

Evaluation of the Performance of Rocking Wall with Eccentrically Braced Frame with Vertical Link Based on the Force Design Method

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ABSTRACT

This study introduces a combined system of Rocking Shear Walls with Eccentrically Braced Frame with Vertical Link (RCSW-EBF). The aim of the study is to investigate the impact of the Force Design parameter (with different beta values) on the behavior of the RCSW-EBF system while keeping the cable area constant. Additionally, the study seeks to explore the effects of cable area on the behavior of the RCSW-EBF system while other characteristics remain unchanged. The 10-story frames are designed in SAP software, and the dimensions of the system sections are determined. These 10-story frames are then modeled in ABAQUS software, and their nonlinear behavior under pushover and cyclic analysis is determined. The finite element modeling has been done with Shell and Wire elements. The results of the cyclic analysis indicate that an increase in the percentage of Brace force (x%) leads to a corresponding increase in wasted energy and the coefficient of energy loss and reducing the design force of the Eccentrically Braced Frame's span and increasing the design force of the Rocking Wall with Concentrically Braced Frames' span led to a decrease in the cyclic diagrams of energy consumption. So, the energy consumption of the RCSW-EBF frame with the design forces of Braced Frame 70% and Rocking wall 30%, Braced frame 80% and Rocking wall 20%, and Braced Frame 90% and Rocking Wall 10% is respectively 12%, 28% and 44% more than the system with the design force of Braced Frame 60% and Rocking Wall 40%.

KEYWORDS

Brace Frame, Vertical link, Rocking wall, Self-Centering Reparability, Force Based Design.

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1. Introduction

In recent years, due to the high vulnerability of buildings designed according to Standard 2800 when subjected to design-level earthquakes and even milder events, the idea of directing damage toward specific, replaceable elements in the structure was introduced. This concept aims to reduce repair cost and time, thereby enabling faster re-occupancy [1].

On the other hand, the rocking phenomenon caused by overturning moment exceeding gravity moments reason, the use of rocking shear walls with post-tensioned cables has been proposed as an effective method for reducing nonlinear behavior and enhancing re-centering capability [2]. In addition, V-EBF bracing systems have attracted attention because of their favorable energy dissipation capacity. Early studies by G-K and colleagues demonstrated the stable hysteretic behavior of this system [3], and Wakabayashi showed that V-EBF is more stable than the inverted-V bracing system [4]. Analytical results by Dosika and collaborators also showed good agreement with experimental shear capacity and confirmed yielding of the web of the link beam [5]. Investigations by Zehraei et al. [6] further indicated the desirable energy absorption performance of the system and response modification factors greater than code-specified values [7]. Combining concentrically braced frames with steel panels also led to confining damage within the damper and facilitating its replacement, and subsequent studies confirmed appropriate distribution of plastic hinges and convergence of analytical and experimental results [8].

Considering the limitations of connections in post-tensioned moment frames and the significant residual deformation in eccentrically braced frames, this study for the first time introduces a hybrid system composed of an eccentrically braced frame with a vertical link and a self-centering rocking steel wall equipped with post-tensioned cables. The system is investigated under cyclic loading to ensure that energy dissipation is provided by the vertical link while re-centering capability is supplied by the rocking wall, and to identify its advantages and drawbacks.

2. Methodology

2.1. Proposed System Mechanism

The behavioral mechanism of the proposed EBF-RCSW system is based on the concept that the eccentrically braced frame with a vertical shear link is responsible for energy dissipation, while the rocking steel shear wall equipped with post-tensioned cables provides self-centering and restores the system to its original position. According to the schematic diagrams in Fig. 1, the base-shear contribution of the rocking wall, the eccentrically braced frame, and the overall hybrid system are defined separately. In this context, the parameter α represents the

ratio of secondary stiffness to initial stiffness, and the parameter β indicates the degree of self-centering capability of the system.

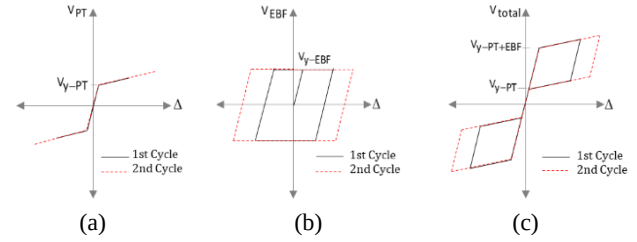


Fig. 1. Schematic force-displacement diagram: (a) Self-centering rocking shear wall, (b) Eccentrically braced frame with a vertical shear link, and (c) Proposed hybrid EBF-RCS system.

2.2. Finite Element Model and Validation

For validation, the experimental model of Qureshi et al. [9], consisting of a rocking shear wall with two post-tensioned cables and a reinforcing bar connecting the wall to the foundation, was re-modeled in ABAQUS. In the modeling process, S4R shell elements were used for the steel wall panel, and T3D2 truss elements were used for the cables. The analysis was conducted in two steps: an initial thermal loading to induce post-tensioning force, followed by dynamic time-history loading. The numerical results showed excellent agreement with the experimental data, with the maximum relative error reported to be less than 4%. Stress distribution results indicated that the highest stress concentrations occur at the cable anchorage region at the top of the wall and at the compression toe region at the bottom, which represent the most likely failure zones.

3. Discussion and Results

In this study, the modeling of the hybrid system consisting of an eccentrically braced frame with a vertical link and a rocking shear wall was carried out using A416 and A992 steel grades and assuming bilinear kinematic behavior. Eight ten-story models with various force-distribution ratios between the frame and the wall, as well as models with different post-tensioning cable areas, were analyzed. The components were modeled using appropriate elements and examined under cyclic quasi-static loading and pushover analysis. The design was performed such that only the vertical link would yield at a drift of two percent, while all other members remained within the elastic range. Mesh density was chosen optimally, and secondary three-dimensional effects were neglected. In comparing the numerical models, the cyclic behavior of the proposed EBF-RCSW system was analyzed by varying the percentage of force distribution between the eccentrically braced frame and the rocking shear wall, as well as by changing the cross-sectional area of the post-tensioned cables. This was done to identify

the influence of each parameter on self-centering capability, secondary stiffness, and energy dissipation. The results showed that increasing the portion of design force assigned to the rocking wall leads to narrower and more flag-shaped hysteresis loops, thereby improving self-centering ability; however, energy dissipation decreases simultaneously. Specifically, the frames with Brace 70% & Rocking 30%, 80% & 20%, and 90% & 10% dissipated 12%, 28%, and 44% more energy, respectively, compared to the Brace 60% & Rocking 40% configuration. In contrast, increasing the cable area without altering the design force significantly increased the secondary stiffness and ultimate strength, while having little effect on self-centering capability. This finding was confirmed through the cyclic curves and stress distributions. Analysis of energy dissipation, presented in Fig. 2, indicated that increasing the force share of the eccentrically braced frame results in substantial growth in energy dissipation (E_p and E_D) and cumulative dissipated energy, whereas changing the cable area has negligible influence.

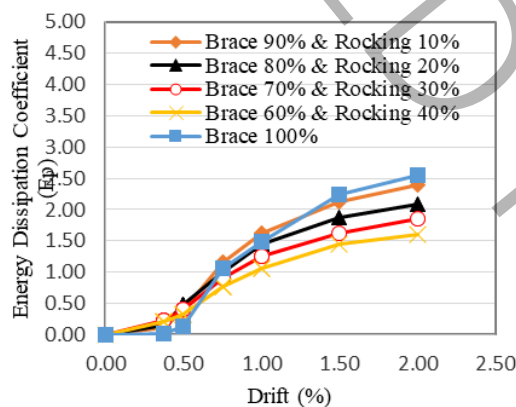


Fig. 2. Energy dissipation coefficient (E_p) of the models with varying force distribution.

This is because energy dissipation is governed by the vertical link, and the design force of the frame was kept constant across the cable models. Compared with similar systems reported in previous studies, the hysteresis loops of the present model exhibit a more pronounced flag shape with a larger enclosed area, reflecting a successful combination of self-centering and energy dissipation.

4. Conclusions

The aim of this study was to develop and evaluate a novel hybrid system composed of an eccentrically braced frame with a vertical shear link and a rocking shear wall, capable of simultaneously providing high seismic self-centering and significant energy dissipation. The performance of this system was assessed through the analysis of four ten-story models, focusing on the influence of two key parameters the distribution of design force and the cross-sectional area of the post-tensioned cables on its cyclic behavior. The results indicated that

increasing the rocking wall's share of the base shear enhances self-centering capability, reduces residual drift, and produces a stable flag-shaped hysteresis response. Conversely, increasing the cable area leads to higher secondary stiffness and greater ultimate capacity, while having limited impact on self-centering performance. The analyses also showed that the proposed system exhibits a more ideal flag-shaped hysteresis curve compared to similar systems reported in previous studies, effectively addressing the shortcomings observed in earlier research. Overall, the hybrid system can serve as an efficient and effective option for seismic design in earthquake-prone regions, offering a balanced combination of cyclic stability, high energy dissipation, and desirable self-centering capability.

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