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Shaking table tests and numerical studies on the effect of viscous dampers on an isolated RC building by friction pendulum bearings

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ABSTRACT

Base isolation is an effective way for diminishing the response of a structure to seismic action. However, this results in large displacements for isolators, particularly for buildings located in near-fault sites. Viscous dampers (VDs) are often used as supplementary devices to reduce those displacements, but there is a potential for significant increases in story drift and floor acceleration of the superstructure. This paper aims to investigate the effect of viscous dampers on a base-isolated 16-storey reinforced concrete (RC) framed structure with friction pendulum bearings (FPBs) through shaking table tests and numerical simulations. First, the similitude design method for small scaled test models was introduced, including the stiffness-based method for FPBs and the energy-based method for VDs. Then a shaking table test for the isolated structure using FPBs was conducted. Experimental and numerical results were utilized to investigate the effect of VDs on both the displacement of the isolators and the response of the superstructure. It is concluded that VDs do not significantly influence either the isolation displacements or the structural response in a small earthquake, but isolator displacements can be remarkably controlled in a strong earthquake at the expense of a slight increase in the superstructure response.

1. Introduction

Base isolation is one of the most widely used and accepted protection systems in seismic regions [1]. Isolated buildings have been built in more than 30 countries, including over 3000 buildings in Japan, over 200 buildings in the USA and many in China, New Zealand, Italy, Russia and Turkey. Isolated structures are characterized by a low frequency of the fundamental mode corresponding to low spectral values for most of the potential earthquake excitations. Thus, there is a significant reduction in the seismic forces acting on the superstructure. However, this reduction is achieved at the expense of a large isolation floor displacement. For this reason, most seismically isolated systems include an energy dissipation mechanism to introduce a higher level of damping in the systems in order to limit the displacement to an acceptable level. Especially in high seismic intensity areas or near-fault sites, displacement restraint devices are needed even though some types of isolators themselves have energy dissipation ability. Thus, viscous dampers are often used in isolation floors as supplementary damping devices thereby creating hybrid base isolation systems (combining isolators with dampers). Many works have been done on the subject of hybrid base isolation system. Kelly [2], Hall [3], Hall and Ryan [4], Providakis [5], Mazza and Vulcano [6], Zargar et al. [7], Fathi et al. [8] and Markou et al. [9] studied this subject using analytical or numerical methods. Others, however, presented experimental and numerical works including Buckle et al. [10], Chang et al. [11], Politopoulos [12], Kani [13], Wolff et al. [14] and Rawlinson et al. [15].

Despite the widespread use of VDs in base isolation, there are certain adverse effects caused by supplementary damping, which create some concerns about their effectiveness. Kelly [2] after an analysis involving linear elastic and linear viscous behavior found out that the isolator displacement and structural base shear may be reduced but floor accelerations and inter-story drift increase. Politopoulos [12] concluded that a viscous damper typically has a favorable effect but increases in damping beyond an optimum value (30%), result in an increase in the acceleration and the elastic force value, even though these values are still lower than those corresponding to low viscous damping (5%). Providakis [5] performed a nonlinear time history analysis and concluded that beyond certain levels of supplemental damping, the isolated buildings still remain vulnerable to damage if drifts are not carefully controlled. Mazza and Vulcano [6] analyzing the nonlinear response of base-isolated framed buildings under near-fault earthquakes found out that supplemental viscous damping at the base is suitable for controlling the isolator displacement, but this does not guarantee a better superstructure performance. Wolff et al. [14] compared the effect on isolation caused by linear and nonlinear viscous dampers and concluded that too much damping is detrimental and it is

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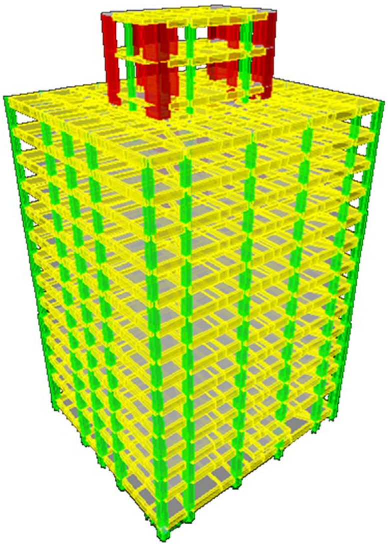

Fig. 1. Three-dimension model of prototype building.

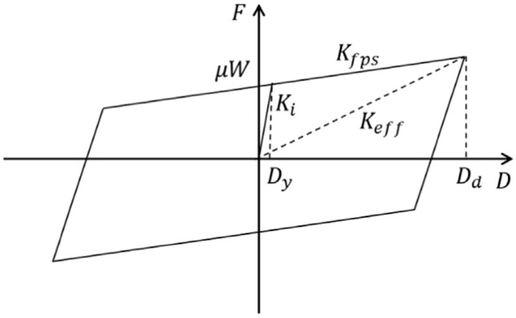

Fig. 2. Simplified mechanic model for FPB.

best to add linear viscous damping. Finally, Rawlinson et al. [15] proposed a type of passive gap damper that allows the base isolation system to meet performance criteria under varying levels of ground excitation, while Zargar et al. [7] evaluated numerically the performance of viscous gap damper models for a system with different periods of isolation.

Based on the above discussion, it is apparent that i) most of the studies on the subject are numerical, ii) the few experimental studies deal with low-rise buildings and iii) the effect of viscous dampers on the response of base-isolated structures is not well understood and a number of certain aspects of the problem require clear and definite answers. In this paper, an attempt is made to provide these answers through well designed and executed tests and numerical studies on a high-rise building. A comprehensive comparison study of experimental and numerical results for a scaled isolated reinforced concrete (RC) frame structure with and without the installation of linear VDs is presented. The paper first discusses the similitude design methods for scaled friction pendulum bearings (FPBs) and viscous dampers (VDs). Then the testing of a 1/15-scaled isolated structure with model FPBs and VDs on the shaking table under minor, moderate and major seismic inputs is presented. Corresponding numerical analyses results are also obtained in good agreement with the tests. Comparison of the tests and numerical results for the cases with and without VDs are then conducted and clear and definite conclusion are drawn. According to the results of this paper, when the seismic intensity is comparatively small, the additional VDs at isolation layer would reduce the seismic response. However, if the seismic intensity goes larger, VDs can introduce an adverse effect on the seismic response of the superstructure.

Table 2
Design parameters of model friction pendulum bearings.

Parameter	Value	Parameter	Value
Radius (*mm*)	145	Period (*s*)	0.76
Vertical load (*kN*)	25	Static friction coefficient	0.03
Kinetic friction coefficient, fast	0.03	Kinetic friction coefficient, slow	0.02
Yield displacement (*mm*)	0.019		

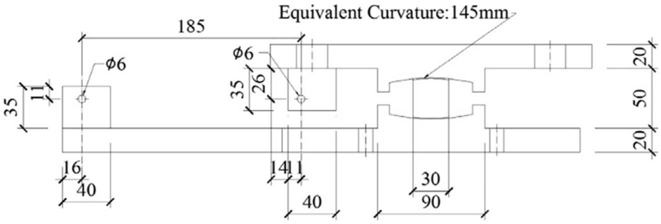

Fig. 3. Front view of the FPB with a position reserved for the damper.

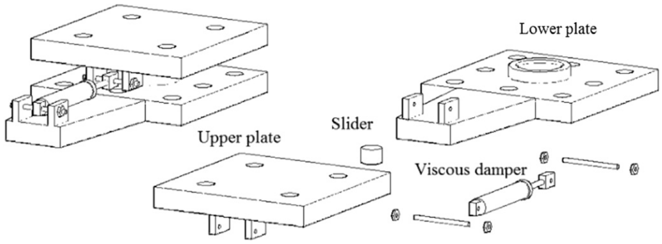

Fig. 4. Three-dimension model of the FPB with a position reserved for the damper.

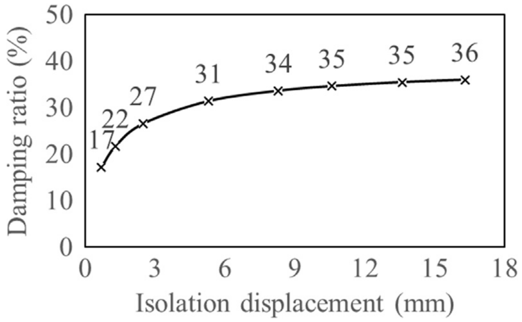

Fig. 5. Critical damping ratio of VDs.

Table 1
Parameter scaling factors for the model superstructure.

Parameter	Relation	Scaling factors	Parameter	Relation	Scaling factors
Length *l*	S_l	1/15	Time t	$S_t = (S_l / S_a)^{1/2}$	0.21
Elastic modulus *E*	S_E	1/5	Acceleration a	S_a	1.5
Strain *ε*	S_ε	1.0	Velocity v	$S_v = (S_l\, S_a)^{1/2}$	0.32
Mass *m*	$S_m = S_\rho\, S_l{}^3$	5.93×10^{-4}	Displacement X	$S_X = S_l$	1/15
Stiffness *k*	$S_k = S_E\, S_l$	1.33×10^{-2}	Force F	$S_F = S_E\, S_l^2$	8.89×10^{-4}
Density *ρ*	S_ρ	2.0			