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SEISMIC PROTECTION OF STRUCTURES USING HYDRAULIC DAMPER DEVICES

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ABSTRACT

In recent years, much attention has been paid to the research and development of structural control techniques with particular emphasis on alleviation of wind and seismic responses of structures. Structural control in civil engineering has been developed from the concept into a workable technology and applied into practical engineering structures. The aim of this paper is to review a state of the art of researches and applications of structural control in civil engineering. It includes the passive control using hydraulic damper devices as diagrams of displacement and acceleration of main parts of system.

KEYWORDS: composite neoprene, rheological modelling, vibration and shock isolator

1. INTRODUCTION

Civil engineering structures located in environments where earthquakes or large wind forces are common will be subjected to serious vibrations during their lifetime. These vibrations can range from harmless to severe with the later resulting in serious structural damage and potential structural failure. The traditional method of antiseismic technique is to increase the stiffness of structures by enlarging the section of columns, beams, shear walls, or other elements, which will enhance the seismic load because of the added mass to structures. As a result, although the cost of structures with traditional antiseismic technique is increased a lot, the safety level of structures is less improved. Another disadvantage of the traditional antiseismic technique is that it focuses on the protection of the structure but neglects the facilities inside the structure. Hence, it cannot be used in some structures whose facilities inside them are very important, such as hospitals, city lifeline engineering, nuclear plants, museum buildings, and the buildings with precise instruments.

Even though engineers cannot design a building which is damage-proof during earthquakes and strong winds, the structural control is promising in reducing the vibration of structures. Different from the traditional antiseismic method, the structural control technique suppresses the structural vibration by installing some devices, mechanisms, substructures in the structure to change or adjust the dynamic performance of the structure.

2. SEISMIC PROTECTION OF STRUCTURES WITH HYDRAULIC DAMPERS

The strengthening method consists in introducing into the structure devices capable to dissipate the energy induced by the earthquake through deformation. The main passive control devices are: yielding metal devices, friction devices, viscous dampers and visco-elastic dampers. A force proportional with the displacement is developed in the hydraulic damper devices, which dissipate the energy through hysteretic cycles of loading-unloading. In the last two devices, the force is proportional with their deformation velocity. These devices have an insignificant effect on the dynamic characteristics of the structure (vibration periods), reducing the structural response at seismic actions strictly by transforming the kinetic energy associated to the masses into heat energy. Unlike the base isolation devices, which act in series with the structure, absorbing the energy and filtering the motion before transmitting it to the structure, internal dampers act in parallel with the structure. The induced energy is absorbed by the system structure - dampers and dissipated according to the characteristics of its components. In order to obtain optimal performance, the dampers have to be tuned to the structure, which is difficult, especially because not all buildings behave better by increasing their damping. The use of modern control procedures depends on the structure type, site conditions, and frequency content of the earthquake. An efficient damper device is the hydraulic damper with viscous fluid. The force developed in a hydraulic damper is proportional with the deformation velocity, $\dot{u}(t)$

$$F_d = c\left|\dot{u}\right|^{\alpha}\,\mathrm{sgn}(\dot{u}) \tag{1}$$

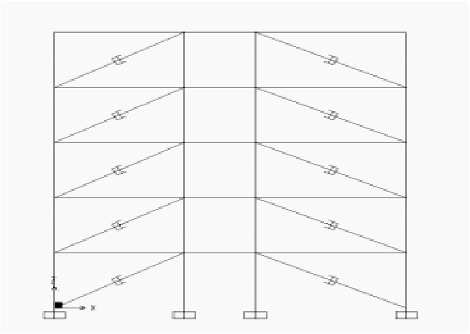

Figure 1 Structure with viscous dampers

Figure 1 shows one structure with linear viscous dampers installed on metallic braces of steel OL37, damper coefficient is c = 10 kNsec/mm. Hydraulic dampers are axial devices whose force is proportional to velocity, whether linear or not. The hydraulic circuit connecting the two chambers in which the cylinder is divided by a piston head, as well as the fluid and the geometric design of the dampers, are different depending on the manufacturer. The hydraulic circuit usually consists of orifices in the piston head or relief valves. Last generation of hydraulic dampers have orifices in the piston head, and commonly have an exponent $\alpha \approx 0.15$. Thus, their reaction is almost constant within a wide velocity range. This permits the devices to already initiate damping reaction at low velocities. The effect maximizes the reduction of displacements owing to the high efficiency of the hysteretic loop. In other words, a device characterized by a larger α exponent at an equal level of maximum load transmitted to the structure permits greater displacement.

3. HYDRAULIC DAMPERS

The physical model of a hydraulic damper is shown in Figure (2). The connection and the symbolisation are presented in Figure (3).

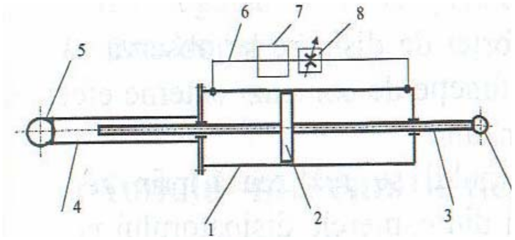

Figure 2 Construction of hydraulic damper

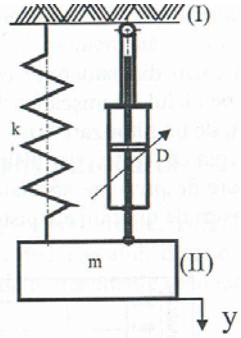

Figure 3 Hydraulic damper symbolization

A damper is achieved as a hydraulic cylinder (1) with two rooms separated by a piston (2). The rooms are filled with a viscous medium (synthetic oil, silicone oil, suspended particles). The piston (2) is in solidarity with piston rod (3). The third room (4) is located inside the compensation tube and is intended to offset expansion or contraction under the effect of viscous heat environment.

The reversible work to reciprocating traction-compression, and dynamic behavior depends on the instantaneous frequency of excitation produced by the earthquake, mechanical shock or vibration.

Using dissipative energy devices seeks to improve the behavior of the structure by increasing the damping, that is necessary for kinetic energy dissipation that occurs in the structure due to seismic motion.

A general characterization of these devices can be made in terms of mechanism dependent on:

-displacement

-speed
-acceleration

These devices can modify the dynamic characteristics of the system, protecting excessive patterns and increase energy dissipation capacity of the structure under the action of seismic loads.

The equation of dynamic equilibrium that characterizes the movement of a structural system generally is evidenced by:

$$Q_I(t)+Q_D(t)+Q_R(t)=-M\ddot{q}_s(t) \tag{2}$$

for generalized system, and in particular the relation (4) can be explained as follows:

$$M\ddot{q}(t)+C\dot{q}(t)+Q_R(q(t))=-M\ddot{q}_s(t) \tag{3}$$

where generalized system forces have the following meanings:

$Q_I(t)$ - inertial forces of the system;

$Q_D(t)$ - system damping forces;

$Q_R(t)$ - system recovery forces (in case of elastic response);

$Q_R(t)=K_q(t)$

M - system mass;

$q_s(t)$ - land acceleration;

C - system damping constant;

K - system stiffness ;

$q(t),\dot{q}(t),\ddot{q}(t)$ - instant structural responses: displacements, velocities and accelerations; [3]

The introduction of damper characteristics change the equation (5) as follows:

$$C\cdot\dot{q}(t)+Kq(t)=-M\left[\ddot{q}(t)+q_s(t)\right]+F_r=0 \tag{4}$$

where Fr is the force of reaction from the damper.

4.NECESSARY CHARACTERISTIC OF THE DAMPER

A necessary characteristic is the law of variation of resistant force according to displacement of the stem of the damper. Thereby it is shown in Figure 3 the theoretical characteristics of strong force sinks without adjustment, and in Figure 4 the theoretical characteristics for sinks featuring adjustable resistance force.

It is noted that this feature is actually dissipated energy to complete the displacement of the damper stem, according to maximum piston stroke.

This energy is the area contained within the parallelogram described by the resistant force (at the piston rod) and the damper instant displacement.

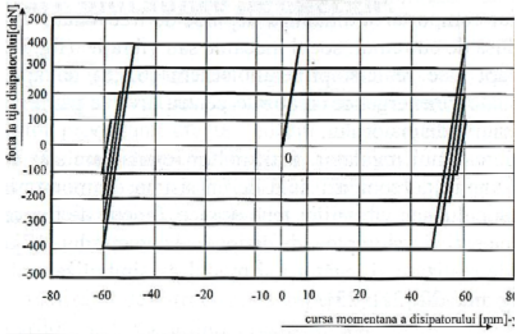

Figure 4 Theoretical characteristic of hydraulic damper

In case of the force adjustment of the damper, it is observed that the dissipated energy on each cycle of movement is variable depending on external commands made by a monitoring system for dynamic phenomenon.

Force adjustment in the system is achieved by adjusting the pressure with special pressure regulators between chambers of damper for the two directions of movement of the piston (stretching and compression).

The provided characteristic of energy dissipation of damper presented in Figure 5 with the specific notations is defined as analytical form as follows:

$$F_{rez}=\begin{cases}\dfrac{2F_0}{\delta}y;\ pentru\ y\in(0,\delta/2); \\ F_0;\ pentru\ y\in(\delta/2,x_0) \\ F_0+\dfrac{2F_0}{\delta}(y-y_0);\ pentru\ y\in(y_0,y_0-\delta) \\ -F_0;\ pentru\ y\in(y_0-\delta,-y_0); \\ -F_0+\dfrac{2F_0}{\delta}(y+y_0);\ y\in(-y_0,-y_0+\delta) \\ F_0;\ pentru\ y\in(-y+\delta;y_0)\end{cases} \tag{5}$$

where

F_0 is the adjusted dissipation force, evaluated as regulated pressure multiplied by the surface area of the front damper piston;

δ - piston stroke to passive opening pressure regulator;

y - damper instant stroke;

y_0 - damper half-stroke .

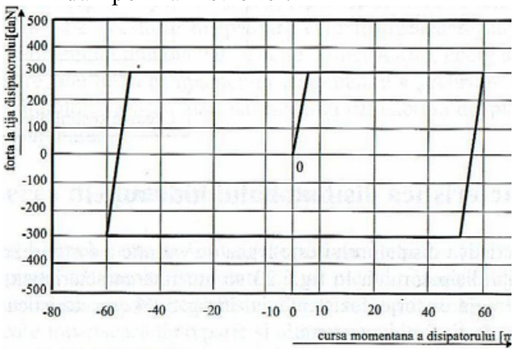

Figure 5 Theoretical characteristic of the damper with adjustable force

5.CONCLUSIONS

Using energy dissipative devices seeks to improve the behavior of the structure by increasing the damping, the necessary dissipation of kinetic energy that occurs in the structure due to seismic motion. Structural response is reduced by changing the left part of the base equation. These devices are provided with special, easy to apply, properties.

A general characterization of these devices can be made in terms of the damping mechanism. It can be dependent on displacement, velocity, acceleration or a combination thereof, referring to amend the relevant part of the equation of motion.

Both the new construction, and existing buildings on seismic rehabilitation should include such damping elements, that should be located so that to exploit the different dynamic behavior of the parts connected and improve energy dissipation and damping response.

The experience of manufacturers in the seismic retrofit of bridges and structures via seismic isolation and energy dissipation devices has demonstrated that hydraulic damper devices can be used in most cases to improve the seismic performance of existing structures at the level required by modern seismic codes

- reducing to a minimum (or avoiding completely) the strengthening of piers and foundations.

- different devices can be used – and combined to solve specific problems presented by a particular structure.

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