Journal of Constructional Steel Research 125 (2016) 15–25

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Seismic assessment of steel frames with triangular-plate added damping and stiffness devices

Farzad Saeedi [a,*], Naser Shabakhty [b], Seyed Roohollah Mousavi [c]

[a] Young Researchers and Elites Club, Birjand Branch, Islamic Azad University, Birjand, Iran
[b] School of Civil Engineering, Iran University of Science and Technology, Tehran, Iran
[c] Department of Civil Engineering, University of Sistan and Baluchestan, Zahedan, Iran

ARTICLE INFO

Article history:
Received 29 October 2015
Received in revised form 24 May 2016
Accepted 6 June 2016
Available online 12 June 2016

Keywords:
Triangular-plate added damping and stiffness
Seismic assessment
Nonlinear static analysis
Global damage parameter
Response modification factor

ABSTRACT

The current paper tries to investigate the seismic behavior and to determine the global damage parameter (GDP) of the moment resisting frames equipped with triangular-plate added damping and stiffness (TADAS) devices. TADAS devices are the most popular metallic dampers in order to dissipate energy in structures and are used in most projects as a passive structural controlling system. Four frame types with 3, 6, 9 and 12-story and three bays are modeled and nonlinear analyses results such as target displacement, effective and elastic lateral stiffness and fundamental period, pushover curve and the response modification factor are estimated and compared for two case of moment resisting frames (MRFs) and moment resisting frames equipped with TADAS devices (TMRFs). The results showed that the response modification factors for TMRFs are higher than the MRFs ones and decrease by 40 percent gradually with an increase in the height of the frames. It was also found that influence of TADAS devices on the increase of the global damage parameter are not so significant for low-rise frames but it is significant for high-rise frames. By using TADAS devices, GDP decreases up to 55 percent averagely.

1. Introduction

Using the inelastic deformation of metals is a useful strategy to dissipate input energy in structures due to the earthquake loads. In traditional structures this inelastic deformation is generally concentrated in beam-column joints and thus is associated with damage to the main structural elements [1]. In order to achieve economical earthquake-resistant buildings, structures must be constructed to absorb and dissipate a large amount of seismic energy. In recent years, a number of researchers have investigated different techniques increasing the building energy absorbing capacity through the use of steel-plate added damping and stiffness (ADAS) device [2–5]. The use of mechanical dampers provides the means for consuming the kinetic energy of a vibrating building without sacrificing the integrity of primary structure elements, and also represents an effective method reducing the possibility of the resonant response [6]. The effectiveness of dampers is now well recognized for consuming much of earthquake-induced energy in disposable elements which are not part of the gravity framing system [7]. During the past years, it had been confirmed that the earthquake-induced energy in a building structure can be effectively dissipated by the use of bolted X-shaped steel plate added damping and stiffness devices. Recent experimental results obtained in National Taiwan University also indicate that properly welded steel triangular-plate added damping and stiffness (TADAS) devices can sustain a large number of yielding reversals without any sign of stiffness or strength degradation. The performance of buildings can be increased employing additional dampers since these devices can absorb and damp some of the earthquake input energy [8]. These devices exhibit stable hysteretic behavior; they are insensitive to thermal effects, and extremely reliable. Bergman et al. [2] evaluated the cyclic testing of steel-plate devices for added damping and stiffness. Whittaker et al. [9] worked on the seismic testing of steel plate energy dissipation devices. Tsai et al. [10] studied on the design of steel triangular plate energy absorbers for seismic-resistant construction. Kobori et al. [11] developed some techniques on the application of hysteresis steel dampers. Two important aspects in the use of energy dissipating devices in earthquake engineering applications are: (i) to have a stable and sufficiently large dissipation capacity capable of controlling the earthquake response of the structure, and (ii) to have a representative model of its cyclic behavior [12]. Earthquake energy dissipation is concentrated in locations which have been designed for this purpose in TADAS device. Energy dissipation demands on other structural members can be substantially reduced, and because the devices are part of the lateral load resisting system only, yielding of

* Corresponding author at: Department of Civil Engineering, Faculty of Engineering, Birjand Branch, Islamic Azad University, P.O. Box: 97177-11111, Birjand, Iran.
E-mail addresses: frd.saeedi@yahoo.com (F. Saeedi), shabakhty@yahoo.com (N. Shabakhty), s.r.mousavi@eng.usb.ac.ir (S.R. Mousavi).

http://dx.doi.org/10.1016/j.jcsr.2016.06.011
0143-974X/

Fig. 1. TADAS device-to-brace connection details [17].

TADAS devices will not affect the gravity load service capacity of the structural system. The TADAS devices can be easily replaced after an earthquake, if necessary [13]. Previously elastic analysis was the main method in the seismic design of structures. However, behavior of structures during recent earthquakes indicates that relying on just elastic analysis is not sufficient. On the other hand, nonlinear dynamic analysis, although yields accurate results, is time consuming and more complex. Such analysis must be repeated for each time step in the acceleration time histories, not to mention the need for delicate interpretation of its results. Researchers have long been interested in developing fast and efficient methods to simulate nonlinear behavior of structures under earthquake loads. The idea of inelastic static pushover analysis was first introduced by Freeman for single degree of freedom (SDOF) systems in 1975. Then other researchers extended this method for multi-degree of freedom systems [14]. To evaluate the nonlinear behavior of the structures, the nonlinear static (pushover) analysis was performed by subjecting a structure to monotonically increasing lateral forces representing inertia forces in an earthquake until a target displacement is exceeded.

The aim of the research is to investigate the nonlinear behavior of TADAS frames by using the nonlinear static analyses. This study mainly focuses on the effects of using TADAS devices and evaluating the impact of nonlinear factors on the responses of structural frames such as target displacement, effective and elastic lateral stiffness and fundamental period, pushover curve and the response modification factor. The results are estimated and compared for two case of moment resisting frames (MRFs) and moment resisting frames equipped with TADAS devices (TMRFs).

2. Triangular-plate added damping and stiffness damper (TADAS)

2.1. General

One of the most effective mechanisms for dissipating input energy to the structure during an earthquake is an inelastic deformation of metals [15]. Fig. 1 depicts the typical configuration of TADAS damper and connection of the device to the brace. Mentioned damper consists of several triangular plates welded to a common base plate as shown in Fig. 1. Each triangular plate is inserted into the slotted base plate before fillet welds are applied to attach the triangular plate. During earthquakes, the interstory drifts cause movement of the upper end of TADAS damper relative to the lower end. This causes yielding of metallic plates of the damper and as a result, the energy is dissipated. Fig. 2 shows the behavior of TADAS damper during earthquake. TADAS is a variation of ADAS consisting of triangular plate elements that are made to deform as cantilever beams [16]. TADAS dampers are usually made from steel. If mild steels are designed to use, TADAS deforms so much when structure vibrates during an earthquake, then there is a permanent deformation.

Because of triangular shapes of TADAS dampers, the metal plates experience uniform flexural strains along their length. Thus, when the strain reaches the yield level, yielding occurs over their entire volume. During cyclic deformations, the metal plates are subjected to hysteretic mechanism and the plastification of these plates consumes a substantial portion of the earthquake energy. The behavior of the TADAS damper under loading shown in Fig. 3.

2.2. Hysteretic damping mechanism

Energy dissipation in different dampers relies on hysteresis materials such as structural steels. Different hysteretic loops for passive control systems and a typical hysteretic loop for a TADAS device, respectively shown in Fig. 4 and Fig. 5. Past experiments have confirmed that the properly designed TADAS devices could absorb a large amount of hysteresis energy, thereby reducing the structural response during severe earthquakes [19]. Generally the device will yield before the frame undergoes inelastic deformations, it has been found that the

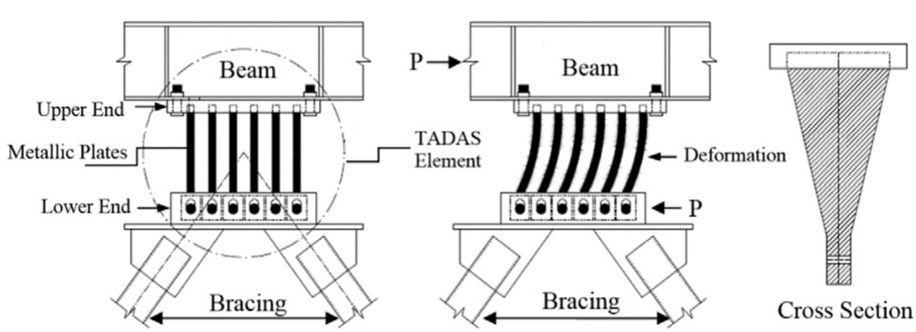

Fig. 2. Deformation of TADAS damper during earthquake [18].