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DESIGN FOR ISOLATED BUILDING WITH OIL DAMPER CONSIDERING STIFFNESS DISTRIBUTION FOR INHOMOGENEOUS MASS RATIO

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Design Method / MDOF Model / Isolated building
Superstructure Period / Mass Ratio / Oil Damper

1. Introduction

Period of superstructure can be used to design isolated building. Chen and Sato [1] proposed a design method (energy balance method) for inhomogeneous mass (IHM) isolated building. However, this method did not consider oil damper. Therefore, this paper introduces a design example for IHM model considering superstructure stiffness distribution and oil damper.

2. Design Flow

Shown in Fig. 1 is design flow, the superstructure period T_U and initial stiffness of superstructure $k_{ini,i}$ are obtained (S1 to S9) by using energy balance method. Then corrected stiffness of superstructure $k_{cor,i}$ can be corrected in S11 by Kokuji method [4] (S9-S10).

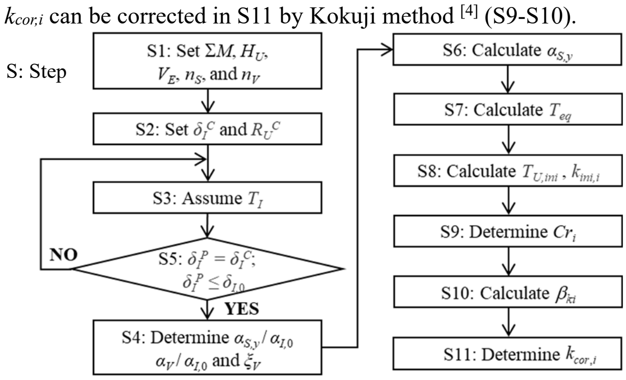

Fig. 1 Design Flow Chart

3. Analysis model and ground motion

The target model shown in Fig. 2 consists of an isolation layer with mass $m_0 = 1.7\times m_1$, and a 4-mass superstructure model with top story mass $m_4 = m_1/10$ (IHM model), where m_1 is the 1st story mass. The superstructure story height is 7.5 m. Initial stiffness-proportional damping ratio of superstructure $\xi_U = 2\%$.

The Restoring force characteristic of isolation layer is shown in Fig 3. The isolation layer is composed of (a) an isolator (linear stiffness k_I), (b) a steel damper (elastic-plastic behavior, initial stiffness k_S, yield shear force $Q_{S,y}$) and (c) an oil damper (damping coefficient C_V).

The ART-KOBE is used as input ground motion. And Energy spectrum is shown in Fig.4.

4. One Design Example

In this chapter, one design example adopting the design flow (Fig. 1) using the IHM model (Fig. 2) and ART-KOBE is introduced.

Step 1: *Set total mass, height of superstructure and input motion*

Total mass ΣM = 181.44 kN·s²/cm (i.e., superstructure + isolation layer); superstructure mass M_U = 117.18 kN·s²/cm; superstructure height H_U = 30 m (Fig. 2). For input ground motion, ART-KOBE is adopted as input ground motion, V_E = 120 cm/s, n_S = 1.6, n_V = 1.

Step 2: *Design Criteria*

Setting the criteria deformation of isolation layer δ_I^C = 40 cm, and the inter-drift of superstructure R_U^C = 1/300. So, The equivalent superstructure height $H_{U,eq}$ = 1/2 × H_U = 15 m (Fig. 2). And the deformation of superstructure $\delta_{U,eq} = R_U^C \times H_{U,eq}$ = 5 cm (Fig. 2).

Step 3: *Assume period of Isolator*

Period of isolator T_I = 4 s is assumed in this design.

Step 4: *Judge of predicted displacement of isolation layer*

In this design, criteria δ_I^C is used as the predicted displacement of isolation layer δ_I^P, therefore $\delta_I^P = \delta_I^C$ = 40 cm. Seismic displacement response of isolator with no-damping $\delta_{I,0}$ is calculated by Eq. (1), therefore $\delta_{I,0}$ = 76.39 cm > 40 cm is known. If any condition above is not satisfied, return to Step 3 and reassume T_I.

$$\delta_{I,0} = \frac{T_I \times V_E}{2\pi} = \frac{4\times 120}{2\pi} = 76.39 \text{ cm} \quad (1)$$

Step 5: *Obtain yield shear force coefficient ratio of steel damper*

Deformation ratio δ_I^C/δ_0 is calculated as:

$$\frac{\delta_I^C}{\delta_{I,0}} = \frac{\delta_{\max}}{\delta_{I,0}} = 0.524 \quad (2)$$

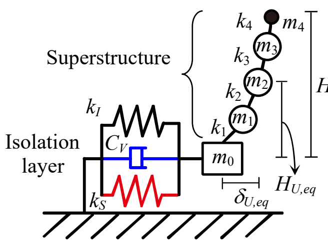

Fig. 2 Analysis model

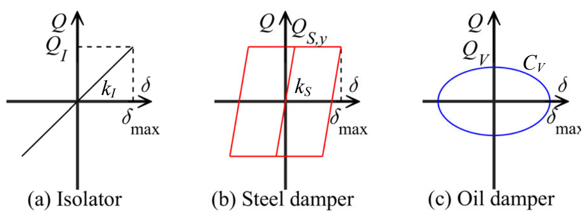

Fig. 3 Restoring force characteristic of isolation layer

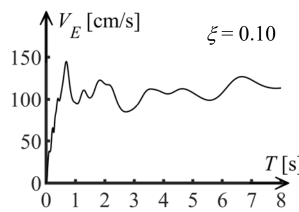

Fig. 4 Energy spectrum

Force ratio $\alpha_V / \alpha_{I,0}$ and $\alpha_{S,y} / \alpha_{I,0}$ can be find by Fig.5 and Eq. (4 - 6). Fig. 5 shows the relationship between $\alpha_V / \alpha_{I,0}$ and $\alpha_{S,y} / \alpha_{I,0}$ when δ_I^C = 40 cm. Select $a = b = 0.5$, so $\alpha_{S,y} / \alpha_{I,0} = 0.054$, $\alpha_V / \alpha_{I,0} = 0.110$.

$$\frac{\alpha_{S,y}}{\alpha_{I,0}} = a \cdot \left(\frac{\alpha_{S,y}}{\alpha_{I,0}}\right)_{\max}, \quad \frac{\alpha_V}{\alpha_{I,0}} = b \cdot \left(\frac{\alpha_V}{\alpha_{I,0}}\right)_{\max}, \quad a + b = 1 \qquad (4, 5, 6)$$

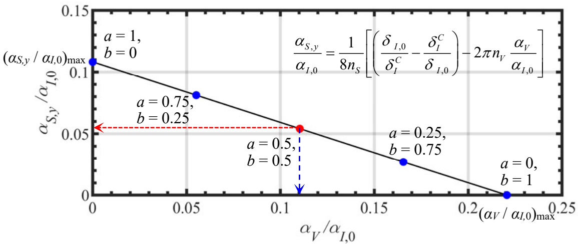

Fig. 5 $\alpha_V / \alpha_{I,0}$ Vs. $\alpha_{S,y} / \alpha_{I,0}$ (δ_I^C = 40 cm)

The damping ratio of viscous damper ξ_V can be calculated by Eq.7[3].

$$\xi_V = \frac{1}{2} \cdot \left(\frac{\alpha_V}{\alpha_{I,0}}\right) \cdot \left\{ \frac{\left[4n_S \cdot \left(\frac{\alpha_{S,y}}{\alpha_{I,0}}\right) + \pi n_V \cdot \left(\frac{\alpha_V}{\alpha_{I,0}}\right)\right]}{+\sqrt{\left[4n_S \cdot \left(\frac{\alpha_{S,y}}{\alpha_{I,0}}\right) + \pi n_V \cdot \left(\frac{\alpha_V}{\alpha_{I,0}}\right)\right]^2 + 1}} \right\} = 0.105 \qquad (7)$$

Step 6: *Calculate yield shear coefficient of steel damper*

The seismic shear coefficient of isolator with no-damping $\alpha_{I,0}$ and the yield shear coefficient of steel damper $\alpha_{S,y}$ can be calculated by Eq. (8) and (9), respectively .

$$\alpha_{I,0} = \frac{2\pi \cdot V_E}{T_I \cdot g} = 0.192, \quad \alpha_{S,y} = \frac{\alpha_{S,y}}{\alpha_{I,0}} \cdot \alpha_{I,0} = 0.01 \qquad (8, 9)$$

Where, g is gravitational acceleration 980 cm/s^2

Step 7: *Calculate Equivalent Period*

The stiffness of isolator k_I is obtained calculated as Eq. (10). In addition, the yield deformation of steel damper $\delta_{S,y}$ is used as 3 cm. The initial stiffness of steel damper k_S is calculated as Eq. (11).

$$k_I = \frac{4\pi^2}{T_I^2} \sum M, \quad k_S = \frac{\sum M \cdot g \cdot \alpha_{S,y}}{\delta_{S,y}} \qquad (10, 11)$$

Equivalent stiffness of isolation layer k_{eq} and equivalent period T_{eq} are calculated as:

$$k_{eq} = k_I + k_S \frac{\delta_{S,y}}{\delta_I^P}, \quad T_{eq} = 2\pi \sqrt{\frac{\sum M}{k_{eq}}} = 3.82 \text{ s} \qquad (11, 12)$$

Step 8: *Calculate natural period of superstructure and stiffness of superstructure*

The superstructure period $T_{U,ini}$ is calculated as [2]:

$$\frac{T_{eq}}{T_U} = \left(\frac{\delta_{U,eq}}{\delta_I^P}\right)^{-\frac{1}{2}}, \quad T_{U,ini} = \frac{T_{eq}}{T_{eq} / T_U} = 1.35 \text{ s} \qquad (13, 14)$$

The stiffness of superstructure k_U is calculated by Eq. (15):

$$k_{ini,i} = \frac{\omega_U^2 m_i \, {}_1\phi_i + k_{iui+1}\left({}_1\phi_{i+1} - {}_1\phi_i\right)}{{}_1\phi_i - {}_1\phi_{i-1}} \qquad (15)$$

Where, ω_U is natural frequency of superstructure, $\omega_U = 2\pi / T_{U,ini}$; ${}_1\phi_i$ is 1st mode Eigenvectors, ${}_1\phi_i = i$.

Step 9: *Design Value of Shear Coefficient Distribution*

The shear coefficient distribution Cr_i are calculated as [4]:

$$Cr_i = \frac{Q_{iso}}{M \cdot g} \cdot \frac{A_i \cdot (Q_S + Q_V) + Q_I}{Q_S + Q_V + Q_I} \qquad (16)$$

$$Q_{iso} = \sqrt{Q_V^2 + Q_I^2} + Q_S = \sqrt{\left(4\xi_V^2 + 1\right)} \cdot Q_I + Q_S \; [3] \qquad (17)$$

Where, Q_{iso}, Q_I, Q_S and Q_V are shear force of isolation layer, isolator, steel damper and viscous damper, separately. Ai is the value of Ai distribution.

Step 10: *Stiffness Corrected Factor for Superstructure*

The stiffness corrected factor β_{ki} (Fig.5) are calculated by Eq. (18) and the design value of inter-layer drift R_{Di} are calculated by Eq. (19).

$$\beta_{ki} = R_{Di} / R_U^C, \quad R_{Di} = \left(Cr_i \cdot \sum_{j=i}^{N} m_j g\right) / \left(k_i H_{Ui}\right) \qquad (18, 19)$$

Step 11: *Corrected Stiffness Confirmed*

The corrected stiffness of each story is confirmed by Eq. (20).

$$k_{cor,i} = \beta_{ki} \times k_{ini,i} \qquad (20)$$

5. Verification

The response distribution is shown of the displacements of isolation layer X_0 and the inter-drift of superstructure R are shown in Fig. 7 (a), (b) respectively, and both in the safe side of criteria δ_I^C = 40 cm and R_U^C =1/300, respectively.

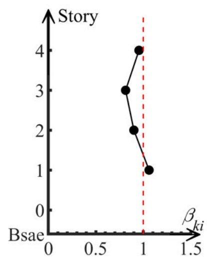

Fig. 6 Stiffness Corrected Factor

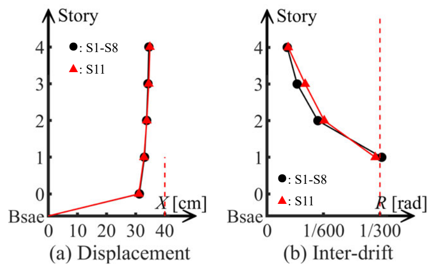

Fig. 7 Vertical Distribution (ART-KOBE)

6. Conclusion

A new design method was introduced based on energy balance method for isolated building with viscous damper in this paper. The stiffness distribution of superstructure was improved and could be considered for analysis of inhomogeneous modeling.

Acknowledgment

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Reference

[1] Chen ZL, Sato D. : Design for Isolated Building Considering Stiffness Distribution for Inhomogeneous Mass Ratio, *AIJ Summaries of technical papers of annual meeting*, 2021.4

[2] Fu HX., Sato D., et al.: Response Prediction Formula for Base-Isolated Building by Using Period Ratio Between Superstructure and Seismic Isolation Layer, *AIJ Journal of Technology and Design*, 2018, 02.

[3] Kitamura H : Seismic Response Analysis Methods for Performance Based Design, 2nd, 2009.4 (In Japanese)

[4] Recommendation for the Design of Seismically Isolated buildings, *AIJ*, p. 136, 2013, 10.

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