論文 / 著書情報
Article / Book Information

論題(和文)	
Title(English)	DESIGN METHOD FOR SHEAR FORCE COEFFICIENT DISTRIBUTION OF ISOLATED BUILDING CONSIDERING INHOMOGENEOUS MODEL
著者(和文)	陳正楽, 佐藤大樹
Authors(English)	Chen Zhengle, Daiki Sato
出典 / Citation	日本建築学会関東支部研究報告集, Ⅰ, , pp. 341-344
Citation(English)	, Ⅰ, , pp. 341-344
発行日 / Pub. date	2021, 3

2020年度日本建築学会
関東支部研究報告集Ⅰ
2021年3月

DESIGN METHOD FOR SHEAR FORCE COEFFICIENT DISTRIBUTION OF ISOLATED BUILDING CONSIDERING INHOMOGENEOUS MODEL

構造ー振動

正会員　○　陳正楽*1　　正会員　　佐藤大樹*2

Isolated Structure　Hysteresis Damper　IHM Model
Shear Coefficient Distribution　Design Method

1. Introduction

Under the influence of the 2011 Tohoku Earthquake, Seismic isolation systems have been applied to base-isolated steel warehouses with the long 1st mode natural period of superstructures. As the roofs of most warehouses are made of steel plates and with small loads, so the rooftop of the most warehouses are light.

Regarding to the story shear force coefficient distribution for designing seismic isolated structures, the Recommendation for the Design of Seismically Isolated Buildings from Architectural Institute of Japan[1)] (Shishin-hou) and the Technical Standards for Seismic Isolated Buildings stipulated with the revision of the Standard Law in 2000[2)] (Kokuji-hou) are used. Besides, Fu and Sato et al. proposed a design method (called energy method, Fig. 1[7)]) which considered the isolation equivalent period ratio to satisfy the design criteria.

However, this method did not consider the distribution of shear coefficient. Therefore, in this paper, 5 design methods for predicting the shear coefficient distribution of superstructure are introduced, and the verification for the story shear coefficient distributions of base-isolated models with various kinds of inhomogeneous mass and stiffness (IHM model, in this paper) are shown.

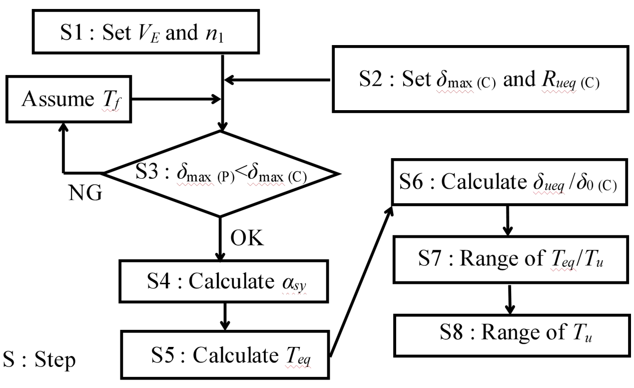


Fig. 1 Design Flow from Fu

2. Determination of Shear Coefficient Distribution

In this chapter, five design methods for layer shear coefficient distribution, referred from 1) to 6), are introduced. Then the verification of the shear coefficient distribution methods, for low-rise buildings of low mass and rigidity on the rooftop floor, is shown in next chapter. The methods can be roughly divided into Shishin-hou based methods and the Notification-based methods. Fig. 2(a) and 2(b) show the each calculation method of the shear coefficient distribution.

2.1 Shishin-hou Method[1)]

According to the seismic isolation structure design guideline, the shear force coefficient α_i of each layer is shown as Eq. 1, in consideration of the influence of higher vibration mode of the seismic isolation structure by the horizontal stiffness ratio β_s, the first story of superstructure to the hysteresis damper.

$$\alpha_i = \alpha_f + a_i \cdot \overline{\alpha}_i \cdot \alpha_{sy} \tag{1}$$

Here, α_f: shear coefficient of elastic bearing material, α_{sy}: load shear force coefficient of hysteresis damper, α_i: optimal yield shear coefficient distribution (Ai distribution), a_i: amplification factor of shear force coefficient of hysteresis damper. a_i is calculated by Eq. 4 from a, obtained by Eq. 3, based on b_s of Eq. 2. Here, k_{u1}: horizontal stiffness of the first story of superstructure, k_s: horizontal stiffness of the hysteresis damper, N: number of the superstructure story. This method is called the Shishin-hou.

2.2 Hosei-hou Method[3)]

Considering that with the longer of the 1st natural period of superstructure, the greater the amplification of the layer shear force coefficient in vertical direction due to the increasing of α_{sy}, Kobayashi et al. proposed a method to evaluate the layer shear force coefficient α_i of each story by Eq. 5, using the response amplification β_i, instead of the amplification factor of shear force coefficient of hysteresis damper a_i according to the

Design Method for Shear Force Coefficient Distribution for Isolated Building Considering Inhomogeneous(IHM) Model

CHEN Zhengle, *SATO Daiki*

seismic isolation structure design guidance.

$$b_s = \frac{k_{u1}}{k_s} \tag{2}$$

$$\overline{a} = \begin{cases} 3.1238 - 0.1238 b_s & 1 \le b_s \le 10 \\ 2.0127 - 0.0127 b_s & 10 \le b_s \le 80 \\ 1 & 80 \le b_s \end{cases} \tag{3}$$

$$a_i = \left(\frac{\overline{a} - 1}{N - 1} \right) i + \frac{N - \overline{a}}{N - 1} \tag{4}$$

$$\alpha_i = \alpha_f + \beta_i \cdot A_i \cdot \alpha_{sy} \tag{5}$$

The response amplification β_i is adopts as the linear distribution, which is similar to the seismic isolation structure design guidance, and is expressed as Eq. 6.

$$\beta_i = \left(\frac{\overline{\beta} - 1}{N - 1} \right) i + \frac{N - \overline{\beta}}{N - 1} \tag{6}$$

$\overline{\beta}$ is calculated as Eq. 7 to 10 by using the seismic isolation factor I and the equivalent damping h_{eq}. Besides, h_{eq} is represented by the percentage value.

$$\overline{\beta} = \frac{s}{I^2} + t \qquad \left(\text{if } \overline{\beta} > u, \overline{\beta} = u \right) \tag{7}$$

$$s = 0.26 h_{eq} + 0.29 \qquad \left(\text{if } s > 5.0, s = 5.0 \right) \tag{8}$$

$$t = 0.60 \tag{9}$$

$$u = 0.09 h_{eq} + 1.28 \qquad \left(\text{if } u > 3.0, u = 3.0 \right) \tag{10}$$

Here, the seismic isolation factor I is defined as Eq. 11, which equals to the ratio of the seismic isolation layer period to initial stiffness T_b and the 1st natural period of the superstructure T_u.

$$I = \frac{T_b}{T_u} \tag{11}$$

2.3 Kokuji-hou Method[2)]

According to the technical standards for seismic isolated buildings (Kokuji-hou No. 2009), the amplification of the layer shear force coefficient by the damper is considered only by the Ai distribution, and the layer shear force coefficient C_{ri} of each story is shown as Eq. 12.

$$C_{ri} = \gamma \frac{\sqrt{\left(Q_s + Q_f\right)^2 + 2\varepsilon \left(Q_s + Q_f\right) Q_v + Q_v^2}}{M_u \cdot g} \times \frac{A_i \left(Q_s + Q_v\right) + Q_f}{Q_s + Q_v + Q_f} \tag{12}$$

Here, γ: factor considering the influence of variations in the mechanical properties of seismic isolation member, M_u: total mass of the superstructure, g: gravitational acceleration, Ai: shear force coefficient distribution of the Building Standards Law (Ai distribution), Q_f, Q_s, Q_v: shear force of the bearing material, hysteresis damper, and fluid damper, when the seismic isolation layer is at the standard displacement. This method is called as the Kokuji-hou.

2.4 Zoufuku-hou and Warimashi-hou[4)~6)]

Iiba et al. showed that the larger the response amplification in the superstructure, the larger the difference between the layer shear force coefficient, calculated by the Kokuji-hou, and the layer shear force coefficient, obtained by the response analysis, becomes. Two methods for calculating the layer shear force coefficients are proposed. One method for calculating the layer shear force coefficient of superstructure α_R is shown as Eq. 13, which multiplies the layer shear force coefficient of the seismic isolation layer C_{r0}, calculated by the Kokuji-hou, by the response amplification factor a.

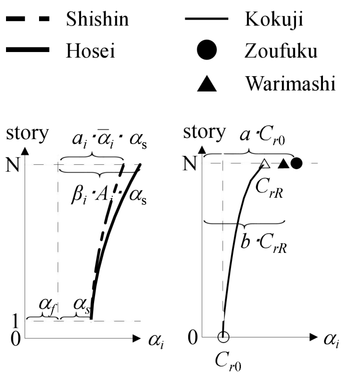
$$\alpha_R = C_{r0} \times a \tag{13}$$

Since the seismic isolation coefficient $I = T_b/T_u$ is becoming less and the nonlinear coefficient NL is becoming greater, the amplification factor of the superstructure tends to be greater. Therefore, the response amplification factor a is proposed as Eq. 14 by using I.

$$a = \begin{cases} 2.19 + 3.95 NL & 0 \le I \le 0.5 \\ 2.31 + 3.34 NL & 0.5 \le I \le 1.5 \\ 1.66 + 2.58 NL & 1.5 \le I \le 3.0 \\ 1.04 + 1.59 NL & 3.0 \le I \le 5.0 \end{cases} \tag{14}$$

Here, NL: non-linear factor based on the maximum response deformation of the seismic isolation layer (as shown in Fig. 3, the area of the Bi-linear type historical curve with respect to the area of the rectangle surrounded by the maximum displacement and the shear force). This method is called as the Zoufuku-hou.

The second method is shown as Eq. 15, which multiplies the shear coefficient of top-story of superstructure C_{rR}, calculated by the Kokuji-hou, by the response premium factor b.
Since the amplification factor of the superstructure tends to be increased slightly as T_{eq}/T_u increases. The response premium factor b is calculated by T_{eq}/T_u as Eq. 16.



(a) Shishin-hou (b) Kukuji-hou

Fig. 2 Previous Methods

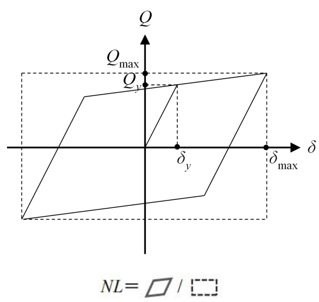


Fig. 3 Non-linear Factor NL

$$\alpha_R = C_{rR} \times b \tag{15}$$

$$b = \begin{cases} 1.61 + 0.31\left(T_{eq}/T_u\right) & 0 \le \left(T_{eq}/T_u\right) \le 0.5 \\ 1.60 + 0.19\left(T_{eq}/T_u\right) & 0.5 \le \left(T_{eq}/T_u\right) \le 1.5 \\ 1.33 + 0.08\left(T_{eq}/T_u\right) & 1.5 \le \left(T_{eq}/T_u\right) \le 3.0 \\ 0.94 + 0.02\left(T_{eq}/T_u\right) & 3.0 \le \left(T_{eq}/T_u\right) \le 5.0 \end{cases} \tag{16}$$

Here, T_{eq}: equivalent period based on the maximum deformation of seismic isolation layer. This method is called as the Warimashi-hou.

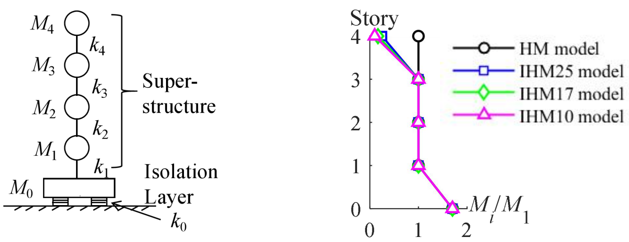
Besides, the response amplification factor a and response premium factor b of the seismic isolation layer are set as 1.0. The response amplification factor distribution and response premium factor distribution are obtained by trapezoidal vertical distribution. Therefore the layer shear force coefficient of the intermediate story can be calculated.

3. Verification of Shear Coefficient Distribution

3.1 Analytical Model

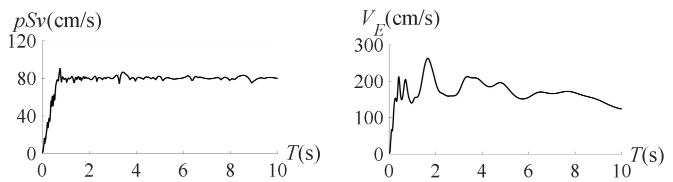
A four-story steel-frame warehouse is used as the model in this paper. The height of each superstructure story is 7.5m from the 1st to the 4th floor. The analytical model is shown in Fig. 4(a). In this paper, the average density of the superstructure ρ = 180 kg/m^3. The mass of isolation layer M_0 is set to be 1.7 times of the first floor M_1. Fig. 4(b) shows the mass distribution standardized by the mass of the first floor. HM model represents the homogeneous mass distribution and IHMx model represents the inhomogeneous mass distribution, of which the mass of top floor is x% (1/4, 1/6 and 1/10, respectively) multiplying the first floor M_1. In vertical axis, Floor 1 to 4 represents the superstructure and Floor 0 represents the isolation layer.

The superstructure and isolators are elastic. The damper is completely elasto-plastic (restoring force characteristics: yield shear force coefficient α_{sy}, yield deformation δ_{sy}). The initial stiffness proportional damping of superstructure h_u = 2%.



(a) Analytical Model (b) Mass Standardization

Fig. 4 Information of Analytical Model



(a) Pseudo Velocity Response Spectrum (h = 5%) (b) Energy Spectrum (h = 10%)

Fig. 5 Input Earthquake

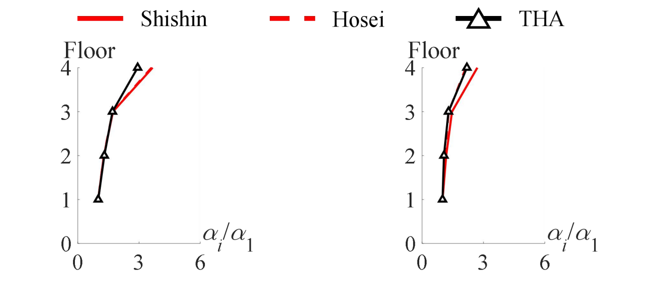
3.2 Input Earthquake

The input seismic motion is used as the HACHINOHE (1968) EW component as the phase characteristic, and it is a notification wave in which the pseudo-velocity response spectrum $_pS_v$ (h = 5%) becomes constant at 80 cm/s after the corner period (which is called ART HACHI). Fig. 5 shows the time-history of acceleration, pseudo-velocity response spectrum $_pS_v$ (h = 5%) and the energy spectrum V_E (h = 10%). In the design method of this paper, the average value of the number of equivalent hysteretic loop n_1 = 6.8 and the equivalent velocity of total energy input V_E = 191 cm/s are used.

3.3 Vertical Distribution

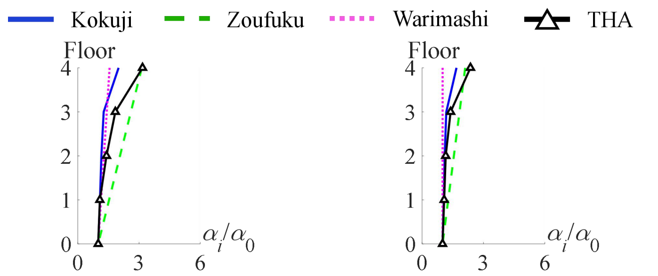
The seismic wave ART HACHI is used as the input motion for time-history analysis (THA). In Fig. 6, the design result examples of the period isolator group T_f = 6s, and the displacement criteria of isolation layer $\delta_{\max(c)}$ = 40cm, 50cm of IHM10 model with lightest top story are shown, by using the methods for shear coefficient distribution mentioned in Chapter 2, based on the design flow in Fig. 1.

According to Fig. 6, the response results of top story shear coefficient tends to be greater than lower stories. Regarding to figure (1), the results of 1st to 3rd story by Shishin-hou and Hosei-hou are almost coincide to the THA results, which shows these two methods may not be safe enough and mal function for IHM models based on the design flow from Fig.1.



(a) $\delta_{\max(c)}$ = 40cm (b) $\delta_{\max(c)}$ = 50cm

(1) Shishin-hou Based Method (IHM10 Model)



(a) $\delta_{\max(c)}$ = 40cm (b) $\delta_{\max(c)}$ = 50cm

(2) Kokuji-hou Based Method (IHM10 Model)

Fig. 6 Vertical Distribution (T_f = 6s, ART HACHI)

As for figure (2), the Kokuji-hou results of top story shear coefficient tends to be greater than lower stories. And the Zoufuku-hou and Warimashi-hou results of entire models are straight lines. But results of Zoufuku-hou are becoming greater than Warimashi-hou in vertical direction. The results of Kokuji-hou and Warimashi-hou tend to be less than the THA results, which means these two methods are completely malfunction to the design flow. Besides, the results of Zoufuku-hou tend to be greater than the THA results, which means the validity of this method can be confirmed.

3.3 Verification of Validity

By using HM model and IHMx model with the initial conditions of the period isolator group T_f = 3s ~ 6s, and the displacement criteria of isolation layer $\delta_{\max(c)}$ = 30cm ~ 60cm. The 1st natural period of the superstructure T_u ranging from 0.8s to 1.4s approximately and yield shear force coefficient of hysterics dampers α_{sy} ranges from 0.005 to 0.02 approximately. Fig. 7 shows the validity of story shear coefficient by making the comparison between THA results and prediction results. Figure (a) to figure (e) represents 5 methods, respectively, and the parameter is the mass distribution of model.

According to the figure (a) and (b), minority results of IHMx model are at the unsafe side of the dash line. And other results are almost coincide to the dash line which means the Shishin-hou and the Hosei-hou may not be completely effective to the design flow. It is considered that the response amplification in vertical direction, due to the variety in mass distribution of the superstructure, can not be sufficiently evaluated. According to the figure (c) and (e), almost the design results of shear coefficient are at the unsafe side, both HM and IHMx model, can be known. And the variety of the results is large. Therefore the validity of Kokuji-hou and Warimashi-hou can not be confirmed. According to the figure (d), minority results of IHMx model are at the unsafe side, but almost the cases are over the dash line, which means the Zoufuku-hou is the most suitable method and the validity can be basically confirmed.

4. Conclusion

In this paper, 5 design methods for predicting the shear coefficient distribution of superstructure are introduced. Amoung these 5 methods for distribution of shear force coefficient, the Shishin-hou and the Hosei-hou are nearly safe to the design flow of HM model but risky to IHMx model. The Zoufuku-hou results are almost at the safe side by comparing with the THA results of shear coefficient. Therefore it can be evaluated that the prediction validity of Zoufuku-hou can be verified for the design flow from Fig. 1.

Reference

1) 日本建築学会：免震構造設計指針，pp.73-110，1993

2) 国土交通省住宅局建設指導課など :免震層建築物の技術基準解説及び計算例とその解説，2001.5

3) 小林正人，谷崎豪，松田紳吾：免震部材の多様化に対応した免震建物の設計用地震荷重分布，日本建築学会構造系論文集，第 77 巻，第 676 号，pp.859-868，2012.6

4) 西村拓也，田村和夫，猿田正明，森川和彦，飯場正紀：免震建築物の層せん断力係数の評価に関する研究（その 1）パラメータスタディ，日本建築学会大会学術講演梗概集（北陸），pp.231-232，2010.9

5) 森川和彦，田村和夫，猿田正明，西村拓也，飯場正紀：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

6) 飯場正紀，田村和夫，猿田正明，西村拓也，森川和彦，北村佳久，小林正人，石原直：免震建築物の設計用地震層せん断力係数に関する検討，建築研究所，建築研究資料，No.162 号，2014.8

7) 付慧鑫，佐藤大樹，北村春幸，松田頼征，宮川和明，植木卓也，村上行夫：上部構造と免震層の等価周期比を用いた免震建物の応答予測式，日本建築学会技術報告集，2018.2

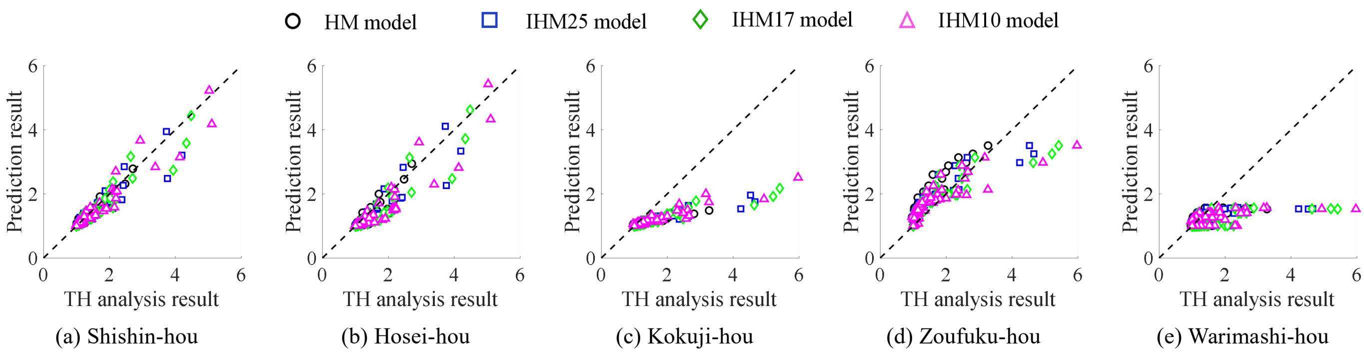


Fig. 7 Comparison of Shear Coefficient Between THA and Prediction

*1 学生会員 東京工業大学 大学院生

*2 東京工業大学 未来産業技術研究所 准教授･博士（工学）

*Graduate Student, Tokyo Institute of Technology [*1]

*Associate Professor, FIRST, Tokyo Institute of Technology, Dr. Eng. [*2]