Response-Spectrum Sensitivity of an Irregular High-Rise RCC Building to IS 1893 Soil Classes: An ETABS-Based Comparative Study

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***Abstract*—This study quantifies the sensitivity of an irregular reinforced cement concrete (RCC) high-rise building to the hard, medium, and soft-soil design spectra specified by IS 1893 (Part 1): 2016. A common three-dimensional ETABS v22 model, approximately 108.1 m high, was analysed by the response-spectrum method while the structural geometry, mass source, member assignments, and loading model were retained. The evaluated outputs were maximum story displacement, story drift, story shear, equivalent-static base shear, response-spectrum base reaction, diaphragm displacement, and the maximum-to-average displacement ratio used to screen torsional irregularity. The design horizontal coefficients were 0.010667, 0.014507, and 0.017813 for hard, medium, and soft soil, respectively. The corresponding equivalent-static base shears were 3290.65, 4475.29, and 5495.39 kN. Independent back-calculation from Vb/Ah produced a consistent seismic weight of approximately 308.50 MN for all three cases, supporting mass-source consistency. Relative to hard soil, the soft-soil spectrum increased maximum story displacement from 36.065 to 70.296 mm (+94.91%), maximum story drift from 0.000417 to 0.000811 (+94.48%), and maximum story shear from 3393.38 to 5495.39 kN (+61.94%). The largest directional drift was 0.000862 in the Y direction, only 21.55% of the IS 1893 limit of 0.004. Conversely, the Y-direction torsional ratios (1.235–1.267) exceeded the 1.2 irregularity threshold for every soil spectrum, demonstrating that plan asymmetry remained a governing configuration issue even when drift compliance was achieved. The study distinguishes soil-spectrum sensitivity from direct soil–structure interaction (SSI): no continuum soil domain or calibrated foundation impedance is evidenced in the available model documentation. The results therefore support preliminary design screening and spectrum selection, while advanced SSI analysis is recommended for site-specific foundation response.**

***Index Terms*—RCC high-rise building; response spectrum; soil class; IS 1893:2016; ETABS; story drift; base shear; torsional irregularity**

I. INTRODUCTION

The seismic response of a reinforced concrete building depends on the interaction of its mass, stiffness, damping, geometry, lateral-force-resisting system, and the frequency content of the design ground motion. Local site conditions enter code-based design through soil-dependent spectra and, in a more complete physical model, through kinematic and inertial soil–foundation–structure interaction. These two effects are related but not interchangeable. A soil-specific design spectrum modifies the input demand, whereas direct SSI also permits foundation translation and rocking, changes system period and damping, and redistributes structural actions [1], [4], [5].

The distinction is especially important for tall, irregular buildings. Plan projections, re-entrant geometry, discontinuous stiffness, and eccentricity between mass and rigidity centres can couple translation and torsion. Recent studies report that site amplification, foundation flexibility, structural height, and ground-motion period content may increase deformation demand, although the effect on base shear can be beneficial or detrimental depending on the structure–foundation–soil system [6]–[11]. Accordingly, a single response quantity is not a sufficient basis for design judgement: force demand, drift, displacement, and torsional response must be interpreted together.

IS 1893 (Part 1): 2016 provides soil-dependent elastic design spectra and limits inter-storey drift to 0.004 times the storey height under the specified design action [1]. For a response-spectrum case, modal maxima are combined and, when necessary, scaled so that the dynamic base shear is consistent with the code minimum. This process makes the selected soil category a consequential modelling choice even when the superstructure model is unchanged.

The present paper converts and audits an existing ETABS investigation of an approximately 108.1 m irregular RCC building. Its contribution is threefold: (i) it consolidates the supplied hard-, medium-, and soft-soil results into a traceable comparison; (ii) it checks internal consistency using the base-shear equation and percentage-change calculations; and (iii) it separates conclusions supported by soil-spectrum sensitivity from claims that would require explicit foundation–soil modelling. No unreported structural-response data are fabricated.

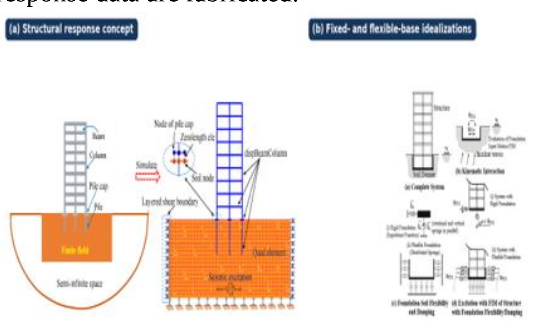


Figure 1. Conceptual structural response and the distinction between fixed- and flexible-base idealizations (source schematics redrawn/assembled from the supplied thesis).

II. LITERATURE SYNTHESIS AND RESEARCH GAP

2.1 Soil spectra and direct SSI

Direct SSI is commonly modelled through discrete springs and dashpots, Winkler or coupled subgrade formulations, substructure impedance functions, or a continuum finite-element domain. Reviews by Bapir et al. [4] and Najar et al. [11] emphasize that the selected representation should be matched to the foundation type, soil nonlinearity, and required response fidelity. Wani et al. [5] compared uncoupled and pseudo-coupled Winkler approaches for an RC building, while Abdel Raheem et al. [12] examined raft-supported moment-resisting frames through static, response-spectrum, and nonlinear time-history analyses. These studies model foundation compliance explicitly; simply changing a design-spectrum soil class does not reproduce their SSI mechanisms.

The literature also rejects a universal assumption that SSI always reduces demand. Requena-Garcia-Cruz et al. [6] reported changes in vulnerability and loss for mid-rise RC buildings when SSI was included. Zhang and far [7] showed that foundation rotation can increase drift even when base shear decreases, while Doğan and Erkan [8] observed material changes in base shear and roof displacement across structural and foundation configurations. Yang et al. [9] further demonstrated that long-period ground motions can interact strongly with frame–shear-wall buildings. The sign and magnitude of an SSI effect therefore depend on period ratios, soil stiffness, foundation type, damping, and response measure.

2.2 Irregular high-rise buildings

Plan irregularity introduces a separate demand mechanism. Kumar and Ghosh [10] found that soil amplification and near-field motion can substantially increase vulnerability in L-shaped RC buildings, while recent soil–foundation–structure studies have highlighted the combined importance of opening patterns, slope conditions, and soil flexibility [13], [14]. For a plan-irregular tall building, soil class and torsional configuration should consequently be reported independently: changing the spectrum may amplify torsion, but the underlying eccentricity originates in geometry and stiffness distribution.

2.3 Research gap and study question

Many comparative ETABS studies label hard-, medium-, and soft-soil response-spectrum cases as SSI studies even when the foundation remains fixed. This blurs the boundary between code-level site-spectrum sensitivity and physical soil–foundation coupling, and it can produce conclusions that are difficult to reproduce. The present study addresses the narrower, answerable question: how sensitive are the code-based force, deformation, and torsional outputs of one irregular high-rise RCC model to the three IS 1893 soil spectra, and which design check governs within the supplied data?

Table 1. Positioning of the present study against representative literature.

Reference	Structural/soil representation	Analysis	Finding relevant to this paper
Wani et al. [5]	G+10 RC building; mat; Winkler and pseudo-coupled SSI	Dynamic FE	Foundation compliance changes period, shear, and drift.
Requena-Garcia-Cruz et al. [6]	Mid-rise RC buildings with SSI	Vulnerability/loss	SSI can worsen seismic performance and losses.
Zhang and Far [7]	High-rise buildings; several foundation/soil cases	Verified FE	Drift and base shear do not necessarily change in the same direction.
Doğan and Erkan [8]	20-storey RC; structural and foundation alternatives	Nonlinear time history	Foundation/SSI assumptions materially alter response.
Kumar and Ghosh [10]	Irregular RC buildings; homogeneous/layered profiles	Pushover, time history, fragility	Site amplification interacts with height and torsion.
Present study	One fixed structural model; three IS soil spectra	Linear response spectrum	Audits spectrum sensitivity; does not claim direct SSI.

III. OBJECTIVES OF THE STUDY

1. To study and model RCC buildings resting on hard, medium and soft soil conditions. Identical superstructure geometry, material properties and loading assumptions are maintained in all models to isolate the influence of soil condition.
2. To analyse the seismic response of RCC buildings using the response spectrum method specified in IS 1893. This method captures modal dynamic behaviour and supports the comparative seismic assessment of multi-storey buildings.

IV. MATERIALS AND METHODS

4.1 Structural model and modelling evidence

The supplied model was developed in ETABS Ultimate v22.7.0. The screen captures show an irregular floor plate with projecting wings, a central core/opening region, wall objects, repeated storeys, and a terrace elevation of approximately 108.1 m. The ETABS story-response plots show levels extending from BASE to TERRACE, with numbered levels through Level 32. Beam assignment labels include B200×700M30 and B300×700M30, and wall labels include W200M30, W250M30, and W300M30. Because the editable ETABS database and complete property tables were not supplied, these labels are treated as model documentation rather than independently verified member-design data.

All three cases use the same visible structural geometry and response-spectrum case name (SPEC1). Thus, differences are attributed to the soil-dependent spectrum and associated design coefficient. The available evidence does not document calibrated translational/rotational foundation springs, dashpots, pile elements, or a continuum soil mesh. The analysis is consequently described as a soil-spectrum sensitivity study.

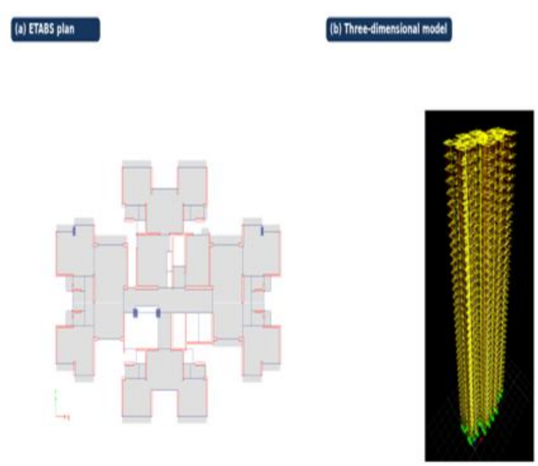


Figure 2. ETABS model documentation: (a) irregular plan and (b) three-dimensional high-rise model.

Table 2. Model definition and evidence audit.

Item	Adopted/observed value	Audit status
Structural system	Multi-storey RCC frame–wall model	Visible in plan and 3-D captures
Plan	Irregular, multi-wing arrangement with central core/opening	Visible; dimensions not fully tabulated
Total height	Approximately 108.1 m	Visible in ETABS output
Concrete grade	M30 in displayed beam/wall property labels	Visible labels; full material table unavailable
Analysis software	ETABS Ultimate 22.7.0	Visible in application title bar
Dynamic case	SPEC1 response spectrum	Visible in story-response panels
Seismic inputs	Z=0.16; I=1.2; R=4; 5% damping	Reported in source study
Soil cases	Hard (Type I), medium (Type II), soft (Type III)	Reported IS 1893 classification
Foundation flexibility	Not evidenced in supplied captures	Direct SSI claim excluded

4.2 Seismic demand and response extraction

For the equivalent-static check, IS 1893 expresses design base shear as

$$V_\beta = A_h W$$

where Vb is the design base shear, Ah is the design horizontal seismic coefficient, and W is the seismic weight. The reported Ah values were 0.010667, 0.014507, and 0.017813 for hard, medium, and soft soil. To verify that only the spectrum changed, W was independently back-calculated for every case as Vb/Ah. The three estimates differed by less than 0.01%, giving a mean of 308,495 kN and confirming a common mass source to the precision of the exported values.

Response quantities were transcribed from the supplied ETABS tables and screenshots. Maximum story displacement, maximum story drift, and story shear were taken from the story-response envelope. Diaphragm UX and UY were retained as a separate centre-of-diaphragm output series; they were not substituted for the story-envelope values. Torsional irregularity was evaluated using the reported maximum-to-average displacement ratio. A ratio above 1.2 was classified as torsionally irregular in accordance with the source study's IS 1893 screening criterion [1].

Percentage change from reference case r to comparison case c was computed as 100(Rc−Rr)/Rr. The hard-soil spectrum was used as the main reference because it generated the lowest demand in the supplied results. No curve ordinates were invented from the screen captures; the original ETABS profiles are shown as evidence, and the comparative charts use only reported maxima.

Table 3. Independent base-shear/mass consistency check.

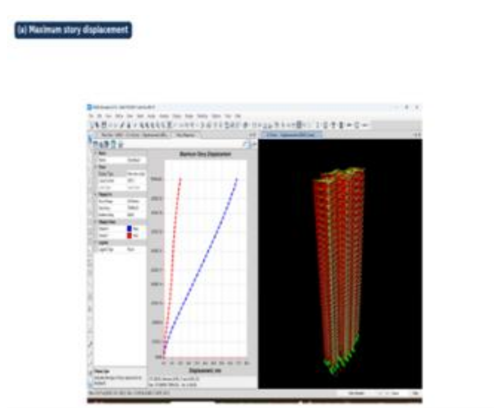
Soil spectrum	A_h	V_β (kN)	Back-calculated $W=V_\beta/A_h$ (kN)	Deviation from mean
Hard	0.010667	3290.654	308,489	−0.002%
Medium	0.014507	4475.290	308,492	−0.001%
Soft	0.017813	5495.392	308,505	+0.003%

Note: Mean back-calculated seismic weight = 308,495 kN (308.50 MN). Small differences arise from rounded Ah values.

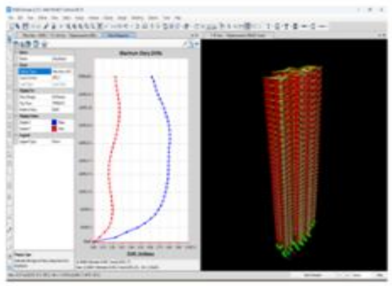
V. RESULTS

5.1 ETABS story-response profiles

The displacement plots rise monotonically toward the terrace, consistent with global cantilever-type lateral deformation. Drift concentrates in the middle-to-upper levels (reported between Levels 21 and 25), whereas story shear is largest near the base and decreases upward as the accumulated seismic mass reduces. The profile shapes remain similar across the three spectra; the dominant effect is a change in magnitude.



(b) Maximum story drift



(c) Story shear

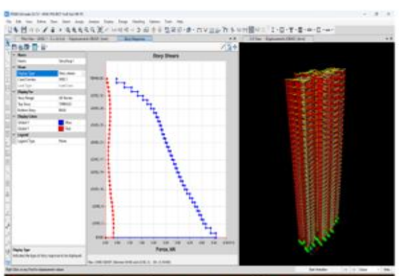
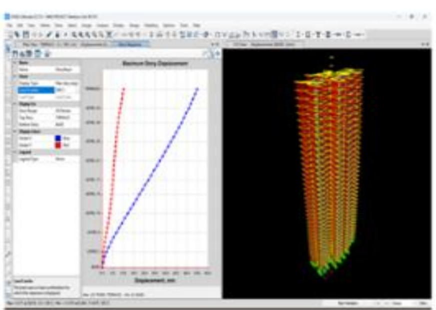
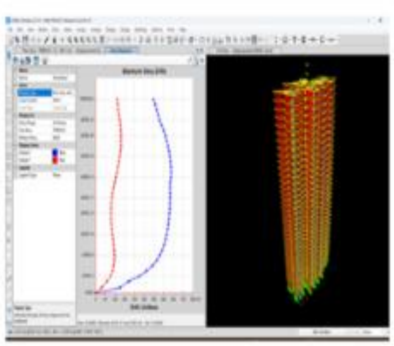


Figure 3. Supplied ETABS response profiles for the soft-soil spectrum: displacement, drift, and story shear.

(a) Maximum story displacement



(b) Maximum story drift



(c) Story shear

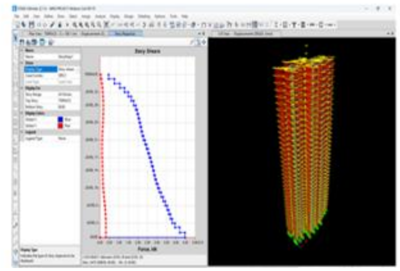
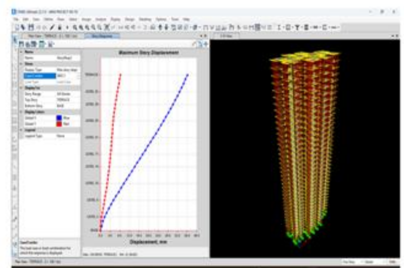
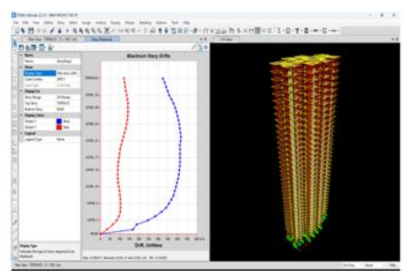


Figure 4. Supplied ETABS response profiles for the medium-soil spectrum: displacement, drift, and story shear.

(a) Maximum story displacement



(b) Maximum story drift



(c) Story shear

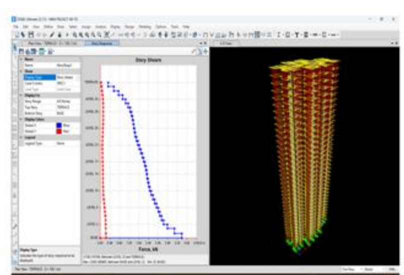


Figure 5. Supplied ETABS response profiles for the hard-soil spectrum: displacement, drift, and story shear.

5.2 Governing story response

The soft-soil spectrum governs all three story-envelope quantities (Table 4 and Fig. 6). Maximum story displacement increases from 36.065 mm for hard soil to 53.793 mm for medium soil and 70.296 mm for soft soil. These changes correspond to +49.16% and +94.91% relative to hard soil. Maximum story drift follows almost the same scaling: +48.92% for medium and +94.48% for soft soil. Maximum story shear increases less steeply, by +31.88% and +61.94%, respectively. Thus, deformation is more spectrum-sensitive than shear for this model.

Table 4. Governing ETABS story-response values.

Soil spectrum	Max. story displacement (mm)	Max. story drift	Max. story shear (kN)	Governing location
Hard	36.065	0.000417	3393.381	Terrace / L21–L25 / near base
Medium	53.793	0.000621	4475.290	Terrace / L21–L25 / base
Soft	70.296	0.000811	5495.392	Terrace / L21–L25 / near base

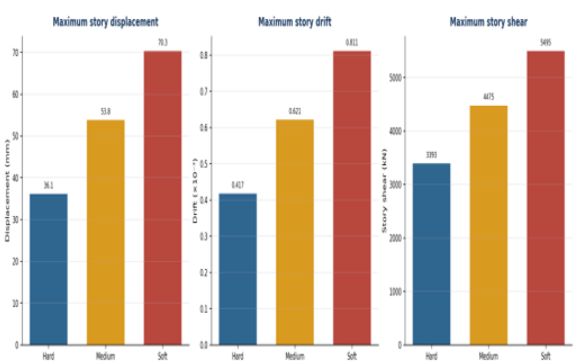


Figure 6. Comparative maxima reconstructed from the audited ETABS outputs.

5.3 Base shear and force consistency

Equivalent-static base shear increases with Ah from 3290.65 kN (hard) to 5495.39 kN (soft). The response-spectrum base reaction equals the equivalent-static value for the medium and soft cases to the reported precision. For hard soil, SPEC X/Y is 3393.38 kN, 3.12% above the equivalent-static value of 3290.65 kN. This difference is consistent with a dynamic result that has been scaled or combined to satisfy a minimum base-shear requirement; the exact ETABS scale factor cannot be independently reconstructed without the model database and modal table.

Table 5. Equivalent-static and response-spectrum base reactions.

Soil spectrum	EQX/EQY reaction (kN)	SPEC X/Y reaction (kN)	SPEC−EQ difference	Interpretation
Hard	3290.65	3393.38	+3.12%	Dynamic result exceeds static check
Medium	4475.29	4475.29	0.00%	Coincident to reported precision
Soft	5495.39	5495.39	0.00%	Coincident to reported precision

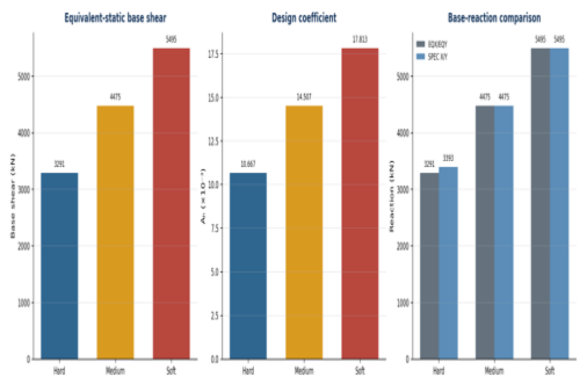


Figure 7. Base shear, design coefficient, and base-reaction comparison.

5.4 Diaphragm displacement, story drift, and torsion

Top-diaphragm displacement rises consistently with the soil-spectrum demand. From hard to soft soil, UX increases from 27.222 to 45.373 mm (+66.68%) and UY from 27.184 to 44.821 mm (+64.88%). These diaphragm values are lower than the maximum story-displacement envelopes and are therefore reported separately rather than merged. The available exports do not identify whether the distinction arises from diaphragm-centre reporting, point-envelope effects, or a different result selection.

Directional story drift is larger in Y for all soil spectra. The maximum seismic drift is 0.000862 for the soft-soil Y case, equal to 21.55% of the IS limit of 0.004. Drift compliance therefore has a substantial numerical margin. Compliance does not remove the torsional concern: X-direction ratios remain close to 1.006, whereas Y-direction ratios are 1.235, 1.236, and 1.267 for hard, medium, and soft spectra. Each Y value exceeds 1.2, and the soft-soil value is 5.58% above that threshold. The small +2.59% rise from hard to soft indicates that the soil spectrum amplifies a torsional tendency primarily created by the irregular plan.

Table 6. Directional displacement, drift, and torsional-irregularity results.

Soil spectrum	UX (mm)	UY (mm)	Drift X	Drift Y	Torsion X	Torsion Y
Hard	27.222	27.184	0.000350	0.000605	1.006	1.235
Medium	37.011	36.934	0.000475	0.000817	1.006	1.236
Soft	45.373	44.821	0.000535	0.000862	1.007	1.267

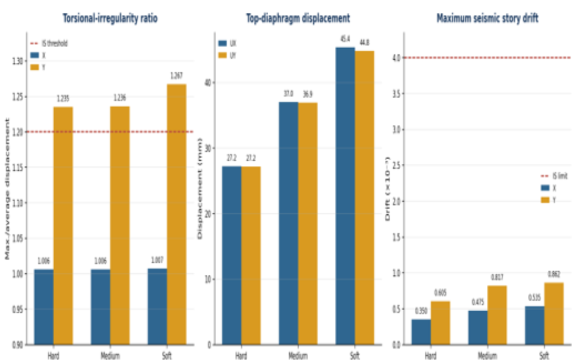


Figure 8. Torsional ratio, top-diaphragm displacement, and directional story drift. Dashed lines show the reported IS screening thresholds.

VI. DISCUSSION

6.1 Engineering interpretation

The results show a monotonic hard-to-soft increase in the selected design-spectrum ordinates and in every extracted force or deformation measure. Within this code-based study, the soft-soil spectrum is therefore the governing preliminary-design case. The near-doubling of maximum displacement and drift is more consequential than the 61.94% shear increase because it signals stronger sensitivity of serviceability and non-structural damage indicators to spectral choice.

The force and displacement trends should not be generalized to direct SSI. Explicit foundation flexibility can lengthen period, add radiation/material damping, and permit rocking; these mechanisms can reduce base shear while increasing drift, as demonstrated in recent high-rise SSI research [7], [8]. The present model isolates the soil-spectrum input rather than those interacting mechanisms. Its conclusions are consequently suitable for code-based spectrum selection and comparative screening, not for predicting foundation settlement, rotation, pile demand, or site-specific wave propagation.

The Y-direction torsional ratio is the most persistent configuration warning. It remains above 1.2 under every spectrum even though story drift remains well below 0.004. This illustrates why drift compliance alone cannot establish satisfactory seismic behaviour. The next design iteration should examine diaphragm eccentricity, stiffness distribution, accidental eccentricity, wall placement, and edge-element demand in Y. If practical, relocating or balancing shear walls may reduce torsion more effectively than simply increasing member sizes.

6.2 Comparison with prior studies

The present increase in deformation for the softer spectrum is directionally consistent with studies reporting greater displacement and drift on deformable or amplifying sites [5], [6], [10], [13]. However, the observed base-shear increase reflects the higher code-spectrum coefficient used here. It does not contradict studies in which explicit SSI reduces base shear through period elongation and damping [7], because the physical and numerical experiments differ. This distinction is the main interpretive contribution of the audit.

6.3 Reliability, reproducibility, and limitations

- The principal maxima, directions, and case names are traceable to the supplied ETABS screenshots and thesis tables; all comparative percentages were recalculated.
- The common seismic weight was verified independently from three Ah–Vb pairs, providing a strong internal consistency check.
- The editable ETABS .EDB file, modal participating-mass table, response-spectrum function ordinates, scale factors, load combinations, and full member/property schedules were not supplied; complete reproduction is therefore not possible.

- Maximum story displacement and top-diaphragm displacement are distinct exported result series. Their difference is retained and disclosed, but cannot be fully diagnosed without ETABS tables.
- No site-specific geotechnical profile, shear-wave velocity, damping curve, foundation impedance, or nonlinear soil model is available. The study must not be presented as a direct SSI simulation.
- Linear response-spectrum analysis cannot quantify yielding, damage progression, collapse margin, or record-to-record variability. Nonlinear time-history and fragility analyses are outside the present evidence base.

VII. FINDINGS AND CONCLUSIONS

7.1 Principal findings

Table 7. Consolidated findings and design implications.

Finding	Audited result	Design implication
Soft spectrum governs	A_h=0.017813; V_β=5495.39 kN	Use the soft-soil spectrum as the critical code case when site classification requires it.
Deformation sensitivity	Soft vs hard: +94.91% displacement; +94.48% drift	Spectrum choice strongly affects serviceability and non-structural demand.
Force sensitivity	Soft vs hard: +61.94% maximum story shear	Foundation and lateral-system actions increase materially.
Drift compliance	Max. seismic drift=0.000862=21.55% of 0.004	All reported cases satisfy the code drift limit with margin.
Persistent torsion	Y ratios=1.235–1.267 >1.2	Plan/stiffness irregularity requires design attention despite drift compliance.
Mass-source consistency	W≈308.50 MN from all Ah–Vb pairs	Supports comparability of the three cases.
Scope boundary	No explicit foundation/soil flexibility documented	Interpret results as soil-spectrum sensitivity, not direct SSI.

7.2 Conclusions

A controlled ETABS response-spectrum comparison was completed for one irregular, approximately 108.1 m RCC building using the hard-, medium-, and soft-soil spectra of IS 1893 (Part 1): 2016. The soft-soil spectrum produced the highest design coefficient, base shear, story shear, displacement, and drift. Relative to hard soil, the soft case increased maximum story displacement by 94.91%, maximum story drift by 94.48%, and maximum story shear by 61.94%. The common seismic weight inferred independently from each base-shear pair was 308.50 MN, confirming consistent mass to the precision of the source outputs. All reported seismic drifts satisfy the 0.004 limit, with the governing value using only 21.55% of the permissible ratio. Nevertheless, the Y-direction torsional ratio exceeds 1.2 for all soil spectra and reaches 1.267 for soft soil. Torsional configuration, rather than code drift, is therefore the persistent design concern in the supplied model. The study also shows that soil-spectrum sensitivity and direct SSI must be distinguished: the available evidence supports the former but does not document foundation compliance or a soil domain. The results provide a useful preliminary screening baseline, while site-specific foundation design requires geotechnical data and explicit SSI modelling.

7.3 Recommended extensions

- Release the ETABS database and tabular exports for independent replication, including modal mass participation and spectrum scale factors.
- Model raft or pile foundations with frequency-dependent translational and rotational impedance, or use a validated continuum soil domain.
- Perform site-response analysis using measured Vs profiles and compare code spectra with site-specific spectra.
- Investigate alternative shear-wall layouts to reduce Y-direction torsion, then repeat response-spectrum and nonlinear checks.
- Use spectrum-compatible nonlinear time histories to quantify hinge formation, residual drift, and collapse margin.

VIII. DECLARATIONS

Data availability. The numerical maxima used in this article are reported in its tables and figures. The original ETABS model database was not available with the supplied Word file; therefore, the analysis cannot be independently rerun from the present manuscript alone.

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Conflict of interest. No conflict-of-interest disclosure was present in the supplied source document. The authors must confirm the final declaration before journal submission.

Author contributions. S.V.W.: modelling, data curation, analysis, and original investigation. A.G.D.: supervision, methodology review, and technical guidance. The contribution statement should be confirmed by the authors before journal submission.

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