Seismic Performance Evaluation of a Hybrid Structural System Combining Concentric Braced Frames and Linked Column Frames (LCFs)

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ABSTRACT

In this paper, the structural behavior of the LCF system with concentric braces under seven near-fault and far-fault ground motion records was investigated. For this purpose, 3, 6, and 12-story structures were designed and modeled. Based on the results, the use of the LCF structural system with concentric braces can improve the structural performance against earthquakes in both near-fault and far-fault zones and reduce structural damage under these earthquakes. Additionally, the analysis of structures designed with box columns shows that their behavior under near-fault earthquakes is appropriate and controlled. The yielding sequence of the utilized fuses indicates the optimal performance of this structural system in limiting structural damage to the sacrificial fuses and preventing damage in the main load-bearing members of the structure.

KEYWORDS

Near-fault and far-fault earthquakes, Performance-based design, Structural fuses, Linked Column Frame (LCF), Concentric Braced Frame (CBF).

1. Introduction

Concentrically braced frames are commonly employed to provide lateral stability against seismic loads. According to the philosophy of seismic design, it is expected that these systems demonstrate stable and sustained inelastic behavior under strong ground motions. In such frames, braces are connected to beams and columns using gusset plates. Inelastic deformations, including tensile yielding and inelastic buckling, occur when the brace yields. Recent experimental studies have shown that the seismic performance of CBFs can be improved by optimizing the gusset plate design and allowing for controlled yielding of the connection [1].

Dual structural systems equipped with structural fuses, such as the Linked Column Frame (LCF) system, have two key functions: resisting lateral seismic forces and using structural fuses to limit deformations in other components, keeping them within the elastic range. Achieving these dual functions is essential for effective seismic design. While displacement-based design methods are generally considered the most reliable approach—despite their practical complexity—traditional force-based methods are relatively simpler but often fall short in ensuring the desired seismic performance [2]

The use of beam-to-column linked systems (LCF systems) can effectively reduce excessive displacements and accelerations in structures, thereby minimizing the demand for ductility. These systems have consistently played a significant role in recent research efforts. By incorporating LCF systems into structural designs, seismic accelerations are notably reduced, which subsequently lowers displacement demands and enhances structural performance. Structures equipped with such systems are capable of achieving Life Safety or Immediate Occupancy performance levels under the specified hazard levels, indicating the high applicability of this type of damper [3]. The original concept of the LCF system stems from the work of Nader and colleagues, which focused on the design of long-span bridges. Later, Dusicka and Iwai introduced the concept of beam-to-column linked frames (LCF) in 2007. This system, consisting of unbraced steel frames, was proposed to enable rapid post-earthquake serviceability. They implemented the LCF system on three-story frames as part of the SAC research project (FEMA-353) [4].

2. Methodology

3. In this study, three steel moment-resisting frame structures were selected based on aspect ratios presented in the textbook Analysis and Design of Tall Buildings, with aspect ratios equal to $\pi/3$, $\pi/2$, and π, respectively, as shown in Figure 7. The selected structures include 3, 6, and 12-story frames, with each story assumed to have a height of 3.2m. Each frame consists of four 5m bays and one bay with a 1.5m link beam. The applied dead and live loads on the floors are considered to be 600 kg/m^2 and 200 kg/m^2, respectively, while for the roof, the dead and live loads are taken as 650 kg/m^2 and 150 kg/m^2. The facade wall load is assumed to be 225 kg/m, and the snow load is taken as 150 kg/m^2. The structures are assumed to be located in Tehran, situated on a local site classified as Soil Type II. The design spectrum parameters based on ASCE 7-10 for an earthquake with a 2% probability of exceedance in 50 years (Maximum Considered Earthquake, MCE) are taken as SMs=1.61 and SM1=1.19. For an earthquake with a 10% probability of exceedance in 50 years (Design Basis Earthquake, DBE), the parameters are SDs=1.07 and SD1=0.79. For a seismic event with a 50% probability of exceedance in 50 years (Service Level Earthquake, SLE), the spectral accelerations at short period and 1s period, based on SAC building data, are taken as 0.514 and 0.288, respectively.

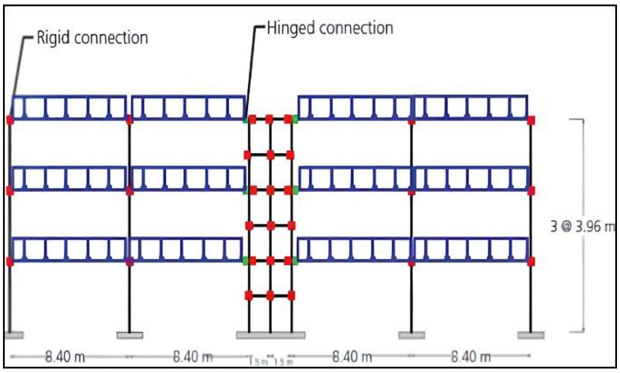

Figure 1: Modeling of the DLCF frame in the paper by Maroufi et al.

4. Results and Discussion

In this study, 3, 6, and 12-story structures with box columns and plate-fabricated beams were designed using a performance-based plastic design method. Each structure was analyzed under seven near-fault and seven far-fault ground motion records using nonlinear dynamic analysis.

shows the drift percentage diagram for the 3-story structure under near-fault earthquakes. According to the figure, the maximum drift percentages for the Imperial Valley, Kobe, Coquille Turkey, Landers, Loma Prieta, Northridge, and Superstition Hills earthquakes are 7.61%, 7.54%, 5.99%, 2.74%, 1.19%, 1.72%, and 0.2%, respectively. In this case, the highest drift percentage corresponds to the Imperial Valley earthquake, and the lowest drift percentage belongs to the Superstition Hills earthquake, which represents a 97.38% reduction compared to the maximum drift.

5. Conclusions

1- Unlike other systems with rapid re-centering ability, such as buckling-restrained bracing where the fuse elements are made from non-structural components or require complex manufacturing, the frame system with a column linked to a concentrically braced frame has an advantage due to the use of a link beam as a fuse element, which is made from the same structural material.

2- According to the drift percentages obtained from the analysis of the designed structures with box columns, their behavior under near-fault earthquakes is proper and controlled. Also, the yielding sequence in the used fuses indicates the optimal performance of this structural system in limiting structural damage to the sacrificial fuses without damage to the main load-carrying members of the structure.

3- Near-fault earthquakes scaled according to the Iranian seismic code 2800 produced higher drifts in the structures.

4- For the 3-story structure under near-fault earthquakes, the highest drift percentage corresponds to the Imperial Valley earthquake, and the lowest to the Superstition Hills earthquake, with a 97.38% reduction relative to the lowest drift. For the 3-story structure under far-fault earthquakes, the highest drift percentage corresponds to the Landers earthquake, and the lowest to the Superstition Hills earthquake, with a 94.58% reduction.

5- For the 6-story structure under near-fault earthquakes, the highest drift percentage is related to the Imperial Valley earthquake, and the lowest to the Superstition Hills earthquake, with a 93.26% reduction. For the 6-story structure under far-fault earthquakes, the highest drift corresponds to the Landers earthquake, and the lowest to the Superstition Hills earthquake, with an 81.63% reduction.

6- For the 12-story structure under near-fault earthquakes, the highest drift percentage is for the

Imperial Valley earthquake, and the lowest for the Loma Prieta earthquake, with a 94.76% reduction. For the 12-story structure under far-fault earthquakes, the highest drift percentage is for the Landers earthquake, and the lowest for the Northridge earthquake, with an 83% reduction.

6. References

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