Structures 7 (2016) 165–183

Contents lists available at ScienceDirect

Structures

journal homepage: www.elsevier.com/locate/structures

A New Metallic Damper for Seismic Resilience: Analytical Feasibility Study

Dhiman Basu *, P.R.M. Reddy

Indian Institute of Technology Gandhinagar, India

ARTICLE INFO

Article history:
Received 15 February 2016
Received in revised form 19 May 2016
Accepted 28 June 2016
Available online 29 June 2016

Keywords:
Added damping and stiffness (ADAS) dampers
Hourglass-ADAS (HADAS)
Storey stiffness
Incremental dynamic analysis
3D-bracing

ABSTRACT

This paper explores the feasibility of a metallic damper that enables dissipation of input energy regardless of the direction of seismic excitation. Also explored is the feasibility of appropriate mounting system. Feasibility study carried out here is restricted to the analytical domain: A ten-storied building located in a seismically active region of India and three seismic events recorded at the Large Scale Seismic Testing (LSST) array, Lotung, Taiwan. Merits of the proposed damper and its mounting system are evident over the commonly used X-plate systems but the extent of benefits depends on the types of ground motion. Component level testing indicates that necking may not be a serious concern in proposed device.

1. Introduction

Principle of conventional earthquake-resistant design that has been applied for the last 75 years is intended to ensure an acceptable safety level while avoiding catastrophic failures and life loss. A large amount of research has been conducted over the last half century into developing the innovative earthquake-resistant systems in order to raise the seismic resilience while keeping the construction costs reasonable. Use of metallic damper as supplemental energy dissipating device is one of the earliest approaches adopted in seismic resilient design. Added Damping and Stiffness (ADAS) dampers are the most commonly used metallic dampers in seismic design. Steel plate ADAS dampers have been the focus of many researchers in augmenting the energy absorbing capacity of a building. Originally manufactured by Bechtel Corporation, ADAS damper is an evolution of earlier X-plate used as a damping source for piping systems [19]. Geometry of the ADAS incorporates several interconnected yielding plates in parallel. A number of researchers have investigated the behaviour of individual ADAS elements including, Bergman and Goel [4]; Whittaker et al. [25,26]; Su and Hanson [20]; and Xia and Hanson [27]. ADAS dampers used in these studies were made of X-shaped steel plates, bolted together through two ends of each plates. These studies have confirmed its suitability for application in buildings to improve the seismic performance. Several other variants of ADAS have been reported (for example, [7,8,14,21]) but this paper considers only X-plate ADAS for further comparison.

The damper is designed to be yielding with a nominal activation load and much before the yielding of building. Early yielding of the damper is thus to avoid inelastic excursion in the primary load resisting structural elements. Whittaker et al. [25,26], proposed a simple procedure defining the force-displacement relation for ADAS dampers, which was based on X-shaped idealization of the plates along with following two assumptions: a) X-plates are rigidly restrained at their ends; and b) X-plates deform in double curvature. Force-displacement plot of the ADAS damper was then idealized as elastic-perfectly-plastic, with plastic (yield) load (P_y) and yield displacement (Δ_y) given by,

$$P_y = f_y \cdot \left(Bt^2/3L\right) \quad ; \quad \Delta_y = f_y \cdot \left(H^2/2Et\right) \tag{1}$$

where, B, t, and H are the width, thickness and height of the damper, respectively; f_y and E are the yield stress and Young's modulus of the material, respectively.

However, ADAS has limited applicability due to the fact that once it is deformed laterally the plates will be subjected to tension resulting in an early failure at the "neck" of the X-shaped plate and thereby reducing the effectiveness of the device. This failure mode was identified in a series of tests conducted at UC Berkeley. In order to improve the weakness of ADAS, Triangular-ADAS (TADAS) was then developed. Further, all the ADAS and TADAS dampers studied to date perform effectively only along the in-plane direction of the mounting system (and not along the out-of-plane direction). Bi-directional seismic demand is met by providing ADAS/TADAS dampers along two orthogonal directions. Consequently, design of a low to medium rise, full-scaled building with ADAS / TADAS elements leads to significantly heavy, and often

* Corresponding author.
E-mail address: dbasu@iitgn.ac.in (D. Basu).

http://dx.doi.org/10.1016/j.istruc.2016.06.011
2352-0124/

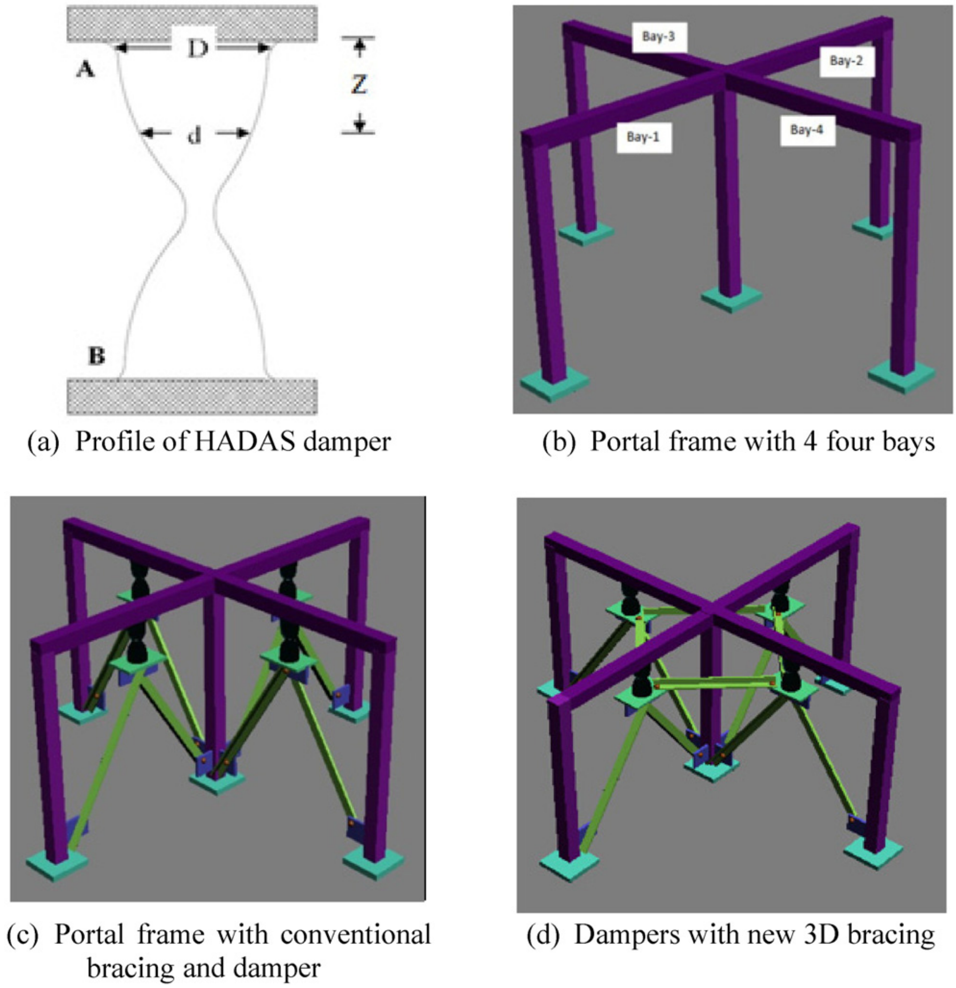

Fig. 1. Development of new 3D bracing system for HADAS damper.

unmanageable, size of the dampers. For example, Tsai et al. [22] reported the design of a twenty storied steel moment resisting frame with TADAS elements that resulted in 33 plates of 476 mm depth, 350 mm width and 50 mm thickness at the first storey level; however, the number of plates decreases at the upper storeys.

This situation can be conveniently improved if a damper effectively performing along both horizontal directions is developed. Objective of this paper is to investigate the feasibility of such a damper without sacrificing any of the benefits of ADAS dampers. Note that such a damper, even if exists, requires a special mounting system which is capable of providing stiffness along two orthogonal horizontal directions. Chevron bracings, commonly used in mounting the ADAS dampers, have negligible stiffness along the out-of-plane direction and hence, are not suitable. Another objective of this paper is to explore the feasibility of such a mounting system. This paper is restricted to exploring the analytical feasibility. Experimental validation will be carried out and reported separately.

In this paper, first, profiling of a 3D damper is presented to enable simultaneous yielding all along its length regardless of the direction of excitation; second, an appropriate mounting system is configured that offers equal rigidity regardless of the direction of excitation; third, design parameters for the damper along with the mounting system are identified; fourth, a step-by-step design process is proposed for a building equipped with the 3D dampers; and finally, the expected performance is compared. One ten-storied building located in seismic Zone V of India and three seismic events recorded at Large Scale Seismic Testing (LSST) Array in Lotung, Taiwan are used for this comparison. A brief comparison is first presented between the building with and without the proposed device followed by a comparison between the same building with ADAS and with proposed device. Emphasis has been paid on the comparison of performance against sustaining a design basis event when using the X-plate ADAS and proposed dampers. A series of device level experimental investigations is also carried out to study the susceptibility of necking in the proposed device.

1.1. Development of 3D Damper and 3D Bracing System

Intuition might suggest that an axisymmetric form of the ADAS X-plate, i.e., an hourglass shape could be a viable solution. Proposed 3D

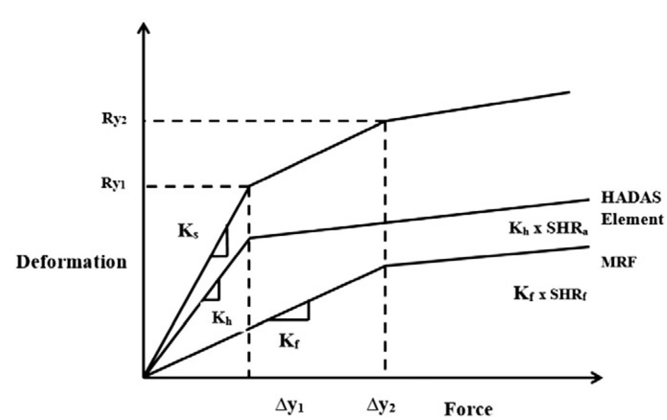

Fig. 2. Tri-linear force deformation plot (modified from [22].