# 論文 / 著書情報
# Article / Book Information

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|---|---|
| 論題(和文) | |
| Title(English) | Effect of Viscous Damping of Isolation Layer on Period Ratio Between Superstructure and Seismic Isolation Layer |
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| 出典(和文) | 日本建築学会大会学術講演梗概集, , , pp. 585-586 |
| Citation(English) | , , , pp. 585-586 |
| 発行日 / Pub. date | 2021, 9 |
| 権利情報 | 一般社団法人 日本建築学会 |

日本建築学会大会学術講演梗概集
（東海） 2021 年 9 月

# EFFECT OF VISCOUS DAMPING OF ISOLATION LAYER ON PERIOD RATIO BETWEEN SUPERSTRUCTURE AND SEISMIC ISOLATION LAYER

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MDOF Model Isolated building Superstructure Period
Equivalent Deformation Prediction Curve Viscous Damping

## 1. Introduction

Period of the superstructure $T_u$ and period of the isolation layer $T_f$ are commonly considered, and that the equivalent period $T_{eq}$ is also being used. Fu *et al.* [1] showed the accuracy of period ratio $T_u/T_f$ but their study did not consider viscous damping of the isolation layer.

Therefore, the purpose of this paper is to confirm the effect of the viscous damping of isolation layer on period ratio between the superstructure and seismic isolation layer when the viscous damping of isolation layer is different.

## 2. Analysis Model and Ground Motions

### 2.1 Analysis Model

Shown in Fig. 1 is the multi-degree-of-freedom (MDOF) model of the base-isolated building considered in this study, where the superstructure has 4 lump-masses $m_i$ ($i$ = 1 to 4) and the isolation layer has a lump-mass $m_0$. $k_i$ is the stiffness of superstructure. The isolation layer is composed of (i) isolator which supports the gravity loads of the building, $k_f$ is the stiffness of isolator, and (ii) hysteretic damper, $k_d$ is the initial stiffness of hysteretic damper, $\alpha_{d,y}$ is the yield shear force coefficient, (iii) viscous damper, $c_f$ is the damping coefficient. The dampers absorb the seismic energy (elastic-plastic behavior).

Fig. 2a, 2b and 2c are the restoring force characteristics of the isolator, hysteretic and viscous dampers, respectively, and Figure 2d is restoring force characteristic of the isolation layer (combined effect). In Fig 2a, $Q_{f,max}$ is the maximum shear force at maximum deformation $\delta_{max}$. In Fig. 2b, $Q_{d,y}$ and $\delta_{d,y}$ are the yield shear force and yield deformation of the hysteretic damper, respectively. In Fig. 2c, $Q_{h,max}$ is the maximum viscous damper force at zero deformation.

For the analysis in this paper, the following values are used: For the 4-DOF superstructure (Fig. 1), $m_1 = m_2 = m_3 = m_4 = 37.80$ kN/s$^2$·cm, the damping ratio $h$ = 2%, and period $T_u$ = 0.5 s, 1.0 s and 2.0 s.

For isolation layer, $m_0$ = 64.25 kN/s$^2$·cm. For the isolator, damping ratio $h_f$ = 0%, 2%, 4% and 10%, period $T_f$ = 3.0 s and 4.0 s. The yield deformation of hysteretic damper, $\delta_{d,y}$ = 3 cm and the yield shear force coefficient $\alpha_{d,y}$ = 0.01 to 0.04.

### 2.2 Input Ground Motions

This paper adopted two artificially generated ground motions: (i) ART KOBE (80 cm/s) which is a pulse-like ground motion, and (ii) ART HACHI (80 cm/s) which is a long-period ground motion. The ground motion level considered are 0.5, 1.0 and 1.5 times.

## 3. Response Prediction Formula

In this chapter, the equivalent period $T_{eq}$ and the equivalent deformation of superstructure $\delta_{u,eq}$ are introduced. As shown in Fig. 3, $k_{eq}$ is the isolation equivalent stiffness when the deformation of isolation layer reaches the maximum $\delta_{max}$, which is calculated by Eq. (1).

The equivalent period $T_{eq}$ is the period based on the equivalent stiffness $k_{eq}$, which is calculated by Eq. (2).

$$k_{eq} = k_f + k_d \frac{\delta_{d,y}}{\delta_{\max}}, \qquad T_{eq} = 2\pi\sqrt{\frac{\sum m}{k_{eq}}} \qquad (1,2)$$

Where, $k_f$ is stiffness of isolator, $k_d$ is initial stiffness of hysteresis damper, $\delta_{d,y}$ is yield deformation of hysteresis damper, $\delta_{\max}$ is maximum deformation of isolation layer, $\Sigma m$ is total mass of isolated building.

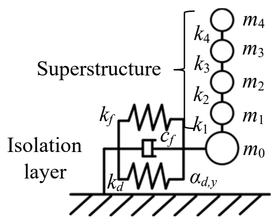
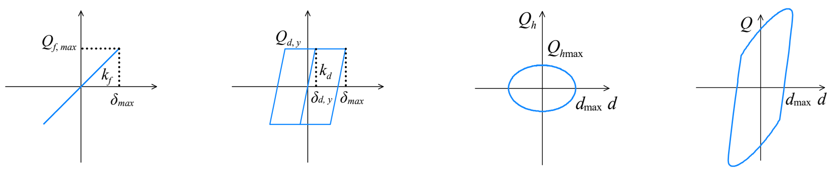



Fig. 1 Analysis model of isolated building




(a) Isolator (b) Hysteretic damper (c) Viscous damper (d) Isolation layer

Fig. 2 Restoring force characteristic of model

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Furthermore, Fig. 4 shows the definition of superstructure and the deformation of isolation layer based on mass system are shown in Fig. 4. The equivalent deformation of superstructure $\delta_{ueq}$ is defined as the difference between the maximum displacement of the first floor and the middle floor of superstructure, which is calculated by Eq. (3). The middle floor is defined as the floor that is the closest to the half-height of superstructure.

According to the reference [1], the relationship between the equivalent period $T_{eq}$ and the natural period of superstructure $T_u$ can be calculated as the root of the ratio of the maximum deformation of isolation layer $\delta_{max}$ and the equivalent deformation of superstructure $\delta_{ueq}$, which is shown as Eq. (4).

$$\delta_{ueq} = x_M - x_1 , \qquad \frac{\delta_{ueq}}{\delta_{max}} = \left(\frac{T_{eq}}{T_u}\right)^{-2} \tag{3,4}$$

Where, $x_M$ is maximum displacement of middle floor of superstructure, $x_1$ is maximum displacement of the first floor of superstructure in the base-isolated structure, $\delta_{ueq}$ is equivalent deformation at half height of superstructure (Fig. 4).

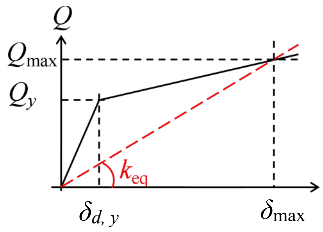

Fig. 3 Seismic isolation equivalent stiffness

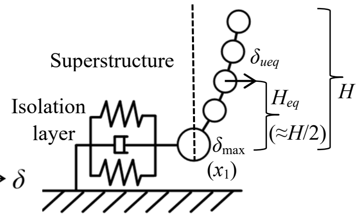

Fig. 4 Deformation based on mass system

## 4. Accuracy of Prediction Formula

In this study, we use time history analysis (THA) method to calculate the response of various viscous damping of isolation layer cases. And then we use the response of THA to check the accuracy of prediction curve shows in Eq. (4).

Fig. 5 shows the relationship between $T_{eq}$ / $T_u$ and $\delta_{ueq}$ / $\delta_{max}$ of THA results. (Eq. (4)) Horizontal coordinate shows the ratio of equivalent period $T_{eq}$ and the natural period of superstructure $T_u$, vertical coordinate shows the ratio the equivalent deformation of superstructure $\delta_{ueq}$ and the maximum deformation of isolation layer $\delta_{max}$. Black dotted curve shows the prediction curve. (Eq. (4)) ○, △ show ART HACHI and ART KOBE. Black, bule, red and green symbols show viscous damping ratio of isolator $h_f$ = 0.00 – 0.10.

According to Fig. 5 we know that the accuracy of prediction values is satisfactory not only no damping cases but also viscous damping of isolation layer cases. In other words, viscous damping of the isolation layer has little effect on the period ratio $T_{eq}$ /$T_u$ between the superstructure and seismic isolation layer.

In addition, we extend the number of mass point of superstructue 4-DOF to 8-DOF, the total mass of building is same, and the prediction curve also has high accuracy for 8-DOF and with viscous damping of isolation layer cases.

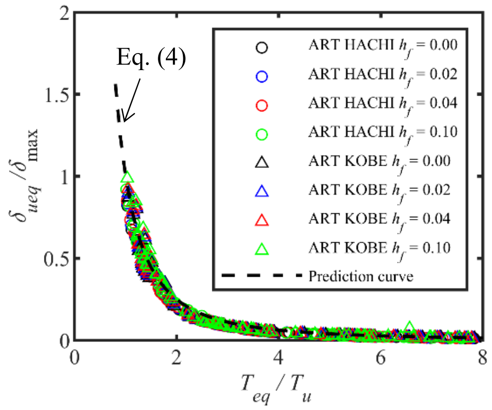

Fig. 5 The relationship between $T_{eq}$ / $T_u$ and $\delta_{ueq}$ / $\delta_{max}$

## 5. Conclusion

This paper confirms the effect of viscous damping on period ratio $T_{eq}$ /$T_u$ between superstructure and seismic isolation layer for various viscous damping of isolation layer. Accordingly, viscous damping of the isolation layer has little effect on the period ratio $T_{eq}$ /$T_u$ between the superstructure and seismic isolation layer.

In addition, we also confirm the effect of the number of mass point on period ratio $T_{eq}$ /$T_u$. And the number of mass point of superstructue has little effect on the period ratio $T_{eq}$ /$T_u$.


## Acknowledgment

This work was supported by JST Program on Open Innovation Platform with Enterprises, Research Institute and Academia (JPMJOP1723).


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