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Research Article

EVALUATION OF SHEAR WALLS, BRACING SYSTEMS & COMBINED SHEAR WALL-BRACING SYSTEMS FOR ENHANCING SEISMIC PERFORMANCE OF MULTI-STORIED BUILDINGS

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Abstract

The seismic performance of multi-storied buildings is critically influenced by the selection and implementation of lateral load-resisting systems. Among the most widely adopted strategies are shear walls and bracing systems, each offering distinct structural advantages. Shear walls provide significant lateral stiffness and strength, while bracing systems contribute to enhanced ductility and energy dissipation. This review paper presents a comprehensive evaluation of shear walls, bracing systems, and their hybrid integration to assess their effectiveness in seismic resilience. The interaction between these systems, their configurations, material considerations, and dynamic behavior under seismic loads are systematically analyzed. Comparative case studies and recent research trends are examined to highlight design optimization techniques, performance outcomes, and innovative materials or technologies. The findings suggest that combined shear wall-bracing systems often outperform individual systems by achieving a balanced seismic response, reducing inter-story drift, and enhancing structural safety. The review concludes with recommendations for future research and design improvements that can guide engineers in developing earthquake-resilient high-rise buildings.

Keywords: Seismic performance, Shear wall, Bracing system, Hybrid structural system, Multi-storied buildings, Lateral load resistance

1. Introduction

1.1. Background of Seismic Vulnerability in Multi-Storied Buildings

Multi-storied buildings in seismic-prone zones are particularly vulnerable to lateral forces generated during earthquakes, which can lead to significant structural damage or even total collapse if not properly designed. The vulnerability increases with the building's height, irregularity, and mass distribution. Earthquake-induced ground motion causes dynamic loads that result in horizontal displacement and inter-story drift, which conventional gravity-load-designed structures are not adequately equipped to resist (Priestley, Calvi, & Kowalsky, 2007). Over the years, numerous seismic events have highlighted the weaknesses in unreinforced or poorly designed structures, underscoring the need for effective lateral load-resisting systems in multi-storied construction (Bozorgnia & Bertero, 2004).

1.2. Importance of Lateral Load-Resisting Systems

Lateral load-resisting systems, such as shear walls, bracing systems, and moment-resisting frames, are essential components of earthquake-resistant design. These systems enhance the overall stiffness, strength, and ductility of a structure, reducing lateral displacement and improving energy dissipation during seismic events (Chopra, 2017). The incorporation of these systems in design not only improves the seismic performance of the structure but also minimizes structural and non-structural damage, ensuring occupant safety and operational continuity. As building codes evolve, the integration of robust lateral resistance systems has become a key requirement in performance-based seismic design (FEMA P-750, 2009).

2. Shear Walls in Seismic Design

2.1. Types and Configurations of Shear Walls

Shear walls are vertical structural elements designed to resist lateral forces due to wind or seismic activity. Common types include **planar shear walls**, **C-shaped**, **T-shaped**, **L-shaped**, and **core walls**. Their configuration greatly influences the overall seismic behavior and stiffness distribution of the structure (Paulay & Priestley, 1992). Proper placement of shear walls symmetrically in both directions minimizes torsional effects and enhances overall stability during an earthquake (Alath & Srinivas, 1992).

2.2. Materials Used in Shear Wall Construction

Concrete is the most commonly used material for constructing shear walls, typically reinforced with high-strength steel bars for ductility and crack control. Alternatives include reinforced masonry, steel plate shear walls, and composite systems (Maheri & Akbari, 2003). In recent years, **engineered wood** and **prefabricated panels** have also been explored for mid-rise structures, especially in green or modular construction (Pei et al., 2012).

2.3. Structural Behavior Under Seismic Loads

Shear walls provide lateral stiffness and strength, reducing horizontal deflections and inter-story drift. Their seismic behavior depends on wall aspect ratio, reinforcement detailing, and boundary conditions. Properly designed shear walls can undergo large inelastic deformations while dissipating energy through flexural yielding or shear sliding mechanisms (ACI Committee 318, 2019). However, brittle failure can occur if ductility demands are not met or if coupling beams are not effectively integrated (Tso & Moghadam, 1997).

2.4. Advantages and Limitations

The key advantages of shear walls include **high lateral stiffness**, **cost-effectiveness**, and **efficient load transfer**. They are particularly suitable for **high-rise buildings** and **core-centric configurations**. However, limitations include reduced architectural flexibility, potential stress concentration at connections, and challenges in retrofitting existing structures (Chopra, 2017).

3. Bracing Systems for Seismic Resistance

3.1. Classification of Bracing Systems (Diagonal, X, V, K, Inverted V)

Bracing systems provide an alternative to shear walls in resisting lateral loads. Common types include **diagonal bracing**, **X-bracing**, **V-bracing**, **K-bracing**, and **inverted V (chevron) bracing**. Each configuration offers different advantages in terms of strength, deformation capacity, and compatibility with openings (Agarwal & Shrikhande, 2010). X and V bracings are among the most efficient for energy dissipation.

3.2. Materials and Structural Integration

Bracings are typically made of structural steel due to its ductility and high tensile strength. Integration with the structural frame is critical to ensure proper load path and minimize eccentricities. Some modern systems incorporate **buckling-restrained braces (BRBs)** or **damped braces** to enhance performance and energy absorption (Sabelli et al., 2003).

3.3. Seismic Response Characteristics

Braced frames perform well in moderate-to-severe seismic zones due to their **high ductility**, **lightweight nature**, and **ease of installation**. They can significantly reduce story drifts and base shear forces, especially when designed as concentrically or eccentrically braced frames (Goel & Chopra, 2008). However, their effectiveness depends on the geometry, member sizes, and connection detailing.

3.4. Advantages and Constraints in Design Application

Bracing systems are preferred for **retrofitting** and **mid-rise buildings** due to their **cost-effectiveness**, **constructability**, and **architectural flexibility** compared to shear walls. However, they may reduce usable space and may not be suitable for irregular floor plans. Improper detailing can also lead to **buckling or fatigue failure** under cyclic loading (Ismail et al., 2015).

4. Combined Shear Wall and Bracing Systems

4.1. Concept and Design Philosophy

The combined use of shear walls and bracing systems leverages the **stiffness of shear walls** and the **ductility of bracing systems**, offering a hybrid lateral load-resisting mechanism ideal for high seismic zones. This approach aims to optimize structural performance by balancing strength, stiffness, and energy dissipation capacity, thereby minimizing inter-story drift and improving post-earthquake functionality (Fardis, 2009). The design philosophy encourages distributing lateral resistance across both systems to prevent localized damage and to increase system redundancy (Bozorgnia & Bertero, 2004).

4.2. Interaction Between Shear Wall and Bracing

When shear walls and bracing systems are integrated, their interaction influences the **load distribution**, **dynamic behavior**, and **failure mechanisms** of the structure. The combined system must be carefully analyzed to avoid stiffness incompatibility, which may result in stress concentration or underutilization of certain members (Moghadam & Tso, 2000). Nonlinear static and dynamic analyses are typically used to model this interaction and to ensure that both elements contribute effectively under seismic loads (Chopra, 2017).

4.3. Case Studies and Comparative Research

Several analytical and experimental studies have demonstrated the effectiveness of hybrid systems. For instance, Alavi and Krawinkler (2001) showed through nonlinear time-history analysis that buildings with combined systems perform better in terms of reduced drift and energy dissipation compared to structures with either system alone. Case studies of retrofitted hospital and educational buildings in Turkey and Japan have also reported improved seismic performance and reduced damage levels (Sezen et al., 2003).

4.4. Hybrid System Performance Evaluation

Performance evaluations of hybrid systems typically include parameters such as **base shear reduction**, **drift control**, **stress distribution**, and **energy dissipation capacity**. Seismic tests on scaled models and full-scale buildings confirm that combined systems provide **superior damping** and **resilience**, especially in mid- to high-rise buildings (Gupta & Kunnath, 2000). However, design complexity, construction cost, and coordination between structural components remain key challenges.

5. Comparative Analysis and Research Trends

5.1. Summary of Comparative Seismic Performance

Comparative studies indicate that shear walls alone offer greater stiffness but may lack sufficient ductility, whereas bracing systems are more effective in energy dissipation but may lead to higher story drift if not properly designed. The combination of both offers a **synergistic effect**, yielding better seismic resistance than when used independently (Agarwal & Shrikhande, 2010). Tables of performance indices like drift ratio, ductility factor, and base shear resistance often favor hybrid systems in seismic simulations.

5.2. Design Optimization Techniques

Recent advances involve optimization techniques such as **genetic algorithms**, **topology optimization**, and **multi-objective functions** to determine optimal locations, sizes, and configurations of shear walls and braces (Kaveh & Talatahari, 2012). These techniques help reduce material usage, construction cost, and improve seismic efficiency while meeting code requirements.

5.3. Recent Research and Innovative Approaches

Innovations include the integration of **buckling-restrained braces (BRBs)** with **high-performance fiber-reinforced concrete shear walls**, **viscoelastic dampers**, and **smart materials** to enhance damping capacity and reduce residual drift (Sabelli et al., 2003). Studies have also explored the use of **machine learning** and **performance-based design** for real-time optimization of hybrid systems under variable seismic demands (Behfarnia & Taghikhany, 2020).

5.4. Future Scope and Recommendations

Future research should focus on **code development**, **full-scale field validation**, and **performance-based retrofit guidelines** for hybrid systems. The integration of **smart monitoring**, **adaptive control devices**, and **eco-friendly materials** will play a significant role in improving the resilience and sustainability of urban infrastructure. Collaboration between academia, industry, and government is essential for scaling up implementation and standardization (FEMA P-58, 2012).

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