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ORIGINAL ARTICLE

Seismic energy dissipation study of linear fluid viscous dampers in steel structure design

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Abstract Energy dissipation systems in civil engineering structures are sought when it comes to removing unwanted energy such as earthquake and wind. Among these systems, there is combination of structural steel frames with passive energy dissipation provided by Fluid Viscous Dampers (FVD). This device is increasingly used to provide better seismic protection for existing as well as new buildings and bridges. A 3D numerical investigation is done considering the seismic response of a twelve-storey steel building moment frame with diagonal FVD that have linear force versus velocity behaviour. Nonlinear time history, which is being calculated by Fast nonlinear analysis (FNA), of Boumerdes earthquake (Algeria, May 2003) is considered for the analysis and carried out using the SAP2000 software and comparisons between unbraced, braced and damped structure are shown in a tabulated and graphical format. The results of the various systems are studied to compare the structural response with and without this device of the energy dissipation thus obtained. The conclusions showed the formidable potential of the FVD to improve the dissipative capacities of the structure without increasing its rigidity. It is contributing significantly to reduce the quantity of steel necessary for its general stability.

1. Introduction

Man has always lived with earthquakes. Some of them are so small that they are not felt; others are so strong that they can destroy an entire city, cause major damage to infrastructures (bridges, buildings, etc.) and kill thousands of people.

During a seismic event, the input energy from the ground acceleration is transformed into both kinetic and potential (strain) energy which must be either absorbed or dissipated through heat. However, for strong earthquakes a large portion of the input energy will be absorbed by hysteretic action (damage to structure). So for many engineers, the most conventional approach to protect the structures (buildings and bridges) against the effects of earthquakes is to increase the stiffness. This approach is not always effective, especially when it is an environment that promotes resonance and amplification of seismic forces.

To do this, the field of the earthquake engineering has made significant inroads catalysed by the development of computational techniques on computer and the use of powerful testing facilities. This has favoured the emergence of several innovative technologies such as the introduction of special damping

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devices in the structures, which have the immediate effect of increasing the critical damping ratio right up 20–30% (against 5% value usually used for metal structures) and at the same time reducing the stresses and strains generated by earthquakes. This approach, is commonly known as the "energy dissipation", and has the capacity to absorb significant efforts without damaging the structure and ensuring the protection of human lives and property [1].

This approach of seismic energy dissipation is made clear by considering the following time-dependent conservation of energy relationship [2]:

$$E(t) = E_k(t) + E_s(t) + E_h(t) + E_d(t) \tag{1}$$

where

E is the absolute energy input from the earthquake motion;

E_k is the absolute kinetic energy;

E_s is the elastic (recoverable) strain energy, and E_h is the irrecoverable energy dissipated by the structural system through inelastic or other forms of action (viscous and hysteretic);

E_d is the energy dissipated by the supplemental damping system and t represents time.

The absolute input energy, E, represents the work done by the total base shear force at the foundation on the ground displacement and thus accounts for the effect of the inertia forces on the structure.

In the conventional design approach, the term E_d in Eq. (1) is equal to zero. In this case acceptable structural performance is accomplished by the occurrence of inelastic deformations, which has direct effect of increasing E_h. Finally the increased flexibility acts as filter which reflects a portion of seismic energy.

Introduction of supplemental damping devices in the structure involves increasing the term E_d in Eq. (1) and accounts for the major seismic energy that is absorbed during the earthquake [6].

In a supplemental dissipation energy system, mechanical devices are incorporated in the frame of the structure or within the base isolation system (Fig. 1).

Among these devices, there are the Fluid Viscous Dampers (FVD) which are included in the passive control systems of structural response. These systems have the ability to transmit developed forces according to the request of the structural response. Passive control devices dissipate energy in the structure, but cannot increase it. Because of their great ability to return a building to its original position after an earthquake, they are increasingly used in the bracing structures in civil engineering in general and in the metallic high-rise structures in particular. The additional cost of the damper is typically offset by the savings in the steel weight and foundation concrete volume [3]. This device and its effect on the seismic structure response are the subject of this study.

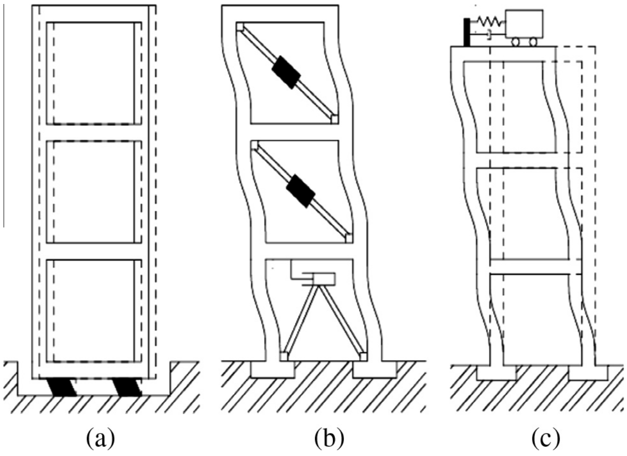

Figure 1 Passive response control system: (a) Seismic isolation, (b) FVD, (c) dynamic vibration absorber [4].

2. Fluid viscous damper

Fluid viscous dampers were initially used in the military and aerospace industry. They were designed for use in structural engineering in the late of 1980s and early of 1990s. FVD typically consist of a piston head with orifices contained in a cylinder filled with a highly viscous fluid, usually a compound of silicone or a similar type of oil. Energy is dissipated in the damper by fluid orifice when the piston head moves through the fluid [5]. The fluid in the cylinder is nearly incompressible, and when the damper is subjected to a compressive force, the fluid volume inside the cylinder is decreased as a result of the piston rod area movement. A decrease in volume results in a restoring force. This undesirable force is prevented by using an accumulator. An accumulator works by collecting the volume of fluid that is displaced by the piston rod and storing it in the makeup area. As the rod retreats, a vacuum that has been created will draw the fluid out. A damper with an accumulator is illustrated in Fig. 2 [6].

2.1. Characteristics of fluid viscous dampers

FVD are characterised by a resistance force F. It depends on the velocity of movement, the fluid viscosity and the orifices size of the piston. The value of P is given by the relationship [7]:

$$P = C_d \cdot \left(u_d^{\bullet}\right)^{\alpha} \cdot \sin\left(u_d^{\bullet}\right) \tag{2}$$

with

$$u_d(t) = u_0 \cdot \sin(\omega \cdot t) \tag{3}$$

where

$u_d^{\bullet}$ is the velocity between two ends of the damper;

C_d is the damping constant;

u_0 is the amplitude of the displacement, ω is the loading frequency, and t is time;

α is an exponent which depends on the viscosity properties of the fluid and the piston.

The value of the constant α may be less than or equal to 1. Figs. 3 and 4 show the force velocity and the force displacement relationships for three different types of FVD. They characterise the behaviour of the viscous damper. With $\alpha = 1$ the device is called linear viscous damper and for $\alpha < 1$ non-linear FVD which is effective in minimising high velocity shocks. Damper with $\alpha > 1$ has not been seen often in practical application. The non-linear damper can give a larger damping force than the two other types (Fig. 3) [8].

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