as consistency checks. The use of a regular plan and the omission of shear walls were deliberate simplifications that make the source of response variation easier to interpret. Several scope boundaries must be emphasised. First, the analysis is linear elastic. It does not model cracking, reinforcement yielding, confined-concrete degradation, joint shear, bar buckling, fibre pull-out, or post-cracking tensile behaviour. Those mechanisms can materially affect the comparative response of HSC and UHPC under severe cyclic loading. Second, material properties, especially the UHPC modulus, were adopted from published sources rather than measured from batches intended for this building. Third, the results are tied to a single accelerogram. Record-to-record variability may change both the magnitude and ranking of demand measures.

The study also does not provide a complete design of reinforcement, beam-column joints, foundations, or connections. Reduced member size must never be treated as a substitute for ductile detailing. In Indian seismic design, the detailing provisions of IS 13920 and the wider requirements of IS 1893 remain essential. Where UHPC is proposed, designers must also establish a material specification, quality assurance plan, fibre distribution control, curing regime, and an appropriate design basis. These requirements are outside the present model but are central to safe real-world implementation.

5.4 Recommendations for future research

The next stage of investigation should be nonlinear. Pushover analysis can identify hinge sequences, stiffness

degradation, and likely failure mechanisms, while nonlinear time-history analysis can estimate residual drift, peak rotation, and collapse-margin indicators. Constitutive models should distinguish between normal concrete, HSC, and fibre-reinforced UHPC, including confinement and post-cracking tension where supported by evidence. A material model calibrated from laboratory tests would be especially valuable for M130 concrete because its response is not fully represented by conventional concrete assumptions.

A multi-record analysis is also needed. A suite of spectrum-compatible motions selected for the site hazard should be scaled and applied in both directions, including vertical motion where relevant. Additional building forms should include taller frames, dual frame-wall systems, setbacks, soft-storey conditions, and outrigger structures. Parametric studies could vary the degree of section reduction independently of material grade, allowing designers to identify a practical stiffness-mass optimum rather than comparing only three final designs.

Finally, structural performance should be coupled with life-cycle cost and embodied-carbon assessment. UHPC can reduce section size and potentially reduce maintenance demand because of its durability, but it may have high binder-related environmental and financial impacts. HSC may offer a favourable intermediate solution. A whole-building evaluation that includes concrete volume, reinforcement congestion, construction speed, quality-control requirements, repair risk, and usable floor area would turn the present mechanical comparison into a more complete decision framework.

6. CONCLUSIONS

A controlled linear time-history comparison was conducted for a G+13 regular RC special moment-resisting frame using M30, M60, and M130 concrete systems. The following conclusions are drawn within the stated analytical scope: (1) higher-performance concrete and associated member resizing shortened the first-mode period relative to M30; M60 had the shortest first period (0.879 s). (2) M60 and M130 reduced peak base shear in both principal directions, with M130 producing the greatest reductions, approximately 11% relative to M30. (3) M60 gave the lowest roof displacement and peak drift, while M130 remained below M30 for both quantities. (4) M130 produced the lowest reported base overturning moment, approximately 10.97% below the M30 value, and representative column force demands were also lower. (5) all models satisfied the stated inter-storey-drift criterion.

The paper's contribution is the use of a common building and loading basis to make these distinctions visible. The results do not support an indiscriminate substitution of one concrete grade for another. Rather, they show that material grade, member resizing, and seismic response must be

evaluated together. For the selected frame, HSC is a compelling option where drift control and construction familiarity govern; UHPC is a compelling option where force demand, overturning demand, and highly loaded compact members govern. This nuanced interpretation is more useful for early design decisions than a single ranking based only on compressive strength.

Accordingly, M130 UHPC was the most structurally efficient option when judged by the global force and overturning-demand measures used in this study, whereas M60 HSC provided the strongest elastic displacement and drift control. The appropriate material choice depends on which of these design priorities is dominant. These results should be validated through nonlinear analysis, multiple compatible records, laboratory material characterisation, and consideration of cost and constructability before they are used for general high-rise design decisions.

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