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Steel plate shear wall with tension-bracing for seismic rehabilitation of steel frames

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ABSTRACT

A rehabilitation technique that utilizes a thin steel plate as a supplemental shear wall system for small, low-rise steel structures is described. In the proposed system, the plate and surrounding boundary elements are installed in the middle of the bay, separate from existing columns. This geometry intends to eliminate the need to strengthen the existing columns, as these typically would have been designed only for the combined forces of gravity and wind. The system employs supplemental elements as tension-only elements to speed up the construction work and to enforce strict capacity design principles (*i.e.*, overstrength is capped). A prototype system was designed using a hierarchical flowchart and a simplified analysis model, and its performance was evaluated through large scale testing. The system achieved stable hysteretic behavior without showing major strength deterioration until large story drifts were reached. A high-fidelity FE model of the system was also developed to reproduce the experimental behavior. The model well traced the test results and was used as a tool for validating the effectiveness of the proposed system geometry.

1. Introduction

The need to retrofit in earthquake prone regions may arise directly from the problem of aging infrastructure, recognition of the vulnerability of existing infrastructure, updates in seismic code requirements, or changes in building performance objectives. The addition of seismic isolation, supplemental bracing, concrete or steel shear walls, and damping devices are some common techniques that have been successfully implemented for improving the seismic performance of existing buildings (*i.e.*, improving stiffness, strength and energy dissipation). However, if the proposed modification results in the need for extensive additional strengthening of existing structural elements, rehabilitation may no longer be a cost-effective alternative to rebuilding. This is particularly true for small, low-rise steel structures, which are the target of the system described in this paper. Thus, the design of the supplemental system must follow a strict capacity design to avoid the major increase in force demand to the existing frames. Moreover, use of heavy construction equipment must be limited or eliminated in order to minimize indirect construction costs and mitigate safety concerns.

In response to these constraints, an approach to design supplemental systems utilizing tension-only elements is proposed for small to mid-sized buildings. The tension-only design can increase the speed of construction by adopting simple connections with rapid and adjustable installation features [1,2]. Such systems rationally implement a strict capacity design philosophy (over-strength is known or capped) and is scalable and adaptable to many bay geometries by eliminating undesirable global and local buckling in supplemental elements. In this paper, the adoption of a steel thin plate within a tension-only design approach is considered. A shear wall made of a steel thin plate resists lateral loads by developing tension field action after the onset of global shear buckling. Such a system, labeled a Special Plate Shear Wall (SPSW), is lighter and more ductile than a reinforced concrete shear wall and can provide the system with a substantial increase in stiffness, load-carrying capacity, and energy dissipation. Since Thorburn et al. [3] introduced the design philosophy for the use of unstiffened thin plates and considered the post-buckling strength of the infill plate for the calculation of shear strength of system, this new design philosophy has been widely adopted by researchers and in the current design codes (*e.g.*, [4–11]). While the SPSW is economical and efficient for increasing the seismic resistant capacity of steel moment frames, this system also significantly increases the force demand in boundary elements (*i.e.*, beams and columns) since inward flexural forces induced by the tension field action in a thin steel plate must be resisted by the flexural bending of boundary elements. This problem has led designers to propose alternative designs to lessen the increase in force demand to the existing frames.

This paper proposes an alternative configuration for SPSWs, where a plate with surrounding boundary elements is installed at the middle of the bay, separate from existing columns. The system incorporates stiffening of vertical boundary elements by tension-rods to ensure stable energy dissipation through the yielding of the thin steel plate

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