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Saw type seismic energy dissipaters: development and cyclic loading test

Serhat Demir *, Metin Husem

Department of Civil Engineering, Karadeniz Technical University, 61080 Trabzon, Turkey

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ABSTRACT

This study presents the experimental, numerical and theoretical studies of a high ductility and energy dissipation capacity passive energy dissipation device called the Saw Type Seismic Energy Dissipaters (STSED), which is expressly developed for building protection during earthquakes. STSED has a series of specially shaped metallic yielding elements capable of dissipating energy by flexural yielding. STSED's key feature is its design that allows for the use of more metallic yielding elements than the existing systems in the literature while simultaneously allowing for a pinned connection with a framing system. The device is presented in detail along with the accompanying equations used to design the prototype. The shape of metallic yielding elements were designed and experimentally optimized in order to reduce stress concentration when subjected to cyclic loadings. Thus, damage was effectively distributed throughout the entire height of the metallic yielding elements. The performance of the prototype was also experimentally tested under cyclic loading. Test results showed that the STSED has both stable and symmetric hysteretic behavior under cyclic loads with high-energy dissipation and no sudden strength degradation. Furthermore, experiments verified that cyclic performance can be accurately estimated using the design equations and nonlinear finite element (FE) analysis as presented in the paper.

1. Introduction

During the last 30 years, as an alternative to conventional methods of earthquake resistant design, new and innovative passive energy dissipation devices have been in various stages of development. In general, the aim of including passive energy dissipation devices in a structure is to reduce the inelastic energy dissipation demand on the framing system of a structure [1,2]. Researchers have developed, as well as analyzed, a variety of passive energy dissipation devices in order to achieve this objective. Devices include friction-slip devices [3–6], viscoelastic dampers [7,8] and metallic yielding dampers [9–21].

Among these devices, metallic yielding dampers are considered to be simple, cost-effective and easy to fabricate. The main advantages of these devices include: stable hysteretic behavior; low-cycle fatigue property; long-term reliability; insensitivity to ambient temperature and materials; behavior familiar to practicing engineers [22]. A variety of metallic yielding dampers, based on steel yielding in either flexure, shear or torsion, have been developed to date. Upon examination of these devices the most common way of mounting is on beams supported by chevron braces or walls [9,14,15,17–19]. This configuration, however, brings with it some disadvantages. Energy dissipation elements are shaped according to the horizontal movement of the frames, which causes the beams to displace vertically as well. Therefore, the elements are exposed not only to bending and shear forces but also to axial compression force, having not been taken into consideration during the design stage. This configuration also causes the beams to be subjected to high additional forces.

The disadvantages mentioned above have led some researchers to design new systems, with metallic yielding elements applied in diagonal braced frames [20,21]. In these systems very few flexural metallic yielding elements were used as energy dissipaters. Also, the fixed end connections between the brace and the framing system caused in-plane rotations of the brace. Thus, the change in the brace angle caused differential flexural deformations. Additionally, when a system has few metallic yielding elements an unexpected failure in a single element has a much greater effect on a building's overall structural response than the failure of an element on a system with more metallic yielding elements.

In this paper, a new metallic yielding device named Saw Type Seismic Energy Dissipaters (STSED), developed with the purpose of providing better building protection during earthquakes, is presented as an alternative high-ductility brace that offers unique properties and structural advantages. STSED's advantageous design allows for the use of more metallic yielding elements than the existing systems in the literature while also delivering a pinned connection between the diagonal brace and framing system.

2. Concept and design of the saw type seismic energy dissipater

A STSED consists of two main parts, the inner core and the outer tube (Fig. 1). The inner core has pinned connection members as well

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* Corresponding author.
E-mail address: s.demir@ktu.edu.tr (S. Demir).

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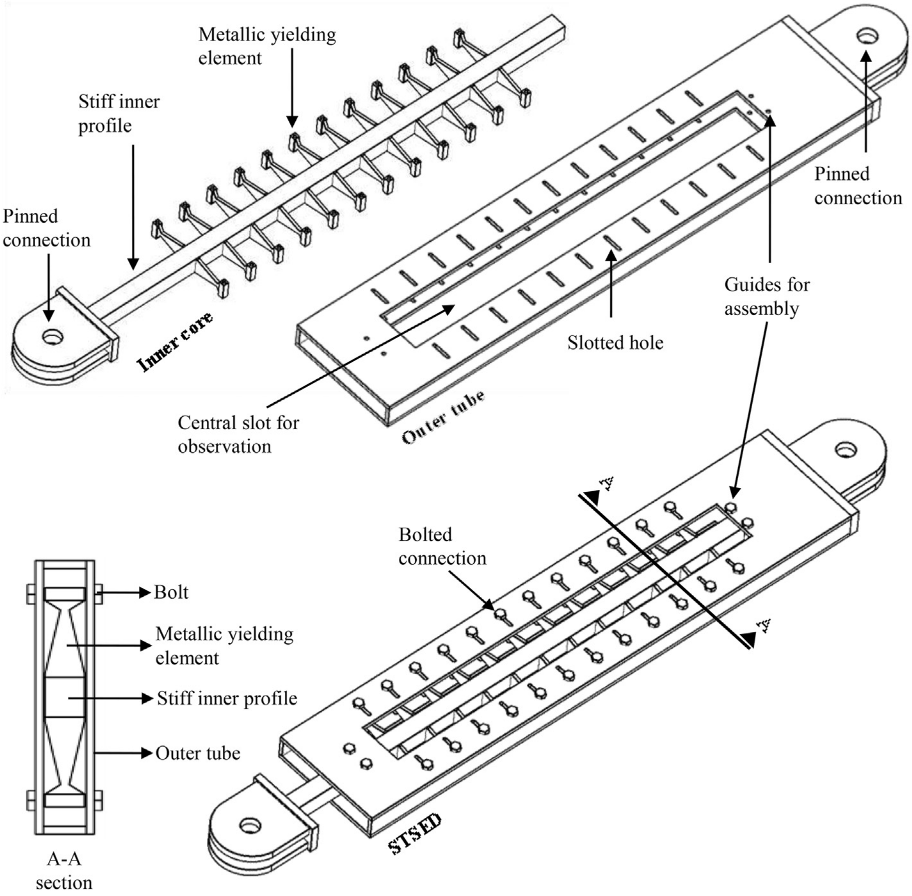

Fig. 1. Geometric illustration of the STSED.

as one-edge welded metallic yielding elements on two sides of the stiff inner profile. The outer tube has pinned connection members and slotted holes in the side plates. In addition, at the each end of central slot in the side pates two pairs of holes are left, which are used as a guide for assembly in connecting the inner core to the outer tube. The inner core is connected to an outer tube through a bolted joint. The ends of the metallic yielding elements have round holes that are bolted to slotted holes in the outer tube. Due to the slotted holes, lateral movement of the ends of the metallic yielding elements is possible. Metallic yielding elements are specifically designed to dissipate energy through flexural yielding when the device is loaded. When the STSED is loaded, both in tension and in compression, flexural yielding of the metallic yielding elements provides symmetrical cyclic behavior as a direct result of the relative movement of the outer tube to the inner core.

The design process of the metallic yielding elements was inspired from triangular added damping and stiffness (TADAS) devices [10]. Like the TADAS, the width of the metallic yielding elements is tapered in such a way that yielding occurs simultaneously over the entire length of the elements (Fig. 2). This significantly reduces the peak strain while simultaneously increasing the ductility of the system.

he response of the STSED device equals the sum of the responses of the metallic yielding elements. Assuming the base of the metallic yielding element is fully restrained and neglecting the shear deformation, theoretical elastic lateral stiffness (k_E), yield load (P_p: the load at which the metallic yielding element plastified) and yield displacement (δ_p) of a STSED can be predicted with Eq. (1), Eq. (2) and Eq. (3), respectively [10]:

$$k_E = \frac{n b_b h^3 E}{6 l^3} \tag{1}$$

$$P_p = \frac{n b_b h^2 \sigma_y}{4 l} \tag{2}$$

$$\delta_p = \frac{2 \varepsilon_y l^2}{h} \tag{3}$$

where n is the number of the metallic yielding elements; h is the metallic yielding element thickness; b_b and l are the base width and the height of the metallic yielding element; σ_y and ε_y are the yield stress and yield strain of the metallic yielding element; and E is representative of Young's modulus.

In addition to elastic stiffness, the STSED also exhibited a post-yield stiffness due to geometric non-linearity and strain hardening within the yielding element. Since the metallic yielding elements are connected to the outer tube by slotted holes, the axial force on the inner core is transmitted to the outer tube by bolts. Therefore, this force is always acting in parallel to the STSED direction, regardless of the deformed shape of the yielding finger. As the metallic yielding element deforms, the bolted end rotates around the bolt. As a result of this rotation, it becomes apparent that a component of the bearing force is responsible for applying the shear and bending moments, while the other component of this bearing force is applying axial force to the metallic yielding element (Fig. 3). This results in a significant increase in both the stiffness and strength at large displacements. Assuming that the metallic yielding element is bending with a constant curvature along its height, the post-yield stiffness of a STSED at a given displacement is approximated by the following equation [20]:

$$P_\delta = \frac{P_p}{\cos(2\delta/l)} \tag{4}$$