OPTIMUM INSTALLATION OF VISCOUS LIQUID DAMPERS IN HIGH-RISE BUILDINGS

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ABSTRACT :

Viscous liquid dampers can be installed in high-rise buildings of high intensive seismic regions to reduce their responses under earthquake. The placements of dampers are limited by some factors, such as architectural space distributions and actual results of energy dissipation. A real high-rise building with strengthened storeys and abrupt changes of vertical stiffness in a high intensive seismic region is brought as an example to discuss the strategy for optimum installation of viscous liquid dampers. Storey displacement angles and bottom shear are set up as optimizing targets and through several cases of different locations and quantities of dampers the optimal strategy of viscous liquid dampers is put forward. The simulation of a finite element model for this actual high-rise building with strengthened storeys draws the conclusion that storey displacement angles and bottom shear of this building with dampers both decline obviously and effects of seismic energy dissipation are nicer. This optimal strategy for dampers is practical.

KEYWORDS: viscous liquid damper, high-rise buildings, strengthened storey, seismic energy dissipation

1. INTRODUCTION

Most damaging earthquakes provided powerful reminders of how vulnerable we all are to the forces of nature. Even in some developed countries, buildings are still quite susceptible to natural disasters, especially to earthquake. Earthquakes throw large damages to buildings and a lot of pains to human beings. Consequently, one of the principal current challenges in civil engineering concerns the development of innovative design concepts to better protect structures, along with their occupants and contents, from the damaging effects of destructive environmental forces including those due to earthquakes [1]. To prevent catastrophic failure of buildings under earthquakes, many new and innovative concepts of structural protection have been advanced for the last thirty years and are at various stages of development now, one of which is passive energy dissipation [1-2]. Some effects have been undertaken to develop the concept of passive energy dissipation or supplemental damping into a workable technology, and a number of these devices have been installed in structures throughout the world. As well-known, viscous fluids can be effectively employed in order to achieve the desired level of passive control for civil structures. Significant effort has been directed in recent years toward the development of viscous fluid dampers for structural application, primarily through the conversion of technology from the military and heavy industry [1]. In this paper, some discussions about optimal installation of viscous fluid dampers in a high-rise building with strengthened storeys are made.

Now, there are many high-rise buildings for business or living either in developed countries or in some developing countries. In these high-rise building, one or some storeys for equipments or hiding when disasters occur may be set up as strengthened storeys. These strengthened storeys are often designed as two modes: one is to place horizontal outriggers between the core tube and the frame, and another is to place belt elements between frames. Strengthened storeys can result in irregularities of structural rigidity and inner forces, and so structural arrangements and selection of rigidities of strengthened storeys should be designed in detail. In this paper, the background structure is a high-rise building with two strengthened storeys in a high intensive seismic region. Firstly, dynamic characteristics of this building are analyzed in detail. Subsequently, the strategy of optimal installation of viscous liquid dampers is discussed.

This building has two towers and thirty-eight storeys, including five storeys of a podium. The structure is a frame-tube structure, its plane dimension is $72m \times 48m$ and the total height is 156m. The standard storey of one tower is looked as Fig.1. The seismic fortification intensity of the region that this building lies in is 8 degree, the classification of design earthquake is the first classification, the ground belongs to Ⅱ, and the characteristic period of the ground is 0.35s.

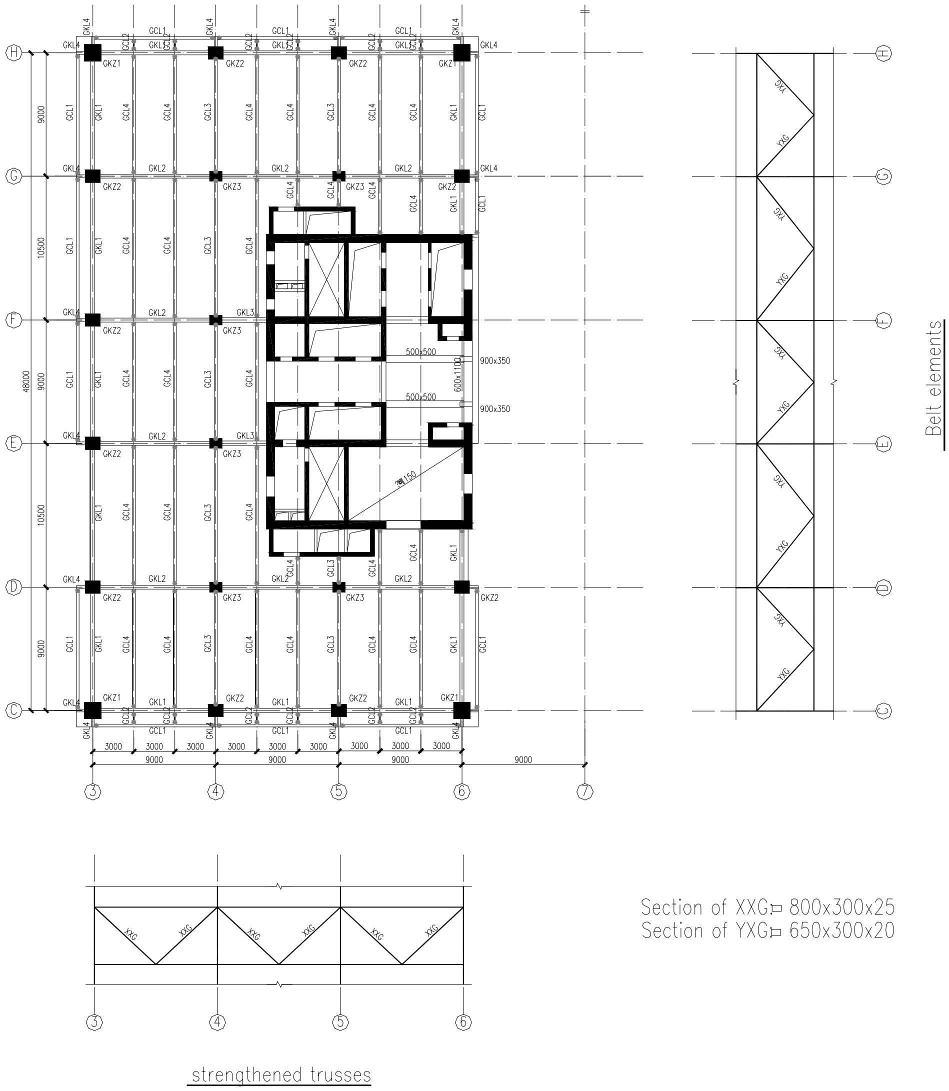


Figure 1 Towers and strengthened elements

Two strengthened storeys are placed on the sixteenth storey and the twenty-seventh storey, which consists of steel braces. The inside strengthened elements are placed under main beams to connect the core tube and the frame. Meanwhile, belt elements are installed between outside frames. The section of inside strengthened trusses is a box of $800 \times 300 \times 25mm$ and the section of belt elements is a box of $600 \times 300 \times 20mm$. The strengthened trusses and belt elements are shown in Fig.1. Because of equipments, there is no plate between the thirty-third storey and the thirty-forth storey. So is the plate between the thirty-fifth storey and the thirty-sixth storey. So abrupt changes of vertical stiffness occurs between the thirty-third storey and the thirty-sixth storey. This affects the rule of lateral displacements of the whole building.

2. ANALYSIS OF DYNAMIC CHARACTERISTICS OF THE BACKGROUND PROJECT

Based on design drawings, a finite element of this building with strengthened storeys is set up and shown as Fig.2. Dynamic characteristics of this building are analyzed and listed in Tab.2.1.

Table 2.1 Dynamic characteristics of the building

Mode	Period(s)	Mass participation percent (%)					
		UX	UY	UZ	RX	RY	RZ
1	3.10	64.65	0.00	0.00	0.00	93.45	0.02
2	2.53	0.00	1.15	0.00	1.72	0.00	0.00
3	2.42	0.00	59.28	0.00	87.84	0.01	3.77
4	2.33	0.03	5.17	0.00	7.56	0.05	47.27
5	1.37	0.00	0.00	0.00	0.01	0.00	21.53
6	1.31	0.00	0.04	0.00	0.03	0.00	0.05
7	0.88	0.14	0.00	0.00	0.00	0.02	0.12
8	0.77	0.00	0.01	0.11	0.00	0.01	0.00
9	0.70	18.72	0.00	0.00	0.00	1.24	0.00
10	0.58	0.00	15.64	0.01	0.93	0.00	2.82

From the Tab.2.1, some conclusion about dynamic characteristics of this building can be drawn as:

(1) The core tube is placed near the inside of the tower and this causes the plane stiffness of the structure to be asymmetric. So, the first mode of the structure is the torsion vibration.
(2) Vertical vibration of the structure plays an unimportant role in dynamic modes and can be ignored in analysis of seismic responses.
(3) Until the thirty-forth mode, the cumulative mass participation percents of the structure in the direction of X and Y rise to 90 percent. So, the higher modes can not be ignored in analysis of seismic responses.

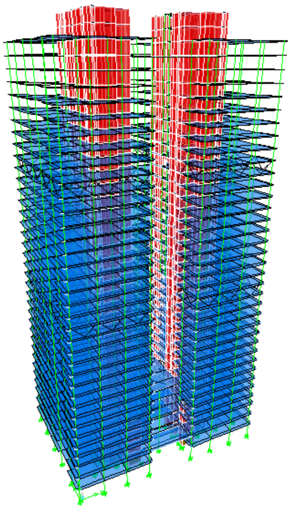


Figure 2 The finite element

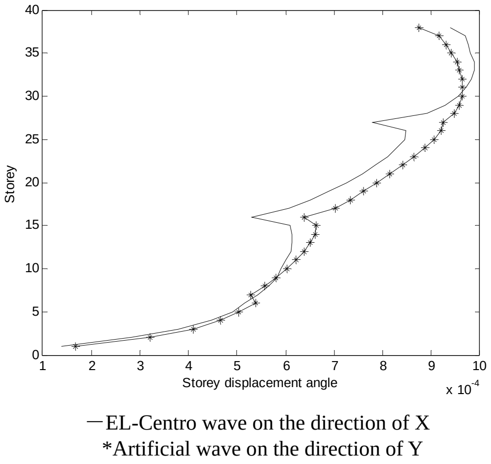


Figure 3 Storey displacement angle

3. ANALYSIS OF SEISMIC ENERGY DISSIPATION

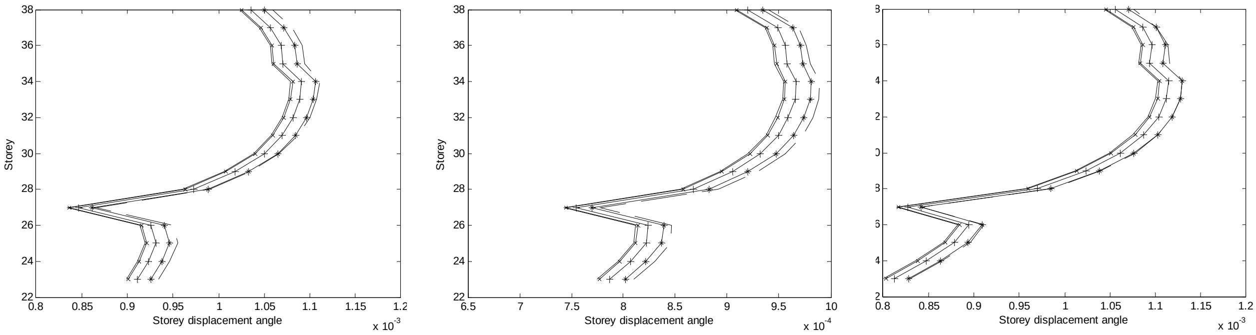
Two natural seismic waves and one artificial wave are regarded as acceleration excitations to be imported into the finite element of this building with two strengthened storeys. The storey displacement angles of every storey of this building under these three seismic waves are shown in Fig.3. From Fig.3, it is clear that the storey displacement angle rises along with the number of the storey and rises to the biggest until from the thirty-third storey to the thirty-six storey in which there is on plate. Generally, the rule of storey displacements of the frame-tube structure under earthquake is: the storey displacement of middle storeys is the biggest and the bottom storey and the top storey is the least. Then from Fig.3, it is revealed that, the loss of two plates results in the rule of the storey displacements of the whole building shifting. At the same time, the storey displacement of the strengthened storey is much less than storeys around it. That is to say, abrupt changes of vertical stiffness nearby the strengthened storey occur. So, when the frame-tube structure with strengthened storeys is applied to the region of high intensive earthquake, the design for it should be analyzed in detail.

Based on dynamic characteristics of this building, it is obvious that viscous liquid dampers are fit to increase its damping ratio, decrease its vibration responses and sections of structural components and make its costs decline. In viscous liquid dampers, its damping force varies with the velocity of the piston as:

$$F \propto V^{\alpha} \tag{3.1}$$

Where, α is a constant, named as damping exponent, varying from 0.5 to 3.0.

Firstly, viscous liquid dampers are installed in the storeys from the twenty-third to the twenty-sixth and from the twenty-eighth to the thirty-sixth in the direction of X. They are linear viscous dampers and α=1. The damping coefficient is $2\times10^{7}\,N\cdot s/m$, and the quantity of dampers in every storey varies from 4 to 10.



Artificial wave EL-Centro wave Federal wave

——without dampers *with four dampers +with six dampers x with eight dampers —with ten dampers

Figure 4 Storey displacement angle of this building with different quantities of dampers

The storey displacement angles of storeys with dampers are shown as Fig.4. From it, it is clear that the storey displacement angles of this building decline sharply because of viscous liquid dampers. But, when the quantity of dampers in every storey becomes to be 10 from 8, this declining becomes unconspicuous. Varieties of bottom shear of this building are shown as Tab. 3.1. It is obvious that, bottom shear of this building declines sharply because of viscous liquid dampers. When the quantity of dampers in every storey is eight, bottom shear declines by 22 percent. When the quantity of dampers in every storey becomes to be 10 from 8, this declining becomes unconspicuous too. So, it is appropriate that eight dampers are installed in every storey.

When the quantity of dampers in every storey is decided, in which storey dampers should be installed may be discussed. Three cases are analyzed: the first is that dampers are installed in from the twenty-third storey to the twenty-sixth storey and from the twenty-eighth storey to the thirty-sixth storey, the second is that dampers are installed in from the thirteenth storey to the fifteenth storey and from the seventeenth storey to the twenty-sixth storey, and the third is that dampers are installed in from the first storey to the thirteenth storey. Bottom shears of this building of these three cases are listed in Tab.3.2. It is clear that results of the first case are the best. That is to say, dampers should be installed in storeys of which the storey displacement angles are large.

Table 3.1 Bottom shear of this building in the direction of X (Unit: kN)

Quantity of dampers	Artificial wave		El-Centro wave		Federal wave	
	Bottom shear	Percent of declining	Bottom shear	Percent of declining	Bottom shear	Percent of declining
0	50611.01	0	51005.92	0	56681.11	0
4	46553.06	8.02%	45904.27	10.00%	51729.61	8.74%
6	42902.95	15.23%	42033.97	17.59%	48411.33	14.59%
8	39466.46	22.02%	39300.06	22.95%	45220.18	20.22%
10	37922.82	25.07%	38121.82	25.26%	43009.62	24.12%

Table 3.2 Bottom shear of this building in the direction of X of three cases (Unit: kN)

Case	Artificial wave		El-Centro wave		Federal wave	
	Bottom shear	Percent of declining	Bottom shear	Percent of declining	Bottom shear	Percent of declining
1	39466.46	22.02%	39300.06	22.95%	45220.18	20.22%
2	41733.84	17.54%	42345.11	16.98%	49165.19	13.26%
3	43955.66	13.15%	44701.59	12.36%	50468.86	10.96%

4. CONCLUSIONS

Through an actual high-rise building with strengthened storeys and abrupt changes of vertical stiffness in high intensive seismic region, its dynamic characteristics, seismic responses and design for seismic energy dissipation are analyzed in detail. Some conclusions are drawn as following:

1. The storey displacements of strengthened storeys are much less than storeys around it and abrupt changes of vertical stiffness of this building occur. So, the design of strengthened storeys should be important and necessary. Its stiffness should be limited, not be much larger than other storeys.

2. Loss of plates affects the rule of lateral displacement of frame-tube structures severely. It will result in essential change of this rule.

3. It is reasonable that viscous liquid dampers are installed in high-rise buildings with strengthened storeys in high intensive seismic region. The storey displacements and bottom shear of this structure decline sharply because of dampers. The storey displacements and bottom shear can be set up as the target for optimization and bottom shear of this building can decrease by 20 percent to 25 percent. So, after the design for optimization, optimum installation of viscous liquid dampers may improve effects of seismic energy dissipation of high-rise buildings with strengthened storeys in high intensive seismic region.

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