T2R2 東京工業大学リサーチリポジトリ Tokyo Tech Research Repository

論文 / 著書情報 Article / Book Information

論題(和文)				
Title(English)	Design for Isolated Building Considering Stiffness Distribution for Inhomogeneous Mass			
著者(和文)	CHEN ZHENGLE, 佐藤 大樹			
Authors(English)	Chen Zhengle, Daiki Sato			
出典(和文)	 │ 日本建築学会大会学術講演梗概集, , , pp. 569-570			
Citation(English)	,,,pp. 569-570			
発行日 / Pub. date	2021, 9			

DESIGN FOR ISOLATED BUILDING CONSIDERING STIFFNESS DISTRIBUTION FOR INHOMOGENEOUS MASS

			正会員	○CHEN Zhengle *
Isolated Building	Energy Based Design	Stiffness Correction	正会員	SATO Daiki **
Shear Coefficient	Mass Distribution			

1. Introduction

Due to the Tohoku Earthquake in 2011, there has been increasing cases of adopting seismic isolation structures to buildings. Fu and Sato *et al.*^[1] proposed a design method (energy balance method) for isolated buildings which obtained the appropriate range of superstructure period to satisfy the criteria. However, this method did not confirm whether the stiffness distribution can be applied to inhomogeneous mass model (IHM model). Therefore, this report introduces a design example for IHM model considering superstructure stiffness distribution based on the design flow (Fig. 1) by Chen and Sato *et al.*^[2].

2. Design Flow

In Fig. 1 showing design flow, the superstructure period T_u and stiffness distribution k_u are initially obtained (S0 to S8) by using energy balance method. Then, by shear coefficient amplification method (S9), k_u can be corrected in S11 by using the design value of deformation R_p (S10).

3. Target Model and Input

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-point superstructure model with top-most story mass $M_4=M_1/10$ (IHM model), where M1 is the 1st story mass. Each superstructure story height is 7.5 m.

the isolation layer (Story 0) is composed of (i) an isolator (linear stiffness k_f) and (ii) a hysteresis damper (initial stiffness k_s). Initial stiffness-proportional damping ratio of superstructure $h_u = 2\%$.



Design for Isolated Building Considering Stiffness Distribution for Inhomogeneous Mass

The Hachinohe (1968) EW component (ART-HACHI) is used as input ground motion. From time-history analysis using ART-HACHI, the equivalent hysterisis loop of input motion $n_1 = 6.8$ and the equivalent velocity of input energy $V_E = 191$ cm/s were obtained.

4. Design Example

The design example adopting the design flow (Fig. 1) using the IHM model (Fig. 2) and ART-HACHI is introduced in this chapter. *Step* 0: *Total Mass and Height of Superstructure*

Total mass M = 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. 3).

Step 1: Input Motion

Using the input earthquake motion as ARTHACHI, $V_E = 191$ cm/s, $n_1 = 6.8$ as Chapter 3.

Step 2: Design Criteria

Assuming the criteria deformation of isolation layer $\delta_{bmax} = 40$ cm, equivalent deformation of superstructure $\delta_{ueq} = 5$ cm, equivalent superstructure height $H_{ueq} = 1/2 \times H_u = 15$ m (Fig. 3). The deformation angle of superstructure $R_{umax} = \delta_{ueq}/H_{ueq} = 1/300$ is known.

Step 3: Isolator Period and Max. Deformation Ratio

Assuming isolator period $T_f = 4$ s, max. deformation of isolation layer without damping δ_0 and max. deformation ratio δ_{bmax}/δ_0 are calculated as:

$$\delta_0 = \frac{T_f \times V_E}{2\pi} = \frac{4 \times 191}{2\pi} = 121.59 \text{ cm}, \quad \frac{\delta_{b \max}}{\delta_0} = \frac{40}{121.59} = 0.33 \quad (1), (2)$$

STEP 4: Yield Shear Coefficient Ratio of Hysteresis Damper

Fig. 4 shows the relation between total shear coefficient ratio of isolation layer α_1/α_0 , shear coefficient ratio of isolator α_0/α_0 (Eq. (3)) and yield shear coefficient ratio of hysteresis damper α_{sy}/α_0 , when $n_1 = 6.8$. Note: the shear coefficient of isolation layer without damper α_0 will be shown next step. Accordingly, $\alpha_{sy}/\alpha_0 = 0.05^{[3]}$.



Zhengle Chen, Daiki SATO

STEP 5: Yield Shear Coefficient of Hysteresis Damper

Eq. (4) gives α_0 , and correspondingly, the yield shear coefficient of hysteresis damper $\alpha_{sy} = (\alpha_{sy}/\alpha_0) \times \alpha_0 = 0.015$ is obtained.

$$\alpha_0 = \frac{2\pi \cdot V_E}{T_f \cdot g} = \frac{2\pi \times 191}{4 \times 980} = 0.306$$
(4)

STEP 6: Equivalent Period

For the case of $T_f = 4$ s (Step 3), isolator stiffness k_f is obtained by Eq. (5). Moreover, assuming yield deformation of hysteresis damper $\delta_{yy} = 3$ cm, the initial damper stiffness k_s is obtained by Eq. (6):

$$k_f = \frac{4\pi^2 M}{T_f^2} = \frac{4\pi^2 \times 181.44}{4^2} = 448 \text{ kN/cm}$$
(5)

$$k_{s} = \frac{\alpha_{sy}Mg}{\delta_{sy}} = \frac{0.015 \times 181.44 \times 980}{3} = 904 \,\text{kN/cm}$$
(6)

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

$$k_{beq} = k_f + k_s \frac{\delta_{sy}}{\delta_{b \max}} = 448 + 904 \times \frac{3}{40} = 516 \text{ kN/cm}$$
 (7)

$$T_{eq} = 2\pi \sqrt{M/k_{beq}} = 2\pi \sqrt{181.44/516} = 3.7 \text{ s}$$
(8)

STEP 7: Equivalent Period Ratio

Equivalent period ratio $T_{eq}/T_u = (\delta_{bmax}/\delta_{ueq})^{0.5} = (40/5)^{0.5} = 2.83.$

STEP 8: Superstructure Period and Stiffness Distribution

By T_{eq}/T_u in Step 7 and T_{eq} in Eq. (8), the superstructure period T_u is initially obtained as $T_u = T_{eq}/(T_{eq}/T_u) = 3.7/2.83 = 1.3$ s. Then, the superstructure stiffness k_u can be initially determined by linear mode shape as:

$$k_{uN} = \frac{\omega_u^2 \times M_N \times \phi_N}{\phi_N - \phi_{N-1}}$$
(N = 4)

$$k_{ui} = \frac{\omega_u^2 \times M_i \times \phi_i + k_{u,i+1} \times (\phi_{i+1} - \phi_i)}{\phi_i - \phi_{i-1}}$$
(i = 2,3)

$$k_{u1} = \frac{\omega_u^2 \times M_1 \times \phi_1 + k_{u2} \times (\phi_2 - \phi_1)}{\phi_1}$$
(9)

Here, linear mode shape $\phi_i = i$ (where i = 1 to 4).

STEP 9: Shear Coefficient of Superstructure

Non-linear coefficient of isolation layer NL = 0.12 is calculated in Eq. (10)^[4], and corresponding shear coefficient amplification factor *a* is obtained by Eq. (11)^[5]. The shear coefficients at *i*-th story α_{pi} are obtained by trapezoidal distribution of factor *a*. Accordingly, they are calculated by Eq. (12) and are indicated in Table 1.

$$NL = \frac{k_s \delta_{sy} \left(\delta_{b \max} - \delta_{sy} \right)}{\delta_{b \max} \left(k_s \delta_{sy} + k_f \delta_{b \max} \right)} = 0.12$$
(10)

$$a = 1.66 + 2.58NL = 1.66 + 2.58 \times 0.12 = 1.97 \tag{11}$$

$$\alpha_{pi} = \left[1 + \frac{i}{N}(a-1)\right] \times \frac{k_{beq} \cdot \delta_{b\max}}{M \cdot g} \qquad (i = 0 \sim 4)$$
(12)

STEP 10: Deformation Angle of Superstructure

The deformation angle of superstructure R_{pu} is calculated by Eq. (13). As Table 1 indicates, all the R_{pu} overpass the criteria 1/300.

$$R_{pui} = \frac{\alpha_{pi} \cdot \sum_{j=i}^{n} M_j \cdot g}{k_{ui} \cdot h_i} \qquad (i = 1 \sim 4)$$
(13)

STEP 11: Stiffness Correction Factor

The prediction value of deformation angle R_{pu} can be used to obtain the stiffness correction factor β_{ku} in Eq. (14) (Table 1). Note, for case $R_p \leq R_{umax}$, the factor $\beta_{ku} = 1.0$.

$$\beta_{kui} = \frac{R_{pui}}{R_{umax}} \quad (\text{minimum value is 1.0}) \tag{14}$$

Multiplying β_{ku} to k_u (Eq. (9)), the correction stiffness distribution k_u' is obtained, indicated in Table 1.

Table 1 Design Values								
Story	0	1	2	3	4			
α_{pi}	0.180	0.223	0.267	0.311	0.354			
R_{pu} (rad)		0.0060	0.0058	0.0056	0.0050			
β_{ku}		1.81	1.74	1.69	1.49			
k_{u}' (kN/cm)	1,352	10,256	8,308	5,065	525			

5. Verification

According to the time-history results of $T_f = 4$ s, $\alpha_{sy} = 0.015$ model in Fg. 5, the displacements of isolation layer and the deformation angle of superstructure *R* are both in the safe side of criteria $\delta_{bmax} = 40$ cm and $R_{umax} = 1/300$, respectively.



Fig. 5 Vertical Distribution (ARTHACHI)

6. Conclusion

In this paper, a new design method was introduced based on energy balance method by Fu *et al.*. By using shear coefficient amplification method, the stiffness distribution of superstructure was improved and could be considered for analysis of inhomogeneous modeling.

Acknowledgment

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

[1] 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 Volume 24 Issue 58 Pages 951-956

[2] Chen ZL., Sato D. *et al*: Energy Based Design Method for Isolated Building Considering Stiffness Distribution of Superstructure. 2020, 11.

[3] Kitamura H.: Seismic Response Analysis Methods for Performance Based Design. 2004, 06.

[4] Kobayashi M., Tanizaki G. *et al*: Vertical Distribution of Seismic Design Load for Seismically Isolated Building Corresponding to Diversity of Seismic Isolation Devices. J. Struct. Constr. Eng., AIJ, Vol. 77 No. 676, 859-868, Jun., 2012

[5] 森川和彦,田村和夫ら:免震建築物の層せん断力係数の評価に関する研究(その2)層せん断力係数評価法の提案,日本建築学会大会学術講演梗概集(北陸), pp.233-234, 2010.9.

** Associate Prof. , FIRST, Tokyo Institute of Technology, Dr. Eng.

^{*}東京工業大学環境・社会理工学院 大学院生

^{**}東京工業大学未来産業技術研究所 准教授・博士 (工学)

^{*} Master Student, School of Environment and Society, Tokyo Institute of Technology