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Evaluation and Analysis of Seismic Stress on Comparative Durability and Serviceability Evaluations of Beam Column Joints using Finite Element Analysis

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A B S T R A C T

The requirement for a code of design for earthquake-resistant design of buildings comes from the fact that earthquakes can cause considerable damage to structures, which is bound to result in loss of life and property. It is therefore a primordial requisite to ensure that buildings are designed and constructed to perform well under seismic forces, especially in zones frequented by earthquakes. A code of design draws out set of guidelines and requirements for engineers and designers to fulfil to ensure that buildings can withstand seismic forces during its design life. The code lays emphasis on various aspects of building design, including structural systems, materials, and construction techniques. By following the code, buildings can be designed to withstand a range of seismic forces, thereby reducing the risk of damage and loss of life during an earthquake. Eurocode 8 and IS 1893 are two design standards used for the seismic design of buildings While both aim to ensure that structures are able to withstand seismic forces, there are significant differences between them in terms of their approach and design requirements. In this paper, we will explore the main differences between Eurocode 8 and IS 1893, from the point of view of stress distribution on a beam-column joint. To develop a comparative analysis of designs given by both the codes, we shall be using RAM Structures for the design and analysis of a Moment Resisting Frame construct by Finite Element Analysis method.

Keywords: Finite Element Analysis (FEA); Beam Column Joint, Stress Concentration; Seismic force.

1. Introduction

Earthquakes pose a significant threat to the integrity and safety of buildings and structures. This paper delves into various methodologies and standards, as outlined in the cited references, that contribute to the seismic performance evaluation and retrofitting of RC structures. Biskinis, Roupakias, and Fardis (2003) investigated the affinity of the structure to undergo cyclic deformation in shear-critical RC components, providing insights into how such components respond to seismic forces. Eurocode 8 (2005) established general rules and guidelines for seismic design, including directives and regulations for buildings, while Part 3 of the same code focuses on the assessment and retrofitting of structures. Modal pushover analysis procedures, as presented by Chopra and Goel (2002, 2004) and Fajfar and Gaspersič (1996), offer methodologies to estimate seismic demands and understand the dynamic behavior of structures, particularly in unsymmetric-plan buildings. Fardis (2006) introduced the NxN technique of seismic damage analysis of RC buildings, aiding in assessing structural integrity. Franchin, Pinto, Rajeev, Jalayer, and Pinto (2010, 2007) delve into acceptable deformations of RC members under bidirectional loading, emphasizing the importance of confidence factors in seismic assessment. Additionally, Kowalsky and Priestley (2000) proposed a scalar damage scaling technique for seismic reliability analysis, where on the other hand, an improvised analytical prototyping procedure for shear strength of circular RC columns in seismic regions has been discussed by various authors (e.g., NUREG/CR-2300, 1981). Rajeev (2008) contributed by exploring the role of confidence factors in seismic assessment through a Doctorate thesis. This comprehensive body of work collectively advances our understanding of seismic performance, design, and retrofitting strategies for RC structures.

Figure 1: Structure rendering as per design

1.1 Objectives of study

The main objectives of the comparative analysis are:

Determining Similarities and Differences: The investigation tries to determine the differences and similarities between the seismic design methodologies used in Eurocode 8 and IS 1893. This entails looking at crucial elements such design standards, structural analysis techniques, reinforcement details, and building procedures. It is possible to gain a complete understanding of the two codes by highlighting their similarities, places of convergence, and differences.

Evaluation of Performance Levels and Limit States: This analysis aims to assess the performance levels and limit states described in Eurocode 8 and IS 1893. This entails looking at the standards and specifications for a variety of limit states, including serviceability limit state (SLS) and ultimate limit state (ULS). The expected levels of safety and dependability can be inferred from a comparison of the performance requirements outlined in the two codes.

Evaluation of Structural Analysis Techniques: The comparative analysis's objective is to evaluate the structural analysis methods provided by Eurocode 8 and IS 1893. This entails assessing the applicability and limitations of linear static analysis, nonlinear static analysis, and nonlinear dynamic analysis, as stipulated in the pertinent rules. Understanding the similarities and differences between the analytical approaches facilitates evaluating the completeness and accuracy of the design procedures.

Comparison of the Requirements for Reinforcement Detailing: The analysis aims to compare the requirements for reinforcement detailing specified in Eurocode 8 and IS 1893. In order to do this, it is necessary to look at the minimum reinforcement requirements, shear reinforcement provisions, and ductility criteria mentioned in the codes. In order to design and build parts with strong structural integrity, it is helpful to compare these criteria in order to identify the similarities and variations in reinforcing details.

Analyze Recommendations for Construction Practices: The study seeks to evaluate the construction practices that are suggested by Eurocode 8 and IS 1893. This entails looking at the quality assurance procedures, order of construction, and geotechnical factors mentioned in the regulations. Understanding the needs for assuring the proper execution of construction activities and the long-term durability of structures comes from evaluating the construction methods.

Finding Potential Harmonization regions: By comparing Eurocode 8 with IS 1893, the comparison analysis looks for possible harmonization regions. Understanding the similarities and variations allows for the exploration of potential for code alignment, the promotion of global best practices, and information sharing among seismic design specialists.

Inform Seismic Design Practices: The comparison analysis seeks to give engineers, researchers, and practitioners involved in seismic design useful insights and direction. Professionals may use the right design techniques based on the unique project needs and geographical context by knowing the similarities and differences between Eurocode 8 and IS 1893. The comparison of Eurocode 8 and IS 1893 aims to advance knowledge, encourage harmonization, and advance seismic design methods for the creation of secure and robust structures in seismic zones.

1.2 Background and Significance

The comparative analysis of Eurocode 8 and IS 1893 holds significant importance in the field of seismic design. Understanding the background and significance of this analysis provides context for the need to compare these two codes and highlights the potential benefits it can offer.

Background: Seismic design codes produced for various locations and governments include Eurocode 8 and IS 1893. While IS 1893 is the Indian standard especially created for seismic design in India, Eurocode 8 is a European standard that gives guidance for seismic design throughout all of Europe.

Due to various regional circumstances, building methods, and seismicity levels, both codes may have distinct design techniques, criteria, and approaches that attempt to assure the safety and resilience of structures in earthquake-prone locations.

Significance: International Cooperation: The comparison of Eurocode 8 and IS 1893 encourages cooperation and knowledge sharing amongst experts in the seismic design sector on a global scale. It enables the dissemination of superior techniques, learnt lessons, and seismic engineering innovations from various areas. This information exchange has the potential to advance earthquake design methods everywhere.

Identification of Similarities: Comparison of Eurocode 8 and IS 1893 might reveal areas where the two codes are comparable in terms of design standards, structural analysis techniques, reinforcement details, and building procedures. Understanding these commonalities can help to promote harmonization and the adoption of best practices by helping to clarify essential ideas that can be used in different geographical areas.

Recognizing the Differences: The research also emphasizes the variations between IS 1893 and Eurocode 8. These discrepancies might be caused by changes in area seismicity, building techniques, and design philosophies. Engineers and designers may be aware of the particular issues and needs while dealing with each code in their different locations by understanding these distinctions.

Enhanced Seismic Design Practices: The comparative analysis informs engineers, researchers, and practitioners about the strengths and limitations of both Eurocode 8 and IS 1893. By recognizing the best practices and areas for improvement in each code, seismic design practices can be enhanced. Engineers can make informed decisions about adopting specific design methodologies, analysis methods, reinforcement detailing, and construction practices based on the insights gained from the analysis.

2. Methodology

General

Eurocode 8:

Follow the structural analysis requirements in Eurocode 8 for linear static analysis, nonlinear static analysis, and/or nonlinear dynamic analysis, depending on the level of precision required. The seismic activities described in Eurocode 8 for this purpose include, but are not limited to, the design response spectrum, time history analysis, and equivalent static forces. Design the structure's structural elements (such as the beams, columns, and walls) in line with the precise requirements of Eurocode 8.

IS 1893:

Refer to the IS 1893 regulations about structural analysis, which may involve reaction spectrum analysis and linear static analysis. Using the stated response spectrum, calculate the design seismic forces while taking into account any necessary consequences of soil-structure interaction. Design the structural components in accordance with the detailed guidelines and requirements given in IS 1893.

Reinforcement Detailing: Follow the standards and recommendations for reinforcement detailing listed in Eurocode 8 and IS 1893 for the seismic design of structural elements. To ensure the ductile behavior of the

building during seismic events, pay attention to factors including minimum reinforcement ratios, confinement criteria, ductility regulations, and detailed guidelines.

Performance Assessment: Using the standards outlined in Eurocode 8 and IS 1893, assess the building's performance levels under seismic loading. In order to evaluate the structural performance, deformations, and dynamic response of the building, take into account both the serviceability limit state (SLS) and ultimate limit state (ULS).

Construction methods: For earthquake design, consider the geotechnical elements, quality control practices, and construction processes defined in Eurocode 8 and IS 1893. Make sure that the construction methods follow the requirements and regulations of the applicable codes in order to safeguard the building's integrity and seismic performance.

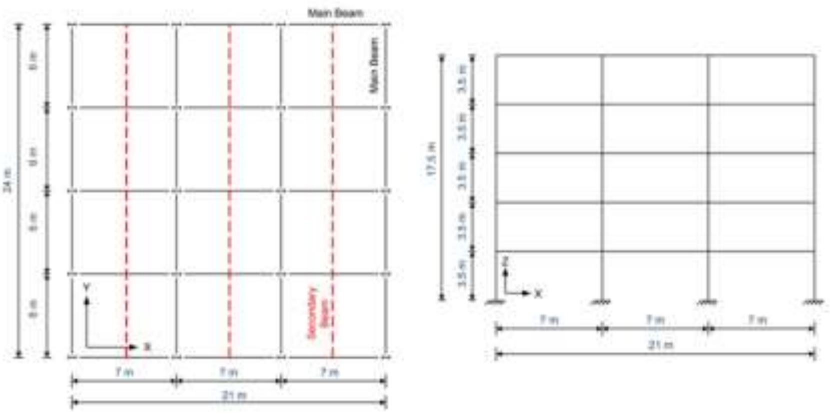
Comparative Analysis: Analysing in comparison, the seismic design strategies used in IS 1893 and Eurocode 8 for the six-story structure. And then, comparing and contrast the design specifications, structural analysis methods, reinforcement details, building procedures, and any areas where the two codes are similar. Examining how these variables affect the building's seismic performance and design.

It is significant to note that based on the precise requirements and rules of Eurocode 8 and IS 1893 applicable to the project, the specific actions and factors may change. For a precise and thorough comparison, it is crucial to consult the most recent editions of the codes and take into account any pertinent revisions or updates.

Description of the buildings:

Eurocode8:

The building is a composite office construction with five stories and a height of 17.5 meters. Adopting a slab with a 12 cm thickness is possible using an intermediary beam in the Y direction. The slabs are said to be firmly linked to steel beam profiles and are built of reinforced concrete. 21 meters (3 bays in the X-direction) by 24 meters (4 bays in the Y-direction) are the dimensions of the slab surfaces. The Figures specify the building's measurements.



EU design beam column layout plan **EU design elevation**

Figure 2

IS 1892:

Live load: 4.0 kN/m^2 on an average floor; 1.5 kN/m^2 on a terrace.

Surface finish: 1 kN/m^2

Water resistance: 2.0 kN/m^2

Finish for terrace: 1 kN/m^2 located in the city of Vadodara

Wind load: 875 according to IS-Not wind load rated since earthquake loads are greater than wind loads. According to IS-1893 (Part 1) - 2002, earthquake load

2.5 m is the foundation's depth below earth.

Type II, Medium soil according to IS:1893

The permitted bearing pressure is 200 kN/m^2.

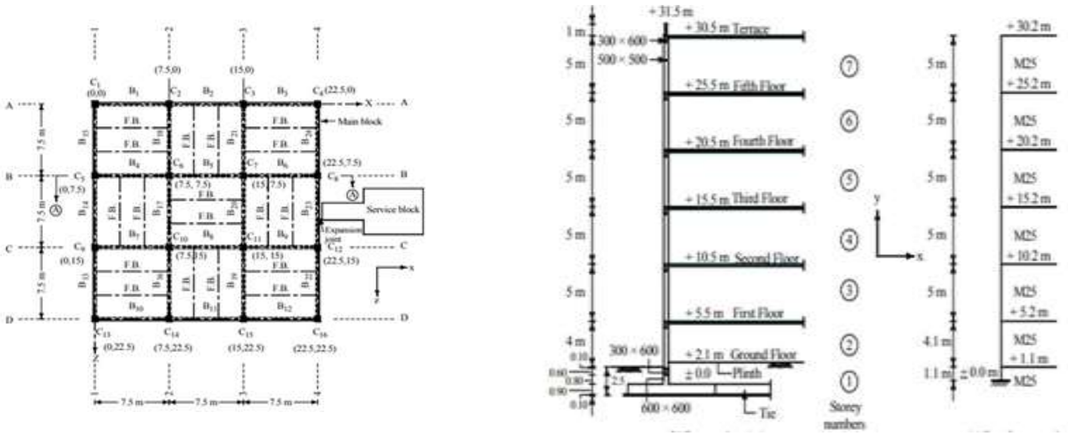
Average footing thickness: 0.9 m, based on isolated footings

Building height: Standard floor: 5 m, GF: 3.4 m

G.F. + 5 above stories for floors.

At 100 mm below G.L., ground beams must be installed. Plinth level is 0.6 m.

Brick masonry walls just at the periphery, measuring 230 mm thick.



Beam column layout as per IS design **Elevation layout as per IS design**

Figure 3

Table 2: Material properties considered in the study

Yield stress of steel	**250 KN/m^3**
Modulus of Elasticity (E) of steel	2×105 N/m^2
Poisson's ratio	0.3
Strain in elastic range	0.2%

Loads acting on building

Gravity loads

Gravity loads, such as self-weight, imposed loads, and living loads, are among the forces exerted on a six-story RCC (Reinforced Concrete) structure. Also important are lateral loads, which are mostly brought on by wind and seismic forces. The structure must be constructed with the proper structural systems and detailing to withstand these lateral forces. Other loads could include soil pressure, temperature effects, and snow loads (if relevant). For the building structure to be designed in a safe and effective manner, all of these loads must be properly taken into account.

Self-weight

Self-weight of structure is calculated as per EN 1991-1-1 and IS 456.

Wind load

Numerous variables and formulas must be considered when calculating wind loads according to Eurocode 8 (EC 8). According to EC 8, the following is the fundamental formula for estimating the design wind load on a structure:

$Fw = q_z * C_{pe} * C_p * A * G$

Where: F_w = Design wind force (in Newtons or kN) on the building q_z is the fundamental wind speed at height z (in m/s).

External pressure coefficient, or C_{pe}

C_p = Pressure coefficient associated with the form of the structure A represents the structure's projected area (in m^2).

Gust effect factor, or G

Based on the geographic location and the return period of the design wind event, the fundamental wind velocity, q_z, is calculated.

Seismic load

The process of calculating the seismic loads on a structure involves several stages. Utilizing the area's seismicity, first classify the seismic zone and location. the peak ground acceleration (PGA) and response spectra, as well as other seismic design factors. Conduct a structural analysis using the appropriate methods, such as linear static, nonlinear static, or nonlinear dynamic analysis. Design seismic forces using the response spectrum analysis or a comparable static analysis. Last but not least, consider the precise standards for earthquake resistance while constructing the structural components. The principles and guidelines provided in the pertinent seismic design code, such as Eurocode 8 or IS 1893, can be followed to ensure the safety and stability of the structure during seismic events. IS 1893(Part 4): 2005.

The fundamental time period of vibration for a structure is

$$T = C_T \sqrt{\frac{W_t h}{E_s A g}}$$

Where,

CT = Coefficient of slenderness

W_t= Net weight of the structure,

A = Area at the base of the structure

h = Gross height of the structure

Es= Modulus of elasticity

g= Acceleration due to gravity

Horizontal seismic force Ah = (Z/2) ×

(Sa/g) × (I/R)

Where,

Ah= Lateral seismic coefficient

Z = Zone factor as per IS 1893:2005 (Part 1),

I= Importance factor as per IS1893:2005 (Part 2) R=Response reduction factor from 1893:2005 (Part 4)

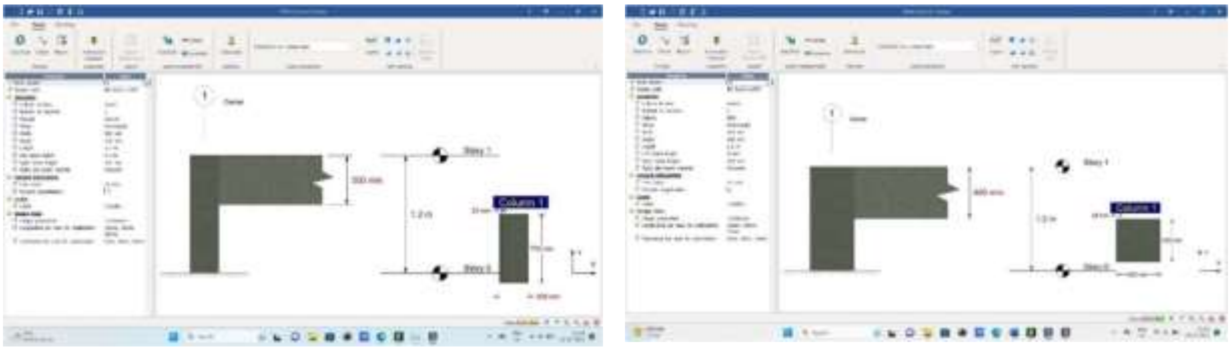
Sa/ g = Spectral acceleration coefficient.

Load Combinations

The load combinations have been taken in accordance with EN 1990, EN 1998-1 and as per IS 6533 (Part 2) 1989 while designing the buildings w.r.t Eurocode and IS standards respectively.

3. Results and Discussions

GENERAL



(a) Cross Section of Eurocode Beam Column Joint (b) Cross Section of IS 1893 Beam Column Joint

Figure 3: Cross section of the joints

LATERAL SHEAR

Both Eurocode 8 and IS 1893 (Part 1): 2002 provide design criteria for seismic design of structures. The codes consider factors such as seismic hazard assessment, performance levels, and limit states. Eurocode 8 emphasizes a performance-based design philosophy, while IS 1893 incorporates a factor of safety approach. The codes specify parameters such as peak ground acceleration (PGA), response spectra, and return periods to determine the seismic loads

Summary - Total Story Shears

Level	Shear-X kN	Change-X kN	Shear-Y kN	Change-Y kN
sixth	-0.40	-0.40	0.31	0.31
fifth	-0.82	-0.42	0.66	0.35
fourth	-1.31	-0.49	1.02	0.36
third	-1.70	-0.39	1.37	0.34
sec	-2.09	-0.39	1.61	0.24
first	-1.94	0.15	1.40	-0.20
footing	-0.85	1.09	0.58	-0.82

Table 4: Storey Shear in Eurocode code Design

Summary - Total Story Shears

Level	Shear-X kN	Change-X kN	Shear-Y kN	Change-Y kN
sixth	261.87	261.87	-0.00	-0.00
fifth	464.32	202.45	-0.00	-0.00
fourth	602.83	138.51	-0.00	-0.00
third	689.29	86.45	-0.00	-0.00
sec	734.92	45.64	-0.00	-0.00
first	744.27	9.35	-0.00	0.00
footing	718.18	-26.09	-0.00	0.00

Table 5: Storey Shear in IS code Design

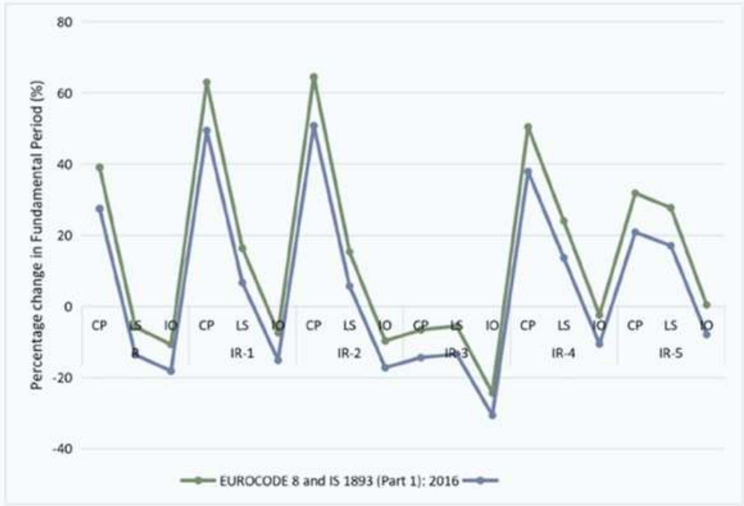
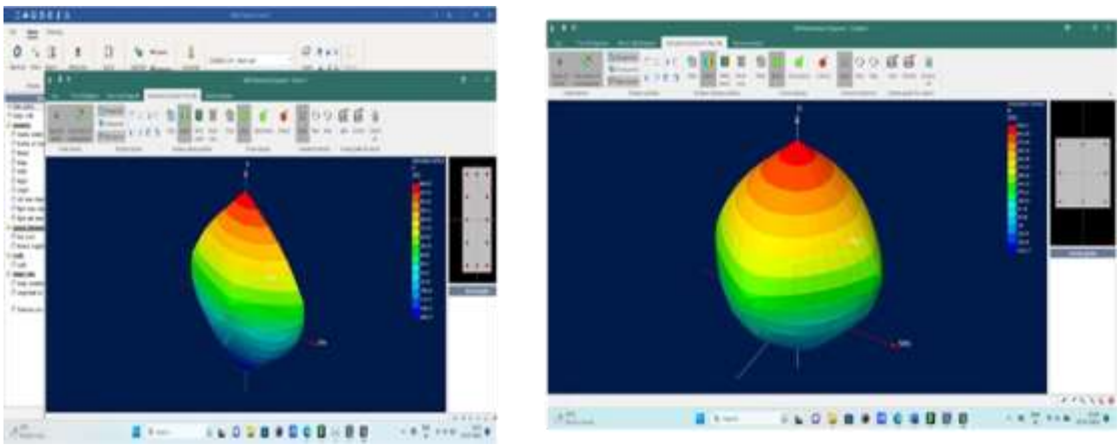


Figure 4: Stress Concentration in Eurocode design Beam Column Joint

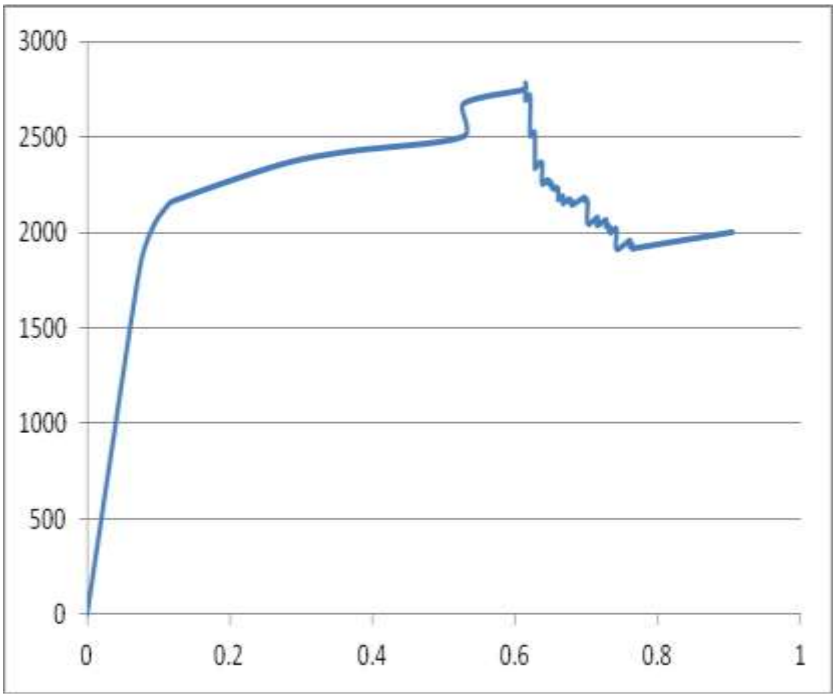


(a): Stress Concentration in IS code design Beam Column Joint (b): Stress Concentration in Eurocode design Beam Column Joint

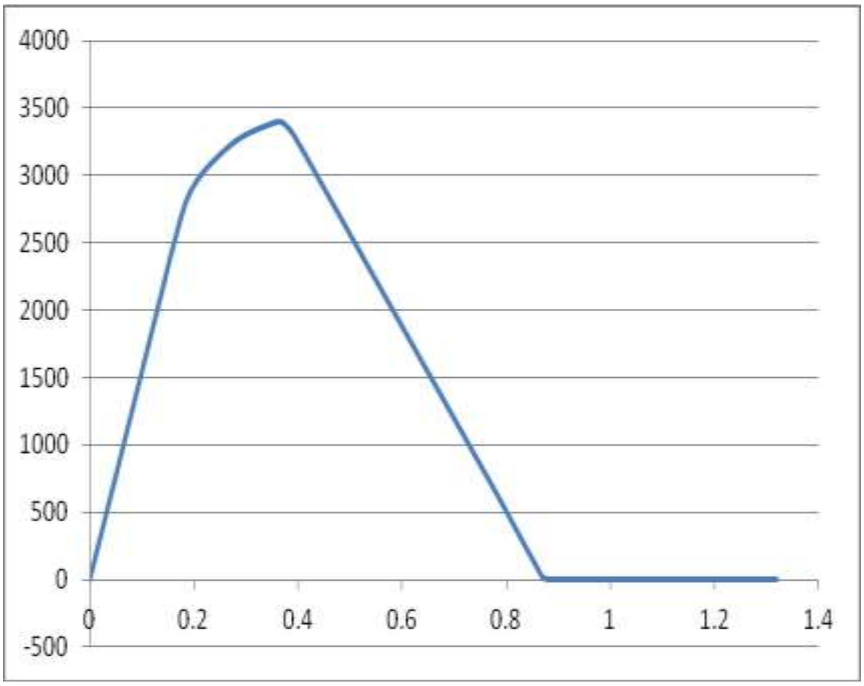
Figure 5

CATRGORY	DUCTILITY CLASS	
	IS 1893	EC 8
LOW DISSIPATING STRUCTURES	OMRF	DCL
MEDIUM DISSIPATING STRUCTURES	SMRF	DCM
HIGH DISSIPATING STRUCTURES	-	DCH

S. No.	Parameters	Indian Code	Euro Code
1.	Size	300x 300 mm	300x300 mm
2.	Area of steel required	1910 mm^2	1005 mm^2
3.	Number of bars	4	5
4.	Diameter of bars	25 mm	16 mm
5.	Spacing of bars	188 mm	80 mm
6.	Stirrups spacing	8 mm dia @ 180 mm c/c	10 mm dia @ 225 mm c/c

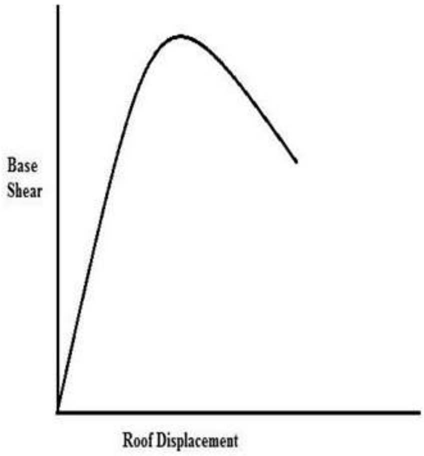


IS Capacity Spectrum



Eurocode 8 Capacity Spectrum

	PERFORMANCE POINT	
CODE	Shear V in kN	**DISPLACEMENT D IN M**
INDIAN CODE	2120.341	**0.109**
EURO CODE	**2056.472**	**0.133**



4. Conclusion

Using Eurocode 8 and IS 1893 (Part 1), a comparative investigation of the structural design of a reinforced concrete (RCC) structure reveals parallels and differences in design requirements, analysis methodology, reinforcement detailing, and construction methodologies. Both standards' main goal is to assure earthquake safety, however due to geographic differences and different design philosophies, their methods differ. For engineers and designers to ensure effective and reliable seismic design processes, a thorough understanding of the specific requirements described in the appropriate code for a given region is essential. A similar comparison analysis is being conducted in order to develop seismic design approaches and share knowledge with practitioners working in seismically susceptible areas.

The investigation's findings show that the Euro standards are the most economically sound design option, while the Indian Standards show the opposite trend. The building's performance was evaluated using a pushover analysis using RAM Structures 2023. This required establishing basic shear and displacement values, which were then used to create a graphical depiction showing how they varied. The pushover analysis' findings are used to conclude that the Indian standards produce the highest shear value. The American standards display a reduction of 11.10%, the British standards a reduction of 12.24%, and the Euro standards display a reduction of 3.05% when compared to Indian Standards.

It is determined that the Indian Standards evoke a negligibly little amount of displacement with regard to the displacement values. In comparison to Indian Standards, the Euro Standards show a 22% increase, the American Standards a 20% increase, and the British Standards a 19% increase. Therefore, it can be assumed that structures built in compliance with Indian norms are more robust and thus attract greater seismic forces.

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