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Importance of interstory velocity on optimal along-height allocation of viscous oil dampers in super high-rise buildings

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A B S T R A C T

The effective way of allocation of viscous oil dampers (capacity or size) is believed to place dampers to the stories which exhibit large interstory drifts. It is shown here that, while this understanding is almost true in rather low or medium-rise buildings, the distribution of the maximum interstory velocities plays a critical role in super high-rise buildings. It is further demonstrated that a large distribution of the maximum interstory velocities can be observed in lower stories in super high-rise buildings and this leads to a large demand of the maximum damping force in lower stories. It is concluded that the demand of relief forces of oil dampers is expressed in terms of (a) the maximum story shear forces of a frame without oil dampers which can be evaluated by the response spectrum method or other conventional methods, (b) the damper damping ratio, (c) the damping correction factor and (d) the higher-mode correction factor.

1. Introduction

There are a variety of passive dampers for building structures under earthquake ground motions [1–4]. Hysteretic steel dampers (shear deformation type, buckling restrained type), viscous wall-type dampers, viscous oil dampers, visco-elastic dampers, friction dampers are representative ones. Recently viscous oil dampers (called oil dampers hereafter) are often used from the viewpoints of stable mechanical properties, low frequency and temperature dependencies and cost effectiveness, etc. together with hysteretic steel dampers.

Many research works have been accumulated so far on the damper optimization [4–19], i.e. damper size and location. While most of them deal with linear responses, quite a few treat non-linear responses in building structures or dampers [11,20–24]. However, there is no research except [22–24] on the optimization of location and quantity of dampers which deals directly with non-linear responses and includes simple and systematic algorithms. Although simple and systematic algorithms for damper optimization are useful in research, more simplified procedures are desired in the usual structural design practice.

The purpose of this paper is to demonstrate that the distribution of the maximum interstory velocities is a key index for evaluating the along-height effectiveness and demand of viscous-type oil dampers and its distribution exhibits special characteristics depending on the number of stories of building frames to be considered. A simplified evaluation procedure of the demand of oil dampers is also presented. It will be shown that the demand of relief forces of oil dampers is expressed in terms of (a) the maximum story shear forces of a frame without oil dampers which can be evaluated by the response spectrum method or other conventional methods, (b) the damper damping ratio, (c) the damping correction factor and (d) the higher-mode correction factor.

Most structural engineers seek for the design procedure to evaluate the required damper capacity (damping coefficient and relief force in the case of viscous oil dampers) directly from the frame response without dampers. Since the existence of two parameters, damping coefficient and relief force, seems to cause a difficulty in investigating the simplified design method for oil dampers, the distribution of damping coefficients is limited to a frame stiffness proportional one. It is also well known that the capacity of oil dampers depends mainly on the relief force (or the limiting damping force) and not on the damping coefficient [23]. It is pointed out in this paper that special characteristics on the effective location and demand of viscous oil dampers can be observed especially in super high-rise buildings and these characteristics can be explained by paying attention to the distribution of the maximum interstory velocities, not the distribution of the maximum interstory drifts.

Once the required linear damper capacity is obtained, it is known [23,25] that the specification of the reduction ratio of the relief force from the corresponding linear damping force is possible so as not to change the displacement response of building frames

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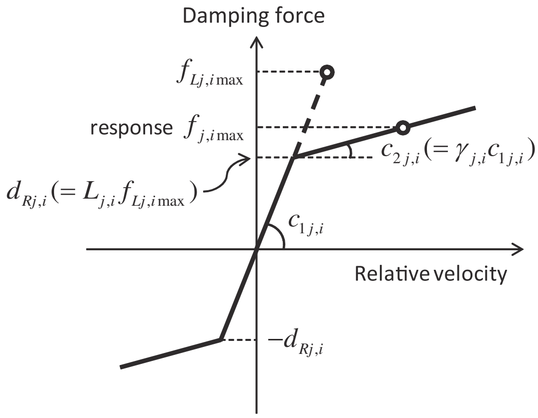

Fig. 1. Damping force–velocity relation of oil damper.

including dampers with the relief mechanism from that of building frames including linear dampers.

2. Frame including oil dampers with relief mechanism

Consider oil dampers with a relief mechanism [23,25] and a planar frame model with those oil dampers. The damping force–velocity relation of the oil damper is shown in Fig. 1.

Let $c_{1j,i}$ denote the damping coefficient of the oil damper in the jth story and ith span under the relief force and $c_{2j,i}$ denote that beyond the relief force. The relief force and the angle of the oil damper from the horizontal line are denoted by $d_{Rj,i}$ and $\phi_{j,i}$, respectively. The ratio of $c_{2j,i}$ to $c_{1j,i}$ is usually specified as 0.05–0.10. Let $f_{j,i\max}$ denote the maximum damping force of the oil damper in the jth story and ith span and let $f_{Lj,i\max}$ denote the maximum damping force of the 'linear oil damper' in the jth story and ith span. The ratio of $d_{Rj,i}$ to $f_{Lj,i\max}$ is called 'the damping force limit ratio' and is defined by

$$L_{j,i} = \frac{d_{Rj,i}}{f_{Lj,i\max}} \tag{1}$$

This damping force limit ratio plays an important role in the design of oil dampers. From Eq. (1), the relief force can be expressed in terms of the damping force limit ratio $L_{j,i}$ and the maximum damping force $f_{Lj,i\max}$ of the linear oil damper.

$$d_{Rj,i} = L_{j,i}f_{Lj,i\max} \tag{2}$$

It is well recognized [23,25] that, when 0.5–1.0 is employed as $L_{j,i}$, the frame including the oil dampers with the relief mechanism exhibits almost the same performance (horizontal displacement, etc.) as the frame including the oil dampers without the relief mechanism, i.e. linear oil dampers.

Because it is well known that, when a sufficient supporting member stiffness is used, the viscous oil damper exhibits a

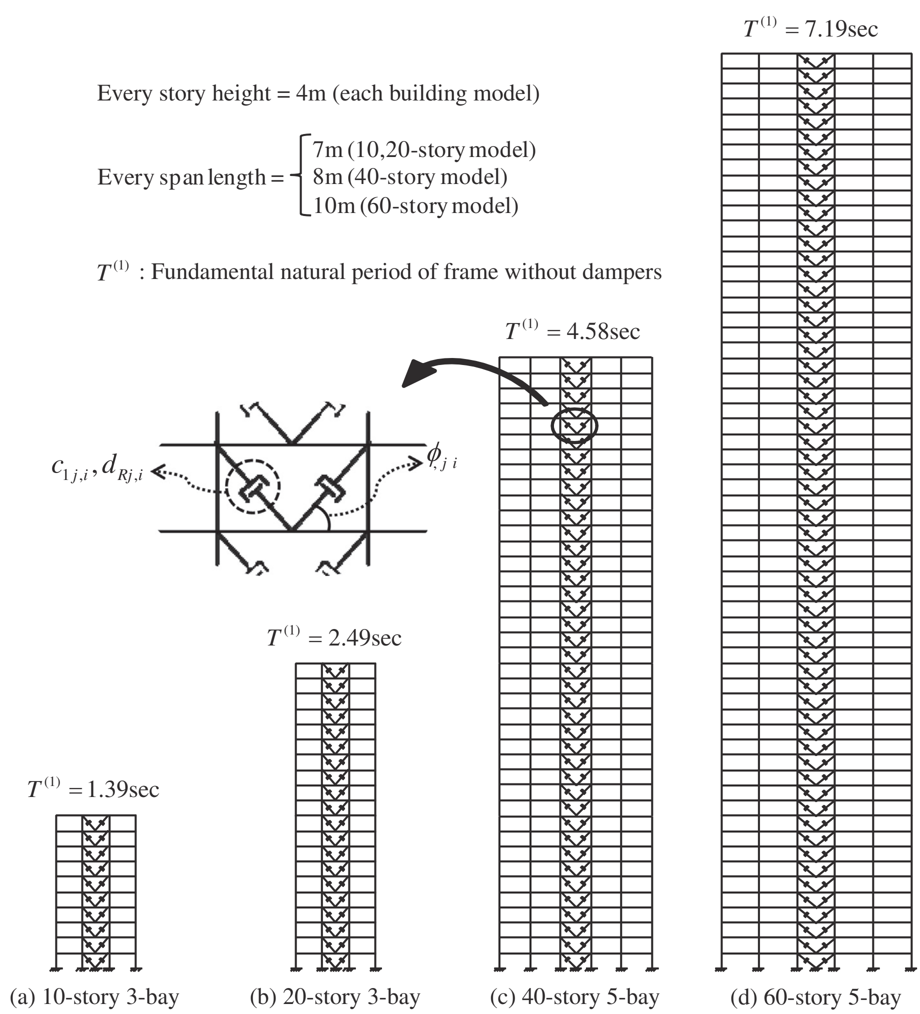

Fig. 2. Planar building model.