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Effect of Mass Distribution of Superstructure on Participation Vectors of Base-isolated Building

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Isolated Building　Eigen Analysis　Mass Distribution
MDOF Model　Participation Vector　Stationary Point

1. Introduction

Li *et al.* [1] confirmed that with the building centre-of-gravity (COG) position decreases, the difference between multi-degree-of-freedom (MDOF) model and two-degree-of-freedom (2DOF) model increases for isolated building and the response of MDOF is increase. However, with the building centre-of-gravity position decreases, the building trends to stable, supposedly. And this situation should be discussed.

Therefore, the purpose of this paper is to confirm the effect of mass distribution of superstructure on participation vectors of the isolated building for MDOF model.

2. Analysis Model and Mass Distribution

Fig. 1 shows the analysis models, (a) is multi-degree-of-freedom (MDOF) model of the base-isolated building, where the superstructure has N lump-masses m_i (i =1~N), and the isolation layer has a lump-mass m_0. k_i (i =1~N) and k_0 shows the stiffness of i story and isolation layer, respectively. (b) is two-degree-of-freedom (2DOF) model of the base-isolated building considered in this study, where the superstructure is considered as a whole lump-mass m_U and the isolation layer has a lump-mass m_0. k_U is the stiffness of superstructure.

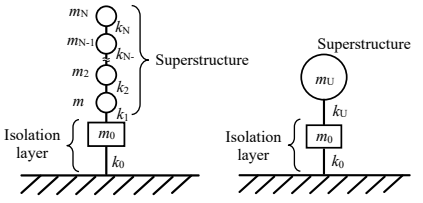
Fig. 2 shows the mass distribution of superstructure for MDOF model, 4 cases ((a)~(b) = Case A ~ Case D) mass distribution are adopted in this paper. Case A is rectangular distribution. The others are trapezoidal distribution. Case B ~ Case D of mass distribution ratio m_N/m_1 = 1/3, 1/6 and 3, respectively. The total mass of superstructure is same for various mass distributions of superstructure from case A to case D. Fig. 3 shows the 1st mode eigenvector of superstructure for MODF model, the 1st eigenvalue shows the linear characteristic. And the 1st eigenvalue of i story ${}_1\phi_i = i$ (i =1~N).

Eq. 1 shows the stiffness of superstructure k_i (i =1~N). Eq. 2 shows the stiffness of isolation layer k_0.

$$k_i = \frac{{}_1\omega^2 \cdot m_i \cdot {}_1\phi_i + \left({}_1\phi_{i+1} - {}_1\phi_i\right) \cdot k_{i+1}}{{}_1\phi_i - {}_1\phi_{i-1}}, \quad k_0 = \frac{4\pi^2}{T_0^2}\Sigma m \qquad (1, 2)$$

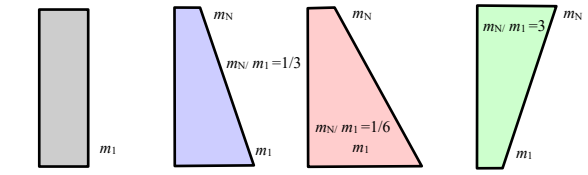
Where, ${}_1\omega$ is 1st circular frequency of superstructure, ${}_1\omega = 2\pi / T_U$. T_U is period of superstructure. Σm total mass of building, $\Sigma m = m_U + m_0$. T_0 is period of isolation layer.

Fig. 4 shows the 1st mode period ratio between 2DOF and MDOF ${}_1T_{2DOF}/{}_1T_{MDOF}$. Fig. 5 shows the 1st mode shape ratio between 2DOF and MDOF ${}_1\phi_{U,2DOF}/{}_1\phi_{N,MDOF}$ when ${}_1\phi_{0,2DOF}$ = ${}_1\phi_{0,MDOF}$ = 1. To see the change of value more clearly, period ratio between superstructure and isolation layer T_0 / T_U is 1.0, the number of mass points is 15. For legend, various lines show mass distributions. According to the Figures, with the building COG position decreases, ${}_1T_{2DOF}/{}_1T_{MDOF}$ and ${}_1\phi_{U,2DOF}/{}_1\phi_{N,MDOF}$ increases when mass ratio is same.



(a) MDOF　(b) 2DOF

Fig. 1 Analysis Model



(a) Case A　(b) Case B　(c) Case C　(d) Case D

Fig. 2 Mass Distribution of Superstructure

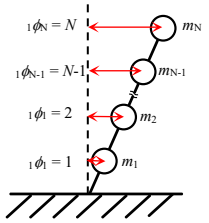


Fig. 3 1st Eigenvector

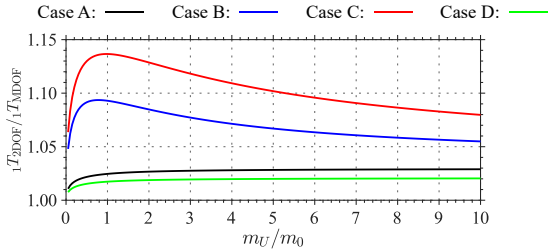


Fig. 4 1st Mode Period Ratio
(T_0 / T_U = 1.0, Sup- 15DOF)

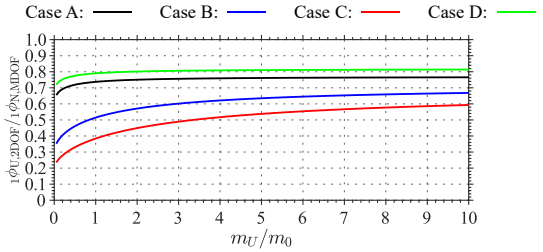


Fig. 5 1st Mode Shape Ratio
(T_0 / T_U = 1.0, Sup- 15DOF)

3. Participation Vector of MDOF Model

Fig. 6 shows participation vectors of 1st mode of Based-isolated building for MDOF model. The mass ratio of superstructure and isolation layer m_0/m_U is 2. (a) ~ (d) are various number of mass points (5, 10 and 20). (1) ~ (4) are various mass distribution of superstructure (case A~D). Horizontal axis is participation vectors of 1st mode ${}_1\beta \cdot {}_1\phi_i$ and vertical axis is story. For legend, colorful solid points are various period ratio T_0/T_U from 1.0 to 5.0, The label has a black stroke when T_0/T_U is 2. (general base-isolated building $T_0/T_U \geq 2.0$ [2])

According to Fig. 6, overview of all subgraphs, a stationary point exists within the participation vectors of different period ratio T_0/T_U. And the participation vector value of this stationary point close to 1. In other words, the response of mass point which closed to this stationary point, almost only effect by 1st mode in dynamic response. The number of mass points hardly influence the position of stationary point. With COG position decreases, the position of stationary point decrease. Therefore, with the building COG position decreases, the difference between MDOF model and 2DOF model increases for isolated building and the response of MDOF is increase.

4. Conclusion

The existence of a stationary point within the participation vectors of different period ratios was confirmed in this paper. And the position of the stationary point moves with the COG.

Reference:

[1] Li J., Sato D.: Prediction Formula of Superstructure for Isolated building Based on 2DOF (Part 1: Equivalent Height of 2DOF Model), *proceeding of the architectural research meetings, Kanto Chapter, Architectural Institute of Japan*, 2023.02.

[2] AIJ: Recommendation for the Design of Seismically Isolated Buildings, pp.131-132,2013, 10.

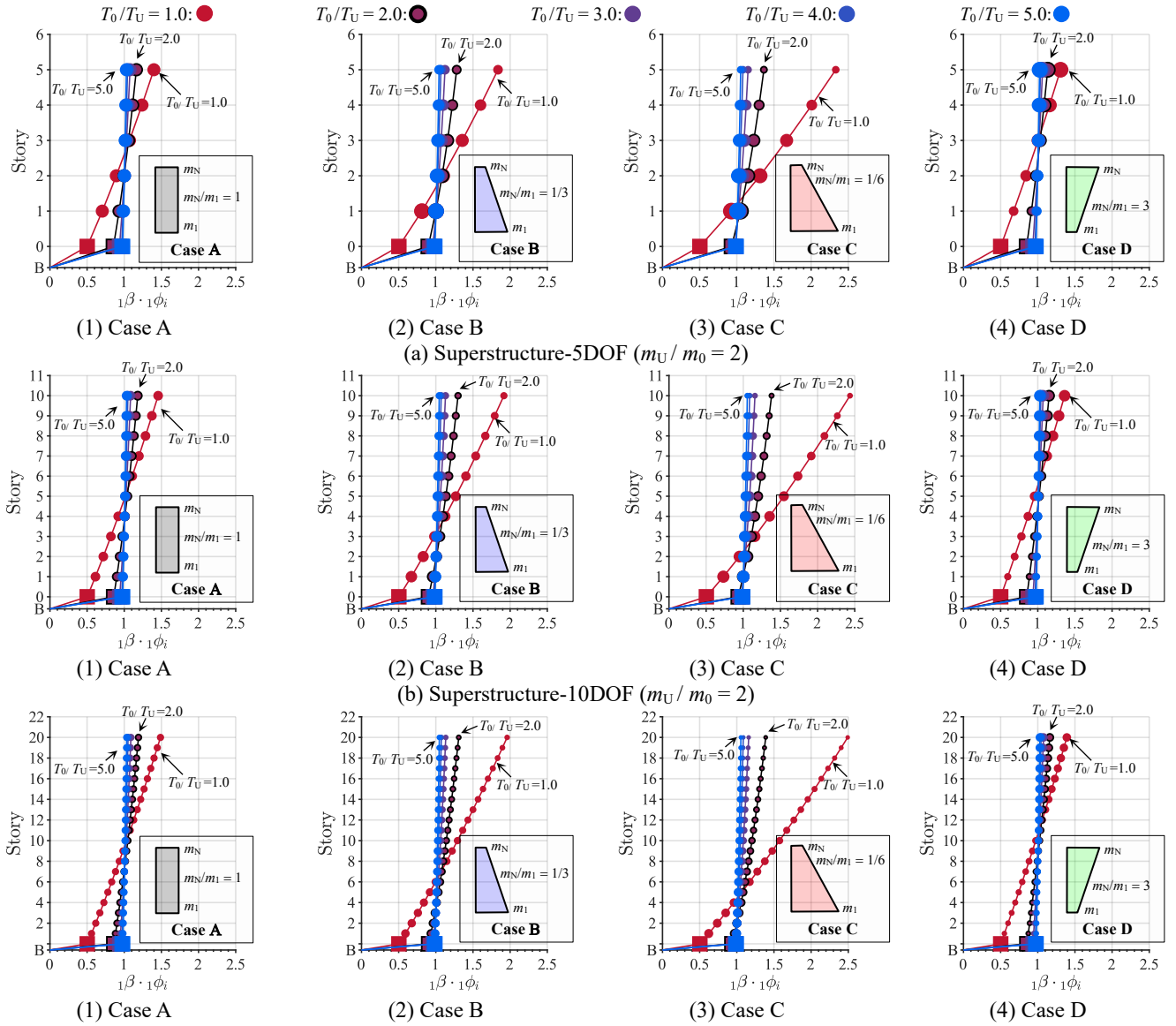


Fig. 6 Participation Vector of 1st Mode of Based-isolated building

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