EVALUATION OF SEISMIC PERFORMANCE FOR INTER-STORY ISOLATION SYSTEM BASED ON MMEB

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Abstract - The simplified three degree of freedom system and energy equation of an inter-story isolation structure is established, the high-order vibration mode energy ratio associated with model-related parameters is examines.Based on the energy balance principle, a multi-modal simplified evaluation method for seismic performance of inter-story isolation structures is proposed.

Based on the multi-modal energy spectrum model, the seismic performance of the inter-story isolation structure is evaluated. The validity of the method and the calculation accuracy is demonstrated by examples. The results show that the predicted displacement distribution of each layer are equivalent to those calculated by elasto-plastic time-history analysis. The calculation method proposed in this paper can take into account the influence of high-order mode, and it has the advantages of good seismic performance analysis and analysis accuracy.

Keywords - Inter-Story Isolation Structure; Energy Equation ; Multi - Modal; Performance Evaluation

I. INTRODUCTION

The inter-story isolation structure is a complex structural system developed on the basis of the base isolation structure. The isolation layer is located on the top of the basement or above the floor, the vibration characteristic is affected by the upper structure and the lower structure of the isolation layer at the same time. This new form of structure has been gradually applied in practical engineering, such as the United States San Francisco 185Berry Street using inter-story isolation technology for added layer reinforcement, Japan Shiodome Sumitomo set isolation layer in the 12 layer of 25 layers [1,2].With the deepening of the application of inter-story isolation technology, it is of great significance to evaluate the seismic performance of such existing buildings.

Unlike the base isolation structure, due to the difference in the position of the isolation layer, the inter-story isolation structure has a multi-modal characteristic, that is, in addition to the basic mode of participation in the contribution of vibration, in some cases, such as the multi-mode coupling effect will appear when the lower part of the structure vibration is prominent. Multiple modal coupling effect is refers to the multi-modal characteristics caused by the interaction of substructure system. Some scholars have proposed some multi-modal seismic performance assessment methods. Chopra et al. [3-5] proposed a multi-modal push-over analysis (MPA) method, which was improved primarily by taking into account the effects of high-order modes on pushover analysis. Fajfar et al. [6-8] proposed N2 method (N for non-linearity, 2 for two mathematical models, MDOF and EDOF), the main feature of which is to simplify the model only by performing single degree of freedom nonlinear time-history analysis (Nonelastic response spectrum) and combined with static nonlinear method to predict the structural elasto-plastic seismic response, to achieve the performance-based seismic design ideas, is currently widely used method. Hernandez-Montes et al. [9] proposed a modified MPA method based on the principle of energy balance. Lin et al. [10-11] proposed the establishment of 2DOF and 3DOF and the original asymmetric structure based on the MPA method to predict the torsional seismic response of the asymmetric structure. The method is to establish an equivalent model by the degree of freedom cohesion predict the torsional effect of the whole structure.

However, the above studies are aimed at the general structure, but for the inter-story isolation structure of this kind of novel system lacks the superior seismic performance evaluation methods. This paper based on the modal energy balance to presents a new method of performance evaluation. This method can be used to seismic performance evaluation of the inter-story isolation structure, which can be applied to the isolated structure and the general structure.

1 Three - degree - of - freedom system characteristics of inter-story isolation structure

The vibration characteristics of inter-story isolation structure are different from those of the base isolation structure. The contribution of the seismic response is related to the first-order vibration mode and the high-order vibration mode [12,13]. In order to simplify the analysis of the isolated structure, [12] [14] proposed the equivalent three degrees of freedom of the isolated structure to quantify the influence of high-order modes.

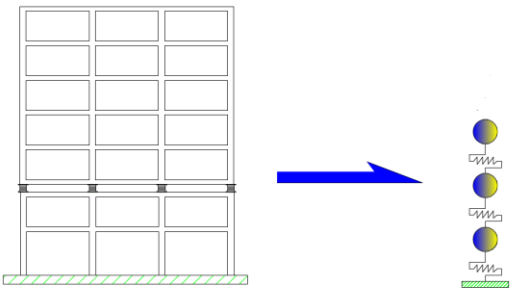


Fig. 1 Simplified model of 3-DOF

As shown in Fig. 1, the three degree of freedom system of inter-story isolation structure is given the following basic assumptions in the simplification process:

1. Eccentric torsion condition of isolation structure is not considered;
2. The base of the isolated structure is a rigid foundation, ignoring the soil-structure interaction;
3. Does not consider the vertical ground motion and torsional ground motion components;
4. Do not consider the the plane bending deformation of floor, the floor is assumed as a rigid model.

2 Process of inter-story isolation structure seismic performance evaluation

The specific steps of structural seismic response under strong earthquake based on the multi-modal energy spectrum are as follows:

(1)With Modal Analysis of the structure, the data can be got such as the structure of the cycle T , the normalized mode vector $\boldsymbol{\Phi}_j$, the mode participation coefficient $\boldsymbol{\Phi}_j$ and the equivalent mass M_j^* ;

(2) To establish the equivalent input velocity spectrum of single degree of freedom system under the action of seismic wave;

(3) For each order ,with multiple modal Pushover analysis, the restoring force model parameters of equivalent single degree of freedom system are obtained;

(4) For each order , energy balance method is applied to the equivalent single degree of freedom system to determine the target displacement ;

(5)According to the target displacement response, the seismic response of each layer is calculated . And according to the seismic response of each layer to evaluated the seismic performance of the structure.

III. CASE ANALYSIS

3.1 Analysis model

Taking a 7-layer reinforced concrete frame structure as an example, to get the seismic performance evaluation of inter-story isolation structure based on multi - mode energy balance method. As shown in Figure 2, the structure facade rules, a total of 7 layers, the first layer of the structure is 4.2m high, the other layer height of 3.9m. Accordance to the aseismatic code of China, the seismic fortification of the structure is 8 degrees (0.2g), and the seismic group is designed as the first group. The site classification is Class II. Frame column section size is 550mm × 550mm, frame beam section size is 300mm × 600mm.Floor and roof dead load (including floor weight) value is 6kN / m2, live load value is 2kN / m2, beam and column concrete grade is C30, beam and column longitudinal reinforcement using HRB400, stirrups using HPB300.The isolation layer is set above the second floor, with isolation layer height of about 2.5m. Reinforcement design information is in Table 1.

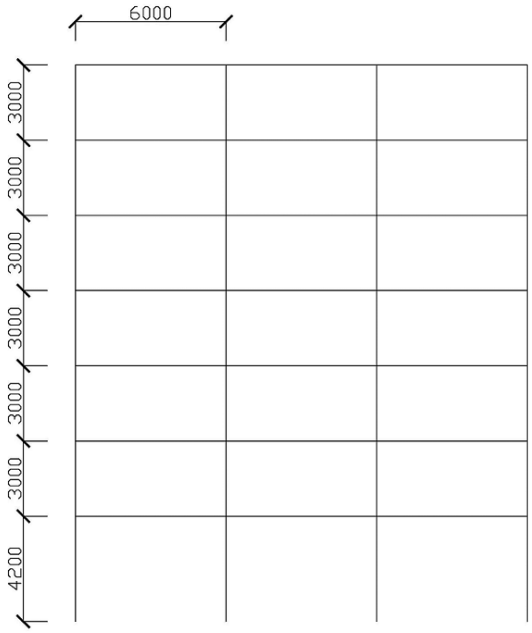


Figure 2 Schematic diagram of RC frame (mm)

floor	Beam top area rebar area (mm2)	Beam bottom reinforced area (mm2)	Column section Reinforcement area (mm2)
8	7982	580	1664
7	1294	720	1664
6	1764	884	1664
5	2294	1147	1664
4	2684	1342	1664
3	2309	1155	1664
2	4805	4154	1664
1	6647	5707	1664

Table 1 Structural reinforcement information

The modal parameters of the first three modes are shown in Table 2. The modal components of the modes are shown in Fig.3.

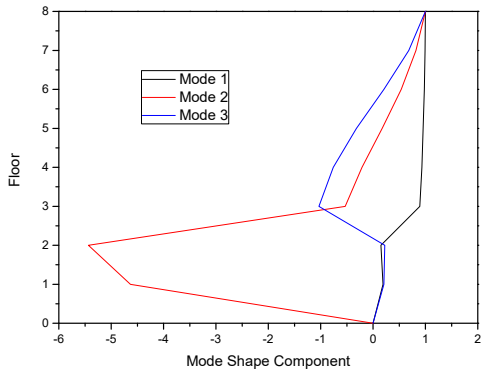


Figure 3 Structural modal components

Cycle (s)			Vibration mode participation coefficient			Modal mass (kg)		
T_1	T_2	T_3	Γ_1	Γ_2	Γ_3	M_1^*	M_2^*	M_3^*
2.815	0.542	0.396	0.95	-0.157	0.067	4.50 × 105	4.45 × 106	2.66 × 105

Table 2 Structural Modal Parameters

3.2 Multi-modal energy balance calculation

The equivalent velocity spectrum of the energy input of each seismic wave is calculated by the elastic time history analysis method, as shown in Fig.4. The total energy input of the example model is calculated from the modal parameters.

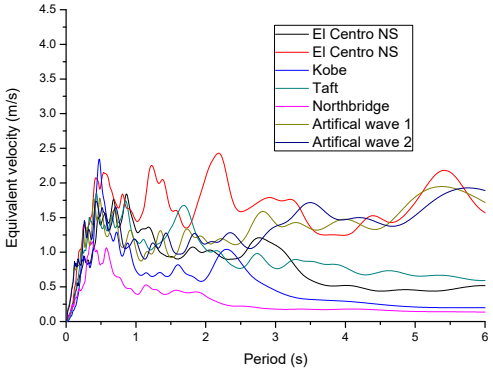


Fig. 4 Total input energy equivalent velocity spectrum

Figure 5 shows the capacity curve obtained by pushing the first order. According to the capacity curve obtained by each order mode, the restoring force model of the equivalent single degree of freedom system can be fitted and then the parameters such as yield force, yield displacement and yield stiffness of each modal are determined. The target displacement are calculated according to the energy balance of each seismic wave. The first-order mode is in the isolated mode, so the target displacement can be determined by the energy balance of the isolated structure. The target displacement of the second-order and third-order mode are determined according to the energy balance of the ordinary reinforced concrete frame. The target displacement of ordinary reinforced concrete frame structures can be obtained from Equation 1:

$$x_m = [\frac{1}{2}M(\frac{T}{2\pi}\alpha g)^2 - \frac{1}{2}M(\frac{T}{2\pi}\frac{f_y}{M})^2]/\ f_y + x_y \quad (1)$$

In the equation, T is the initial period; α is the seismic influence coefficient; g is the gravitational acceleration; f_y is the yield force; x_y is the yield displacement.

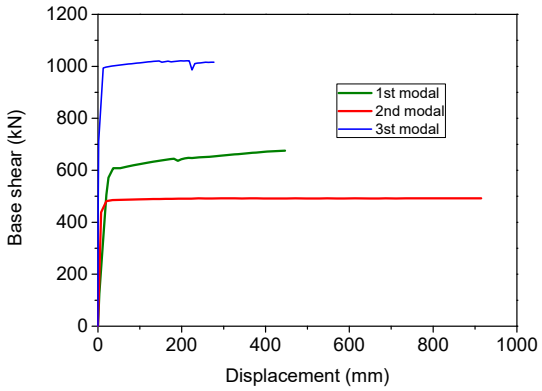


Fig.5 Capacity curve of structure

The target displacement corresponding to each mode is calculated by the mode vector, and the combined displacement is calculated as follows:

$$\mathbf{x} = \sum_{n=1}^{N} \mathbf{\Phi}_n \Gamma_n D_n X_{\text{mass},n} \quad (2)$$

In the equation, $X_{\text{mass},n}$ is the vibration mass participation coefficient.

3.3 Time history verification

The finite element model of the structure is established by using SeismoStruct nonlinear finite element software. The finite element model is based on the

finite element flexibility method, The dynamic elastoplastic finite element model is shown in Figure 6. Concrete constitutive choose nonlinear constant confinement concrete model - con_cc model, reinforcing bar constitutive using Menegotto - Pinto steel model - stl_mp model, introduced by Filippou etc etc Menegotto - Pinto model of directional strengthen rules, the restoring force model of isolation bearing choose Symmetric linear curve - lin_sym linear spring and Bilinear kinematic curve - bl_kin bilinear restoring force model. In the structural analysis, only the one-way horizontal seismic action is considered, and the structure is embedded on the foundation, ignoring the soil-structure dynamic interaction and considering the second-order gravitational P-△ effect of the structure. In the time analysis, the damping is Rayleigh damping, Take 5%.

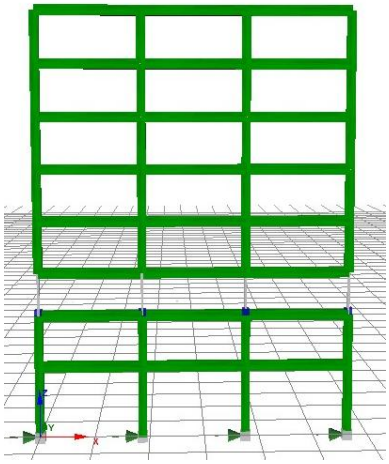


Fig.6 Dynamic elasto-plastic FEM of inter-story isolated structure

Figure7 shows the comparison of the results of the layer displacement history analysis and the multi-modal energy balance method for the 7-layer inter-story isolation structure under the action of seven seismic waves. It can be seen from the graph that the results of multi-modal calculation are close to those of elasto-plastic time history analysis.

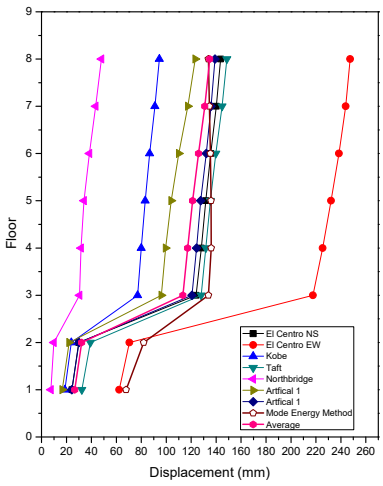


Figure 7 Comparison of multi-modal energy balance method and time history analysis

IV. CONCLUSION

In this paper, the method of seismic performance for inter-story isolation system based on the multi-modal energy balance method is presented. The rationality of the proposed method is verified by the analysis of the elastic time history analysis. The main conclusions are as follows:

(1)Based on the modal energy method, the ratio of the high order mode energy of inter-story isolation structure can be considered.
(2) The method of calculating the seismic performance of the seismic performance for inter-story isolation system based on the multi-modal energy balance method is improved compared with the traditional method, and the influence of the high order mode can be considered. The method is simple and accurate.
(3)The method can be applied for isolation structure and general structure.

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