The optimal damper placement configuration for three-dimensional RC building

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Abstract. During an earthquake, high-rise buildings attempt to dissipate energy by generating swaying motion, which causes inevitable building damage. The dampers or passive energy dissipation devices can significantly diminish the energy emitted by earthquakes and reduce building damage accordingly. Especially for high-rise building structures constructed in an earthquake-prone area, it is necessary to install a sufficient number of dampers to reduce the building response. The passive energy dissipation devices present such an optimal performance depends on their locations in the building structures. Therefore, the objective of this paper is to observe an optimal placement configuration of passive energy devices lest excessive installment of the devices. The proposed approach is performance-based optimizations, which seismic performance of buildings considered is story drift of the building. This study focuses on optimizing fluid viscous dampers (FVD) placement incorporated into three-dimensional (3D) regular RC building structure. The result shows that fluid viscous dampers (FVD) when incorporated into three-dimensional of regular RC building structures can modify the performance of the building to fulfill the code standard of allowable drift ratio. It will be then suggested to be prevention acts to improve the performance of high-rise buildings under earthquakes excitation. Hence, the protection of the occupants therein can be accomplished.

1. Introduction
There are three main periods of structural design. The first is the classical era, where only vertical loads are considered in structural design. The second is the modern era, where dynamic loads have been used in design. The third is the postmodern era when energy is absorbed by active, passive or hybrid systems using technological tools and methods. Passive energy dissipation systems include a set of materials and
tools to increase damping, stiffness and strength and achieve the best performance when exposed to wind, earthquakes and explosions or other types of vibrational effects. [1]

The traditional earthquake resistant design approach relies on inelastic deformation behavior in several major structural zones to take in earthquake energy that subjected to, typically, the beam ends and column ends. Conversely, in structures integrated with passive dampers, earthquake energy is directly transferred to its dissipative mechanism, thereby being able to reduce the burden received by the main structure and reduce the possibility of structural damage [2-3]. While absorbing energy, the damper slowly reduces the amplitude caused by the earthquake [4].

Installation can be easily integrated in diagonal bracing, chevron brace or with other configurations. Can be an integration of new structural design (planning phase), it can also be a method of strengthening the structure in the service period (strengthening), as well as a strategy for post-earthquake building retrofitting. Passive dampers are very widely applied in structures because they are effective with affordable price [5-7].

Passive earthquake dampers as earthquake mitigation have been developed in recent years, accompanied by rapid application in construction, this provides an evolution in the structure design guidelines to supplement additional damping in buildings [8-11]. However, the efficiency of passive energy dissipation placement configuration still can be thoroughly investigated and improved. Furthermore, current codes, especially Indonesian codes (SNI), do not provide a method or guidelines for optimal passive energy dissipation device configuration.

This paper is intended to investigate the optimal placement configuration of passive energy dissipation device, or commonly called as damper, based on the story drift of structure. This study focuses on optimizing fluid viscous dampers (FVD) placement configuration when incorporated into three-dimensional of regular RC building structures.

2. Research methodology
The model of the building used in this study is a reinforced concrete (RC) open frame system. Due to symmetrical design, it is regular building with 3 bays in both X and Y directions. The height of each story is 4.5 m and the span of each bay is 5 m. The cross section of the columns is 400 mm by 400 mm and the dimension of frame beams is 250 mm by 350 mm. To evaluate the seismic responses of the building, with and without damper, the structure of the building is modelled and analyzed using ETABS software, as shown in figure 1.

![Figure 1. 3D model of the building](image-url)
Figure 2. Flowchart of the proposed method

Figure 2 shows the process of this proposed methodology to obtain optimal damper placement configuration. In order to create the proposed method, literature review is the first step taken in this study. Then, time history analysis has been conducted to validate the design regarding the seismic response. Three ground motions, comprising Altadena, Sylmarr, and Newhall earthquake, are used in this time history analysis. The graphs of acceleration versus time for component 0º and 90º are shown in figure 3 and figure 4, respectively.

The compliance of story drift with the code standard, ASCE 7-10 or SNI 1726-2012, is examined. When the drift ratio of the structure is found more than the allowable one, the iteration of adding damper need to be carried out. The damper will be placed at the floor whose drift ratio is the highest.

3. Results and Discussion

The building structure used in this study is assumed as Risk Category III. The $S_{05}$ and $S_{01}$ used in this study is 0.62 and 0.38, respectively. Hence, seismic Design of this building is categorized as D. In accordance to ASCE 7-10 or SNI 1726-2012, the allowable story drift of this structure is 51.92 mm.

The result of seismic performance analysis of the building without damper is shown in figure 5 and figure 6 for displacement and story drift, respectively. In figure 5, the displacement of the building due to Newhall earthquake is the greatest, it is approximately five times of the response caused by Altadena and Sylmarr earthquake. Figure 6 shows also the story drift of the building due to the excitation of three ground motions, Altadena, Newhall, and Sylmarr. It can be seen Newhall earthquake causes the story drift of the building exceed the maximum limitation.
Figure 3. Acceleration versus time data, component 0º (a) Altadena Earthquake, (b) Sylmar Earthquake, (c) Newhall Earthquake records

Figure 4. Acceleration versus time data, component 90º (a) Altadena Earthquake, (b) Sylmar Earthquake, (c) Newhall Earthquake records

Figure 5. Displacements of the building without damper
In the figure 6, the highest point of story drift is placed in 3rd floor. Therefore, the first iteration of adding damper is needed. Considering torsional responses [12], the configuration of the dampers is placed in the corner bay of each floor. The illustration of the first iteration is shown in figure 7.

![Figure 6. Story drift of the building without damper](image)

The result of seismic performance analysis of the first iteration is shown in figure 8. After first iteration, the behavior of building is changing. On the 3rd floor where the damper added, the drift ratio of the structure decrease. However, the seismic response of the building caused by Newhall earthquake still beyond the allowable story drift.

![Figure 7. First iteration of added damper configuration (a) 2D, (b) 3D](image)
In order to decrease the remaining exceeding story drift, the second iteration of adding dampers is needed. As seen in figure 8(b), the second added dampers should be located at 2<sup>nd</sup> floor. The 2D and 3D illustration of this second added damper is shown in figure 9.
Figure 10 shows the result of seismic performance analysis of the building after second iteration of adding dampers. In figure 10 (a), it can be seen the story drift caused by Newhall earthquake is under the limitation. The displacement, as shown in figure 10(b), is also reduced by 10%.

![Seismic Response Graphs](image.png)

**Figure 10.** The seismic response of the building after second iteration of added damper

4. Conclusion
The proposed methodology for optimizing damper placement configuration for three-dimensional RC building based on the story drift of structure is investigated. The fluid viscous dampers (FVD) when incorporated into three-dimensional of regular RC building structures can modify the performance of the building to fulfill the code standard of allowable drift ratio.

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