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Minimization Of Soft Storey Effects In Symmetrical Structure Using IS Code Method

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Abstract
Soft storey configurations in multi-storey buildings significantly increase vulnerability to seismic forces, particularly in high-seismic zones across India. This empirical study investigates the effectiveness of Indian Standard (IS) code provisions in mitigating soft storey effects in symmetrical structures. The research employs dynamic analysis on various symmetrical building configurations with soft storeys at different levels, comparing their seismic performance before and after implementing IS code recommendations. Five structural models with varying soft storey positions were analyzed using response spectrum analysis under seismic conditions typical of Indian seismic zones III and IV. Results demonstrate that implementing IS 1893:2016 provisions for soft storey mitigation reduced inter-storey drift by 37-42% and decreased storey displacement by 28-33% compared to conventional designs. The study found that soft storeys at lower levels exhibited 1.8 times higher vulnerability than those at intermediate levels. Design modifications including enhanced column stiffness, strategic shear wall placement, and increased beam-column capacity ratio proved particularly effective, with combined implementation reducing the structural vulnerability index by 45.6%. These findings validate the effectiveness of IS code provisions while offering optimization strategies for symmetrical structures in India's seismic regions.

Keywords: *Soft storey, Symmetrical structures, Seismic performance, IS 1893:2016, Inter-storey drift.*

1. Introduction

Background

Soft storey configurations represent one of the most critical vulnerabilities in multi-storey buildings subjected to seismic forces. This architectural feature, characterized by a significant reduction in stiffness or strength in a particular storey compared to adjacent ones, has been implicated in numerous structural failures during past earthquakes in India, including the devastating Bhuj earthquake (2001) and the Sikkim earthquake (2011). In the Indian context, rapid urbanization and increasing land scarcity have led to widespread adoption of buildings with open ground floors for parking or commercial spaces, inadvertently creating soft storey conditions. While such designs offer functional advantages, they pose substantial seismic risks, particularly across India's seismically active regions where approximately 59% of the land area falls under moderate to severe seismic zones [1]. The Bureau of Indian Standards has developed comprehensive seismic design codes, with IS 1893:2016 (Part 1) specifically addressing the design considerations for soft storey structures. These provisions recommend various mitigation strategies, including enhanced design forces for columns, strategic placement of structural elements, and specific detailing requirements [2].

However, the practical implementation and effectiveness of these code provisions in symmetrical structures typical of Indian urban construction require systematic evaluation through empirical research.

Problem Statement and Research Significance

Despite the availability of codified guidelines, soft storey failures continue to occur during seismic events in India. This persistence of vulnerability suggests potential gaps between theoretical code provisions and practical implementation, particularly for symmetrical structures which, despite their regularity in plan, may exhibit complex behavior when incorporating soft storeys. The unique construction practices, material properties, and seismic conditions in India necessitate region-specific assessment of code effectiveness rather than relying solely on international studies.

This research addresses this critical knowledge gap by empirically investigating the effectiveness of IS code provisions in minimizing soft storey effects in symmetrical structures. The study's significance lies in its comprehensive approach to quantifying the improvements in seismic performance achieved through code-compliant designs and identifying optimal implementation strategies suited to Indian construction practices. By providing empirical validation of code provisions, this research aims to enhance the resilience of India's built environment against seismic hazards, potentially contributing to reduced economic losses and improved life safety during future earthquakes.

Research Objectives and Scope

The primary objective of this research is to evaluate the effectiveness of IS code provisions in mitigating soft storey effects in symmetrical structures under seismic loading conditions representative of Indian seismic zones. Specifically, the study aims to:

1. Quantify the reduction in seismic vulnerability achieved through implementation of IS 1893:2016 provisions for soft storey mitigation in symmetrical structures.
2. Analyze the differential impact of soft storey locations (ground floor, intermediate floors) on structural performance before and after code implementation.
3. Identify optimal combinations of mitigation strategies prescribed by IS codes for different structural configurations and seismic zones in India.
4. Develop practical recommendations for structural engineers to enhance the effectiveness of code implementation in Indian construction practices.

The scope of this study encompasses reinforced concrete moment-resisting frame structures with perfect symmetry in plan, typical of residential and commercial constructions in urban India. The analysis focuses on buildings with 8-15 storeys, representing the prevalent mid-rise construction in tier-1 and tier-2 Indian cities. While acknowledging the importance of construction quality and material properties, this study primarily examines design aspects and structural behavior rather than implementation challenges.

2. Literature Survey

The catastrophic impact of soft storey failures during earthquakes has stimulated extensive research globally, with significant contributions from Indian researchers addressing the unique regional context. Chandrasekaran and Roy [3] conducted one of the pioneering studies on soft storey effects in Indian buildings following the 2001 Bhuj earthquake, documenting a 68% higher failure rate in buildings with open ground storeys compared to regular configurations. Their field observations highlighted the inadequacy of conventional design approaches in addressing soft storey vulnerabilities, particularly in buildings constructed before the implementation of modern seismic codes.

Regarding analytical approaches, Halkude et al. [4] compared the seismic performance of regular and soft storey frames using equivalent static and response spectrum methods, observing that soft storeys exhibited 1.5-2.3 times higher inter-storey drift ratios compared to regular frames. Their study emphasized the limitations of linear analysis methods in capturing the complex behavior of soft storey structures, recommending non-linear approaches for comprehensive assessment. Building on this work, Rajeev and Tesfamariam [5] incorporated fuzzy-based vulnerability assessment to evaluate soft storey buildings in the Indian context, establishing a correlation between structural irregularity indexes and observed damage during past earthquakes.

The effectiveness of code provisions has been scrutinized by several researchers. Agrawal and Chourasia [6] evaluated the impact of implementing IS 1893:2002 provisions on soft storey structures, finding that the magnification factor of 2.5 for beam and column design forces resulted in a 35-40% reduction in inter-storey drift and enhanced overall performance. However, their study noted that the code provisions were more effective in moderate seismic zones (Zone III) compared to high seismic zones (Zone IV and V), suggesting the need for zone-specific modifications. Kaushik et al. [7] further examined the revised provisions in IS 1893:2016, documenting improvements in addressing soft storey effects through enhanced design requirements and more comprehensive consideration of irregular configurations.

Alternative mitigation strategies have also been explored extensively. Ravindra et al. [8] investigated the effectiveness of shear walls in mitigating soft storey effects in Indian buildings, concluding that strategic placement of shear walls reduced lateral displacement by 45-60% and substantially improved energy dissipation capacity. Similarly, Bhosale et al. [9] evaluated the performance of steel bracing systems as retrofitting solutions for existing soft storey buildings, demonstrating their effectiveness in enhancing stiffness and strength while maintaining functional requirements.

Recent studies have increasingly focused on performance-based approaches. Sharma et al. [10] developed a performance-based framework for evaluating soft storey structures in the Indian context, integrating regional seismic hazard data with structural vulnerability metrics to provide a more comprehensive assessment than conventional code-based approaches. Their findings indicated that performance-based design could achieve more efficient solutions than blanket application of code provisions, particularly for complex structural configurations.

Despite these significant contributions, there remains a notable gap in empirical validation of current IS code provisions specifically for symmetrical structures with soft storeys. Most existing studies either focus on irregular configurations or employ theoretical models without comprehensive empirical validation. Additionally, the relative effectiveness of different mitigation strategies prescribed by IS codes and their optimal combinations for symmetrical structures requires further investigation, particularly considering the unique construction practices and seismic conditions across different regions of India.

3. Methodology

Research Design and Analytical Framework

This study employs a comprehensive analytical methodology to evaluate the effectiveness of IS code provisions in mitigating soft storey effects in symmetrical structures. The research design integrates computational modeling, dynamic analysis, and comparative assessment to quantify the improvements in seismic performance achieved through implementation of code recommendations. Five prototype building models representing typical symmetrical structures with soft storeys at various levels were developed based on prevalent construction practices in urban India. Each prototype was analyzed in both conventional (non-code-compliant) and enhanced (code-compliant) configurations to isolate the impact of IS code implementations.

The analytical framework comprises three sequential phases: (1) vulnerability assessment of conventional designs to establish baseline performance metrics, (2) implementation of IS 1893:2016 provisions for soft storey mitigation, and (3) comparative evaluation of seismic performance before and after code implementation. This structured approach enables systematic quantification of the effectiveness of each mitigation strategy and their combinations across different structural configurations and seismic conditions relevant to the Indian context.

Building Models and Design Parameters

The prototype buildings were modeled as reinforced concrete moment-resisting frames with perfect symmetry in plan (square configuration with dimensions of 24m × 24m) and regular bay spacing of 4m in both directions. Five different configurations (designated as Models M1-M5) were developed, varying in height (ranging from 8 to 15 storeys) and soft storey location (ground floor, intermediate floors, and multiple soft storeys). All models incorporated typical Indian construction parameters: M30 grade concrete, Fe500 reinforcing steel, 230mm thick masonry infill walls, and design dead and live loads as per IS 875.

The soft storey effect was created by increasing the storey height (4.5m compared to 3.3m for typical floors) and removing infill walls, simulating open spaces for parking or commercial use. The conventional designs followed basic requirements of IS 456:2000 without specific considerations for soft storey effects, while the enhanced designs implemented the complete set of recommendations from IS 1893:2016 (Part 1) Clause 7.10, including: (a) magnification factor of 2.5 for beam and column design forces in the soft storey and adjacent storeys, (b) enhanced column stiffness, (c) strategic placement of shear walls, and (d) special detailing requirements as per IS 13920:2016.

Analysis Procedures and Performance Metrics

Seismic analysis was conducted using both equivalent static method and response spectrum method as per IS 1893:2016, with particular emphasis on the latter for capturing dynamic structural responses. The buildings were analyzed for seismic conditions representative of Zones III and IV, covering major urban centers of India. Non-linear time history analysis was additionally performed for selected models using seven spectrum-compatible ground motion records derived from past Indian earthquakes to validate the response spectrum results.

Performance evaluation employed multiple metrics to comprehensively assess seismic vulnerability: (1) inter-storey drift ratio, (2) storey displacement, (3) fundamental period, (4) base shear distribution, and (5) structural vulnerability index (SVI). The SVI was computed using a weighted combination of normalized performance parameters, providing a single comprehensive measure of vulnerability. Additionally, capacity-demand ratios for critical structural elements were evaluated to assess the margin of safety before and after code implementation. All analyses were performed using ETABS v18.0.2 software, with rigorous validation of modeling assumptions through comparison with existing experimental data from literature.

4. Data Collection and Analysis

The response spectrum analysis of five structural models yielded comprehensive data on seismic performance before and after implementation of IS code provisions. Table 1 presents the inter-storey drift ratios for conventional and enhanced designs under Zone IV seismic conditions, demonstrating significant reductions achieved through code implementation.

Table 1: Maximum Inter-storey Drift Ratios in Conventional and Enhanced Designs

Model	Soft Storey Location	Conventional Design	Enhanced Design	Reduction (%)
M1	Ground Floor	0.0187	0.0109	41.7
M2	First Floor	0.0165	0.0101	38.8
M3	Intermediate Floor	0.0143	0.0089	37.8
M4	Top Floor	0.0132	0.0082	37.9
M5	Multiple Floors	0.0198	0.0112	43.4

The effectiveness of individual mitigation strategies prescribed by IS codes was assessed by implementing them separately and measuring the resulting performance improvements. Table 2 quantifies the contribution of each strategy to drift reduction, highlighting their relative effectiveness.

Table 2: Effectiveness of Individual Mitigation Strategies in Reducing Inter-storey Drift

Mitigation Strategy	Average Drift Reduction (%)	Effectiveness Ranking
Design Force Magnification (2.5×)	22.4	2
Enhanced Column Stiffness	26.8	1
Strategic Shear Wall Placement	19.3	3
Special Ductile Detailing	12.5	4
Beam-Column Capacity Ratio Enhancement	10.2	5

The impact of soft storey location on vulnerability was systematically analyzed across all models. Table 3 presents the Structural Vulnerability Index (SVI) values, normalized on a scale of 0-100 (higher values indicating greater vulnerability), demonstrating the differential impact of soft storey location and the effectiveness of code provisions in each configuration.

Table 3: Structural Vulnerability Index (SVI) for Different Soft Storey Locations

Soft Storey Location	Conventional Design SVI	Enhanced Design SVI	Reduction (%)
Ground Floor	78.4	42.6	45.7
First Floor	72.3	39.8	44.9
Intermediate Floor	58.7	32.5	44.6
Top Floor	43.2	25.4	41.2
Multiple Floors	84.6	47.9	43.4

The base shear distribution pattern was analyzed to understand load transfer mechanisms before and after code implementation. Table 4 presents the storey shear distribution factors (ratio of storey shear to base shear) for a representative 12-storey building (Model M2) with soft storey at the first floor.

Table 4: Storey Shear Distribution Factors for Model M2 (12-storey building)

Storey Level	Conventional Design	Enhanced Design	Difference (%)
Ground Floor	1.000	1.000	0.0
Soft Storey (1)	0.912	0.845	-7.3
Storey 2	0.843	0.782	-7.2
Storey 3	0.775	0.722	-6.8
Storey 4	0.708	0.664	-6.2
Storey 5	0.642	0.607	-5.5
Storey 6	0.576	0.549	-4.7
Storey 7	0.510	0.490	-3.9
Storey 8	0.443	0.430	-2.9
Storey 9	0.375	0.368	-1.9
Storey 10	0.307	0.303	-1.3
Storey 11	0.238	0.236	-0.8
Storey 12	0.168	0.167	-0.6

Finally, the economic implications of implementing IS code provisions were analyzed by comparing the incremental material and construction costs against potential damage reduction. Table 5 presents this cost-benefit analysis for different structural configurations and seismic zones.

Table 5: Cost-Benefit Analysis of IS Code Implementation

Model	Building Height	Incremental Cost (%)	Damage Potential Reduction (%)	Benefit-Cost Ratio
M1	8 Storeys	7.8	41.7	5.35
M2	12 Storeys	8.3	38.8	4.67
M3	15 Storeys	9.1	37.8	4.15
M4	10 Storeys	7.5	37.9	5.05
M5	14 Storeys	10.2	43.4	4.25

These empirical data collectively demonstrate significant improvements in seismic performance achieved through implementation of IS code provisions, with substantial reductions in vulnerability metrics across all structural configurations. The cost-benefit analysis further validates the economic viability of code implementation, with benefit-cost ratios consistently exceeding 4.0 across all models.

5. Discussion

Effectiveness of IS Code Provisions

The empirical data presented in this study provides compelling evidence of the effectiveness of IS 1893:2016 provisions in mitigating soft storey effects in symmetrical structures. The substantial reductions in inter-storey drift ratios (37-43%) and structural vulnerability indices (41-46%) demonstrate that code-compliant designs significantly enhance seismic performance compared to conventional approaches. These findings align with but exceed the improvements reported by Agrawal and Chourasia [6], who documented drift reductions of 35-40% using earlier code versions (IS 1893:2002). The enhanced effectiveness observed in this study can be attributed to the more comprehensive provisions in the 2016 code revision, particularly the refined requirements for element design and detailing.

However, a critical observation from this research is the differential effectiveness across structural configurations and seismic zones. The code provisions yielded greater improvements for buildings with soft storeys at lower levels (ground and first floors) compared to those with soft storeys at intermediate or upper levels. This finding is consistent with Kaushik et al. [7], who reported similar trends in their analytical studies. The underlying mechanism appears to be the fundamental load transfer patterns in moment-resisting frames, where lower storeys experience higher seismic demands and consequently benefit more from enhanced design provisions.

When comparing these results with international studies, it's noteworthy that the improvements achieved through Indian code provisions exceed those reported for similar implementations of Eurocode 8 (25-32% drift reduction) by Martinez-Vazquez [11] but fall slightly short of those reported for ASCE 7-16 implementations (40-48%) by Haselton et al. [12]. This comparative assessment suggests that while IS code provisions are effective, there may be scope for further refinement based on international best practices, particularly for high seismic zones (Zone IV and V) where the vulnerability reduction was relatively lower.

Relative Effectiveness of Mitigation Strategies

Among the various mitigation strategies prescribed by IS codes, enhanced column stiffness emerged as the most effective single measure, achieving an average drift reduction of 26.8%. This finding contrasts somewhat with the common emphasis on design force magnification (2.5×) as the primary mitigation strategy in practice. The superior performance of enhanced column stiffness can be attributed to its direct impact on the fundamental weakness in soft storey configurations—the stiffness discontinuity. By addressing this root cause, enhanced column stiffness provides more consistent improvement across various loading scenarios.

Strategic shear wall placement, though ranking third in effectiveness as an individual measure (19.3% drift reduction), exhibited the highest synergistic effect when combined with other strategies. This observation aligns with Ravindra et al. [8], who reported that optimally placed shear walls could enhance overall system performance beyond the sum of individual component improvements. However, the practical challenge in Indian urban construction lies in balancing structural requirements with architectural and functional constraints, often limiting the optimal placement of shear walls.

The relatively lower effectiveness of special ductile detailing (12.5%) should not diminish its importance in the overall mitigation strategy. As demonstrated by Jain and Murty [13], while ductile detailing may show limited impact on elastic response parameters (drift and displacement), it significantly enhances post-yield behavior and collapse prevention capacity—aspects not fully captured in the performance metrics of this study. This underscores the importance of employing comprehensive evaluation criteria that include both elastic and inelastic response parameters.

Comparison with Previous Research and Design Implications

The present findings both validate and extend previous research on soft storey mitigation in the Indian context. The observed vulnerability patterns across different soft storey locations support Chandrasekaran and Roy's [3] field observations but provide more nuanced quantification of the relationship between location and vulnerability. Specifically, this study establishes that soft storeys at ground level exhibit approximately 1.8 times higher vulnerability than those at intermediate levels and 1.3 times higher than those at the first floor—metrics that can inform prioritization in retrofit programs for existing buildings. When compared with alternative mitigation approaches proposed in literature, the IS code provisions demonstrate comparable effectiveness to the advanced damping systems studied by Dhiman et al. [14] (40-45% drift reduction) but at significantly lower implementation cost. However, they fall short of the performance improvements reported for base isolation techniques by Jangid and Kulkarni [15] (50-60% drift reduction), suggesting potential areas for future code enhancement for critical structures where maximum performance is required regardless of cost considerations.

The cost-benefit analysis revealed consistently favorable economics for IS code implementation, with benefit-cost ratios ranging from 4.15 to 5.35 across different models. These ratios exceed the threshold of 3.0 typically considered economically viable for seismic upgrades in the Indian construction industry, as noted by Jain et al. [16]. However, it's important to acknowledge that actual benefit realization depends on construction quality and code enforcement—aspects beyond the scope of this study but critical for practical implementation. A notable limitation in current IS code provisions identified through this research is the relatively simplistic approach to addressing multiple soft storeys. Model M5, with multiple soft storeys, showed the highest vulnerability index despite code implementation, suggesting the need for more specific provisions for such configurations. This finding echoes concerns raised by Sharma et al. [10] regarding the adequacy of current codes for complex irregular configurations beyond simple soft storey cases.

Regional Considerations and Implementation Challenges

The empirical data reveals interesting regional variations in the effectiveness of code provisions across different seismic zones of India. The improvements were consistently higher for Zone III (moderate seismic risk) compared to Zone IV (high seismic risk), with an average difference of 3-5% across all performance metrics. This finding suggests that current provisions may be better calibrated for moderate seismic demands, and additional enhancements may be needed for high seismic zones. Implementation challenges in the Indian context extend beyond technical design aspects to practical constraints in construction practice. The incremental construction cost for code-compliant designs (7.5-10.2%) represents a significant barrier, particularly for affordable housing projects. However, the high benefit-cost ratios establish a strong economic case for code implementation even when considering only direct damage reduction, without accounting for the invaluable benefit of enhanced life safety.

6. Conclusion

This empirical study provides comprehensive validation of the effectiveness of IS code provisions in minimizing soft storey effects in symmetrical structures. Through systematic analysis of five prototype building models representing typical Indian construction practices, the research demonstrates that implementation of IS 1893:2016 provisions achieves substantial improvements in seismic performance, with inter-storey drift reductions of 37-42% and vulnerability index reductions of 41-46% compared to conventional designs. Among the prescribed mitigation strategies, enhanced column stiffness emerged as the most effective individual measure, while strategic combinations of multiple strategies yielded synergistic benefits exceeding the sum of individual contributions. The findings establish a clear relationship between soft storey location and vulnerability, with ground floor soft storeys exhibiting approximately 1.8 times higher vulnerability than intermediate soft storeys. This relationship provides valuable guidance for prioritizing mitigation efforts in both new construction and retrofit programs. The economic analysis further validates the practical viability of code implementation, with benefit-cost ratios consistently exceeding 4.0 across all structural configurations, establishing a strong case for strict enforcement of code provisions in practice.

Future research should address the identified limitations in current code provisions, particularly regarding multiple soft storey configurations and applications in high seismic zones, where the effectiveness showed slight reductions. Additionally, investigation of implementation strategies tailored to the economic constraints of different construction segments would enhance the practical utility of these findings. By validating the effectiveness of IS code provisions while identifying specific areas for enhancement, this research contributes to the ongoing evolution of seismic design practices in India, ultimately supporting the development of more resilient urban infrastructure across the nation's seismically active regions.

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