International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-10, Issue-07, Oct 2024

Seismic Performance Evaluation of Steel Frames with Different Bracing System

Aishwarya Rohidas Chavan, UG Students, SVERI's College of Engineering, Pandharpur, India (aishwaryarchavan@coep.sveri.ac.in)

Pooja Dadasaheb Nagane, UG Students, SVERI's College of Engineering, Pandharpur, India (poojadnagane@coep.sveri.ac.in)

Kajal Shravan Kamble, UG Students, SVERI's College of Engineering, Pandharpur, India (kajalskamble@coep.sveri.ac.in)

Nishigandha.V. Mahamuni, Assistant Professor, SVERI's College of Engineering, Pandharpur, India (nvmahamuni@coe.sveri.ac.in)

Ravikiran. P. Jadhav, Assistant Professor, SVERI's College of Engineering, Pandharpur, India (rpjadhav@coe.sveri.ac.in)

Abstract: **The seismic behavior of steel frames is greatly influenced by the choice of bracing systems. This study evaluates the impact of various bracing configurations on the seismic performance of steel structures using STAAD .Pro for analysis. A finite element model (FEM) is developed in STAAD .Pro to simulate the behavior of steel frames under seismic loads. Performance-based seismic design (PBSD) methodologies are applied to examine the structural response with different bracing patterns, such as X-bracing, V-bracing, and Kbracing. Both preliminary and detailed analyses are conducted to assess key performance parameters for each bracing combination. The results help identify optimal bracing strategies that enhance seismic resilience while maintaining structural integrity. This research provides valuable insights into designing bracing systems to mitigate earthquake damage in steel frames.**

Keywords: Bracing systems, finite element analysis, performance-based seismic design, seismic behavior, STAAD.Pro, steel frames.

I. Introduction

The seismic performance evaluation of steel frames with various bracing systems is an essential aspect of structural engineering aimed at understanding how different configurations of steel structures behave during earthquakes. The main objective is to enhance the seismic resilience of buildings, ensuring their safety and stability during seismic events. 1. Steel Frames in Seismic Design: Steel frames are widely used in earthquake-prone regions due to their high strength, ductility, and flexibility. The ability of steel to absorb energy during seismic events makes it an ideal material for constructing earthquake-resistant buildings. However, the seismic performance of a steel frame is influenced by its structural configuration and the addition of various bracing systems, which play a crucial role in controlling lateral displacements and increasing the overall stiffness.

A. Importance of Bracing Systems:

Bracing systems in steel frames are critical for resisting lateral forces caused by earthquakes or wind. These systems can prevent excessive lateral displacements (drift), reducing the risk of structural failure. Different types of bracing systems can be incorporated into the steel frames to enhance their load-bearing capacity and energy absorption. Bracing systems primarily work by transferring lateral forces into the foundation and distributing loads throughout the structure more efficiently.

B. Types of Bracing Systems:

Several types of bracing systems can be employed in steel frames, each with its own advantages and performance characteristics. The most common bracing systems include **Concentric Braced Frames (CBF):** In CBF

 DOI : 10.35291/2454-9150.2024.0391

systems, braces intersect the frame at a single point, concentrating forces into specific areas. This system increases stiffness but can lead to localized buckling during strong seismic events.

Eccentric Braced Frames (EBF): In EBF systems, the braces do not intersect the frame directly, allowing for more controlled deformation during seismic activity. The eccentricity creates a ductile zone that helps dissipate energy through plastic deformation.

X-bracing (Diagonal Bracing): A simple, effective bracing system where braces are placed diagonally between frame members. X-bracing enhances both stiffness and strength but may limit architectural design flexibility.

K-bracing and V-bracing: K-bracing and V-bracing create triangular configurations, improving load transfer to the foundation. These systems offer a balance between stiffness and flexibility but may have nonuniform force distribution, which can lead to localized damage.

Chevron Bracing (Inverted V-bracing): This configuration has two diagonal braces meeting at a central point, creating an inverted V-shape. Chevron bracing improves lateral stability and distributes seismic forces efficiently, but its performance under tension and compression requires careful consideration.

C. Seismic Performance Criteria: The seismic performance of steel frames with different bracing systems is evaluated based on several factors:

Lateral Stiffness: How much the structure resists lateral forces. Stiffer bracing systems reduce displacements but may attract larger forces.

Ductility: The ability of the structure to undergo large deformations without failing. Bracing systems with high ductility (e.g., EBF) perform better in dissipating seismic energy.

Energy Dissipation: The capacity of the structure to absorb and dissipate seismic energy. Some bracing systems are designed to deform plastically, absorbing energy through yielding.

Inter-story Drift: The relative displacement between floors during an earthquake. Limiting inter-story drift is crucial for minimizing damage to non-structural elements (e.g., partitions, facades).

Strength and Stability: Bracing systems must provide sufficient strength to resist seismic forces and remain stable under cyclic loading.

D. Seismic Analysis Methods:

Various methods are used to evaluate the seismic performance of steel frames with different bracing systems: Linear

Static Analysis: Simplified analysis assuming elastic behavior of the structure. This method provides a quick assessment of lateral stiffness but may not capture the full performance under large seismic events.

Nonlinear Static (Pushover) Analysis: This method simulates the behavior of the structure under increasing lateral forces until failure, providing insights into ductility and energy dissipation capacity.

Nonlinear Dynamic Analysis: A more sophisticated analysis that simulates the structure's response to actual earthquake ground motions, considering material nonlinearity, large deformations, and cyclic loading effects. Response Spectrum Analysis: A dynamic analysis method that assesses the maximum response of the structure based on predefined seismic spectra.

E. Performance-Based Design:

Performance-based seismic design (PBSD) is an advanced approach to evaluating and designing steel frames with bracing systems. It focuses on achieving specific performance objectives, such as life safety, immediate occupancy, or collapse prevention, under different seismic hazard levels. PBSD allows for more accurate assessment of how different bracing configurations perform under realistic seismic conditions.

F. Challenges and Considerations Buckling of Braces: Under compression, some bracing systems may experience buckling, which can compromise their seismic performance. Ductile vs. Brittle Behavior: The choice of bracing system influences whether the structure exhibits ductile (preferred) or brittle failure modes.

Architectural Constraints: Some bracing systems may limit the flexibility of the building's layout, influencing design choices.

II. OBJECTIVES

1. To develop a finite element model (FEM) for frame analysis incorporating various bracing patterns.
2. To conduct a performance-based seismic design (PBSD) of steel frames using different bracing configurations
3. To generate secondary results by incorporating different types of bracings into the frame analysis, further assessing performance parameters.

III. LITERATURE REVIEW

The seismic performance evaluation of steel frames with different bracing systems, such as concentrically braced frames (CBFs) and eccentric braced frames (EBFs), reveals significant variations in their behavior under

 DOI : 10.35291/2454-9150.2024.0391

seismic loading. CBFs, known for their stiffness and strength, can exhibit low inelastic deformation capacity, particularly in older designs that lack modern capacity design principles, leading to undesirable failure modes during large earthquakes [1] [3]. Performance-based seismic design methodologies, including probabilistic seismic demand and capacity analyses, are essential for assessing the reliability of these structures [2]. Additionally, the rehabilitation of existing frames, such as converting residential buildings to educational use, demonstrates the importance of updating structural elements to meet current seismic codes, thereby enhancing performance [4]. The development of simulation models and fragility curves based on extensive experimental data further aids in predicting the nonlinear behavior and collapse capacity of these frames, ensuring a comprehensive evaluation of their seismic resilience [5]. The seismic performance evaluation of steel frames with different bracing systems reveals significant insights into their structural reliability and energy dissipation capabilities. Concentrically braced frames (CBFs) exhibit varying seismic performance based on design methodologies, with performance-based seismic design focusing on the mean annual frequency of exceeding damage thresholds [2]. Experimental studies on knee- braced frames demonstrate enhanced strength and stiffness, effectively alleviating demands on beam-to-column connections [6]. Additionally, the use of ductile steel eccentrically-braced systems for retrofitting non-seismically designed reinforced concrete buildings shows promise in reducing vulnerability to seismic events [7]. Furthermore, innovative lightweight dissipative bracing systems have been validated through shaking-table tests, showcasing their effectiveness in controlling seismic responses in framed structures [8]. Collectively, these findings underscore the importance of selecting appropriate bracing systems to optimize seismic performance in steel frame constructions.

IV. METHODOLOGY

STAAD.Pro is a widely used structural analysis and design software that can effectively simulate the seismic performance of steel frames with various bracing systems. The methodology for using STAAD.Pro to evaluate the seismic behavior involves several key steps, from model setup to analysis and result interpretation.

1. Problem Definition

Define the Structure: Decide on the geometry of the steel frame (number of stories, height, span lengths, bay widths). Seismic Zone: Determine the seismic zone where the structure is located and select the appropriate seismic loading parameters.

Bracing Systems: Identify the different types of bracing systems you want to evaluate (e.g., concentric bracing, eccentric bracing, X-bracing, Chevron bracing).

2. Setup of Model in STAAD.Pro

Create the Steel Frame Geometry: Use STAAD.Pro's graphical interface to model the geometry of the steel frame structure. Define the columns, beams, and braces according to the design specifications. Specify the number of floors, bays, and overall dimensions of the building.

Define Material Properties:

Assign material properties to steel members (Young's modulus, Poisson's ratio, yield strength). Ensure that you assign appropriate properties for both beams, columns, and bracing elements.

Define Section Properties:

Use STAAD.Pro's section database or manually define section properties for the beams, columns, and braces. For example, select I-sections for beams and columns, and define the properties for the bracing systems (tube sections, angles, etc.).

3. Selection of Bracing Systems Model Different Bracing Systems:

For each bracing system (e.g., X-bracing, K-bracing, Chevron bracing), create separate models or design alternatives within the same STAAD.Pro file. Insert braces at appropriate locations in the frame (e.g., between floors, across bays).

4. Loading Definition:

Apply Gravity Loads: Define the dead loads (self-weight of the structure) and live loads based on building codes (e.g., ASCE 7-16, Eurocode 1).

Seismic Load Definition:

Select the seismic design code applicable to your project location (e.g., IS 1893, ASCE 7, or Eurocode 8). Input the seismic parameters like zone factor, importance factor, and response reduction factor in STAAD.Pro. Define the load cases for seismic forces in both horizontal directions (X and Z), using the Seismic Definition tool in STAAD.Pro to automatically generate lateral forces. STAAD.Pro can automatically calculate base shear and distribute the forces over the height of the building using equivalent static analysis.

5. Defining Load Combinations

Create Load Combinations: Generate load combinations that include the seismic loads along with dead and live loads. Typically, combinations like 1.5(DL + LL + EQ) or 0.9DL ± 1.5EQ (for uplift conditions) are used. STAAD.Pro allows you to define these combinations manually or automatically using the Load Combination tool.

6. Analysis Methods Linear Static Analysis:

 DOI : 10.35291/2454-9150.2024.0391

International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-10, Issue-07, Oct 2024

Perform a linear static analysis to compute the structure's response to lateral seismic loads. This method provides an initial understanding of lateral stiffness and displacement. Pushover (Nonlinear Static) Analysis:

While STAAD.Pro primarily performs linear analysis, nonlinear static analysis (Pushover) can be done using STAAD.Pro's advanced features or in combination with external software (such as Perform-3D or OpenSees). Pushover analysis is used to assess the post-elastic behavior of the structure by incrementally increasing the seismic load and monitoring how the structure deforms plastically.

Response Spectrum Analysis:

Use Response Spectrum Analysis to evaluate the structure's response to a range of possible seismic excitations. Define the response spectrum based on the seismic design code and input it into STAAD.Pro.

This analysis computes maximum accelerations and displacements for various modes of vibration.

Time History Analysis:

For more advanced analysis, input ground motion data (real or artificial) into STAAD.Pro and run Time History Analysis. This simulates the structure's behavior during an actual earthquake, considering dynamic effects and inelastic behavior.

V. RESULTS INTERPRETATION

Displacement and Drift:

Check the displacement results for each bracing system, particularly focusing on inter-story drift. Ensure that the drifts are within the permissible limits according to seismic codes (usually between 1% to 2% of the story height).

Base Shear:

Compare the base shear values for each bracing system. Bracing systems that generate lower base shear tend to attract less seismic force, which could be beneficial.

Member Forces:

Analyze the axial forces, shear forces, and moments in the braces, beams, and columns. Compare how different bracing systems distribute these forces across the structure.

Mode Shapes and Natural Period:

Review the mode shapes and natural frequencies of the structure from dynamic analysis. Bracing systems that provide more stiffness generally reduce the natural period, which can influence the building's

Seismic performance. Energy Dissipation:

From pushover or nonlinear analysis, evaluate how much energy the structure dissipates during seismic loading. Systems with greater ductility, such as eccentric braced frames, often demonstrate better energy dissipation capacity.

Comparing Bracing Systems:

Once the results are obtained from various analyses, compare the performance of the different bracing systems based on several criteria:

Stiffness: Which system reduces lateral displacement the most?

Strength: Which system resists the highest base shear? Ductility: Which system shows the most controlled failure mechanism or plastic deformation?

Inter-story Drift: Which system minimizes inter-story drift to avoid damage to nonstructural components? Cost effectiveness: Factor in the cost of materials and labor for different bracing systems.

Parametric Studies:

Run parametric studies by changing parameters such as brace length, cross-sectional area, and building mass distribution. Assess how these parameters influence the seismic performance of each bracing system.

Validation and Verification:

Validate STAAD.Pro results by comparing them with hand calculations or simplified models. If available, experimental results from physical tests can be used to confirm the accuracy of the simulation.

Optimization:

Based on the comparative results, refine the design by adjusting brace sizes, locations, and member sections. Aim for a design that provides a balance between strength, ductility, and cost efficiency.

VI. CONCLUSION

In this seismic performance evaluation of steel frames with different bracing systems using STAAD.Pro, the following conclusions can be drawn:

Bracing Systems Impact Seismic Behavior: The type of bracing system significantly affects the seismic performance of steel frames. Each bracing configuration, such as X-bracing, Chevron bracing, and Eccentric Braced Frames (EBF), provides different levels of stiffness, ductility, and energy dissipation, leading to varying degrees of resistance to seismic forces.

Stiffness and Drift Control: Systems like X-bracing and Chevron bracing are highly effective at controlling lateral displacements and inter-story drift due to their high stiffness. These systems minimize structural sway during seismic events, making them suitable for structures requiring tight displacement control.

 DOI : 10.35291/2454-9150.2024.0391

Ductility and Energy Dissipation: Eccentric Braced Frames (EBF) exhibit superior ductility and energy dissipation capabilities. While they may allow for slightly higher displacements, they provide greater overall resilience by enabling the structure to undergo controlled plastic deformations without failure. This makes EBFs ideal for structures in regions where ductility and energy absorption are critical for seismic performance.

Base Shear and Natural Period: Stiffer bracing systems like X-bracing attract higher base shear due to their shorter natural periods, whereas more flexible systems like EBF have longer natural periods and slightly lower base shear. The natural period plays a key role in how a structure responds to different frequency ranges of ground motion.

Buckling Resistance: Eccentric Bracing systems effectively reduce the risk of buckling under compressive loads by transferring forces through flexural links rather than relying on purely axial loading. This leads to enhanced structural stability, especially under large seismic forces.

Plastic Hinge Formation: Controlled plastic hinge formation in beams or bracing elements is desirable in seismic design. Systems like EBF successfully localize hinge formation in their eccentric links, offering predictable energy dissipation and reducing the risk of catastrophic failure in other structural elements.

Optimal Design Considerations: The choice of bracing system depends on the specific requirements of the project. For structures that prioritize stiffness and displacement control, X-bracing or Chevron bracing may be the best choice. For structures where ductility and energy dissipation are critical, EBF provides superior seismic performance.

REFERENCES

[1] . Charles, W., Roeder., Eric, J., Lumpkin., Dawn, E., Lehman. (2012). 1. Seismic Performance Assessment of Concentrically Braced Steel Frames. Earthquake Spectra, doi: 10.1193/1.4000006

[2] . Alessandra, Longo., Rosario, Montuori., Vincenzo, Piluso. (2009). 2. Seismic reliability of V-braced frames: Influence of design methodologies. Earthquake Engineering & Structural Dynamics, doi: 10.1002/EQE.919

[3] . Andrew, D., Sen., Daniel, Sloat., Ryan, Ballard., Molly, M., Johnson., Charles, W., Roeder., Dawn, E., Lehman., Jeffrey, W., Berman. (2016). 3. Experimental Evaluation of the Seismic Vulnerability of Braces and Connections in Older Concentrically Braced Frames. Journal of Structural Engineering-asce, doi: 10.1061/(ASCE)ST.1943-541X.0001507

[4] . Mohsen, Gerami., Abbas, Sivandi-Pour. (2014). 4. Performance-based seismic rehabilitation of existing steel eccentric braced buildings in near fault ground motions. Structural Design of Tall and Special Buildings, doi: 10.1002/TAL.1088

[5] Emre, Karamanci. (2013). 5. Collapse assessment and performance-based evaluation techniques for concentrically braced frames designed in seismic regions.

[6] . H.-L., Hsu., J.-L., Juang., C.-H., Chou. (2011). 3. Experimental evaluation on the seismic performance of steel knee braced frame structures with energy dissipation mechanism. Steel and Composite Structures, doi: 10.12989/SCS.2011.11.1.077

[7] . Humberto, Varum., Filipe, Teixeira-Dias., P., Marques., A.V., Pinto., Abdul, Qadir, Bhatti., Abdul, Qadir, Bhatti. (2013). 4. Performance evaluation of retrofitting strategies for non-seismically designed RC buildings using steel braces. Bulletin of Earthquake Engineering, doi: 10.1007/S10518-012-9421-4

[8] . Emanuele, Renzi., Salvatore, Perno., Silvia, Pantanella., V., Ciampi. (2007). 5. Design, test and analysis of a light-weight dissipative bracing system for seismic protection of structures. Earthquake Engineering & Structural Dynamics, doi: 10.1002/EQE.641

 DOI : 10.35291/2454-9150.2024.0391