TWO STEP DESIGN METHOD FOR BASE ISOLATION STRUCTURES

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ABSTRACT :

Two step design method for base isolation structure was put forward based on Code [Seismic Code, 2001]. Aimed on the pioneer process of project, simplified method was adopt in the first step, for the estimation of isolation layer, and only a few basic data of structure was required. In the second step, aimed on detail design, the step-by-step time history analysis was adopted for determination of superstructure, foundation and base isolation device. Computer software based on above method with user-friendly interface, pre-processor and post-processor was developed for practical engineering design of superstructure and foundation.

KEYWORDS: base isolation structure, two step design method, simplified estimation method, time history analysis, program development

1. INTRODUCTION

The main content of base isolation structure design consists of two parts: the first is design of base isolation device, and the second is design of structural elements above the isolation layer. They are two closely connected aspects. Combined with the concrete facts of base isolation technique in China, it is suggested that two step design method may be used to design base isolation device.

2. TWO STEP DESIGN METHOD FOR BASE ISOLATION STRUCTURE

In order to ensure continuity of structure design, two step design method for base isolation structure was put forward based on Code. The contents of two step design method are as follows: Aimed on the pioneer process of project, simplified method was adopt in the first step, for the estimation of isolation layer, and only a few basic data of structure was required. In the second step, aimed on detail design, the step-by-step time history analysis was adopted for determination of superstructure, foundation and base isolation device.

2.1. The First Step Design Method for Base Isolation Structure

Base isolation device can lengthen the natural period of structure, which the dynamic characteristic of the structure will be changed to achieve the aim of reducing the earthquake effect on superstructure. It is main earthquake resistance element, and then others are in on a secondary status. The first step design method refers to using simplified method for the estimation of isolation layer. According to structural importance, specific site conditions and basic situation of building structure such as the number of layers, building area, it can judge whether or not this building is suitable for adopting base isolation technique, and provide basis for decision-making of structural scheme.

2.1.1 Two hypothesis of the simplified method

(1). Because the much great stiffness than isolation layer and usually unification translation under earthquake action, superstructure is regarded as a rigid body.

(2). Neglect the influence of variance of superstructure damping.

2.1.2 The calculation formula of horizontal seismic decrease coefficient

When evaluating the seismic decrease effect, comparison and analysis about the ratio of maximum story shears were made in the two situations of isolated building and non-isolated building. However, most superstructures corresponding to base isolation structure do not exist, the assumption was usually adopted that superstructure were identical with or without isolation.

Therefore, the concept of horizontal seismic decrease coefficient is as follows:

When buildings are subjected to the influence of frequently occurred earthquakes, in order to improve the seismic fortification target in the actual application, horizontal seismic decrease coefficient is equal to the ratio of horizontal seismic effect coefficient of isolated building and non-isolated building multiplied by 1/0.7. The horizontal seismic decrease coefficient shall be determined by the following formula [Seismic Code, 2001]:

$$\Psi = \frac{a_1 \cdot G_{eq}}{a \cdot G_{eq}} / 0.7 = \frac{a_1}{a} / 0.7 \tag{1}$$

Where, a − seismic effect coefficient corresponding to fundamental period of non-isolated building;

a_1 − seismic effect coefficient corresponding to fundamental period of isolated building;

G_{eq} − the representative value of the total gravity load. In the computation of seismic action, the representative value of gravity load of the building shall be taken as the sum of standard values of the weight of the superstructure and components plus the combination values of variable loads on the superstructure.

2.1.3 The basic thought of simplified method

Superstructure is simplified as equivalent SDOF for base isolation structure, and then horizontal seismic effect coefficient corresponding to fundamental period of isolated building is calculated by setting the expected horizontal seismic decrease coefficient. Natural vibration period of base isolation structure shall be determined by seismic effect coefficient curve, thus total horizontal stiffness of isolation layer will be determined.

2.1.4 The concrete procedure of simplified method

(1). In the preliminary design stage, the representative value of the total gravity load is estimated from experiences of existing buildings. Natural vibration period of non-isolated building may be determined by empirical formula, and then horizontal seismic effect coefficient corresponding to fundamental period of non-isolated building shall be determined by seismic effect coefficient curve.

(2). There is a corresponding relationship between horizontal seismic decrease coefficient and seismic decrease effect (Table 1). In the design, the definite target of seismic isolation design is proposed, namely the target of decreasing seismic intensity. Superstructure is designed according to seismic intensity decreased. Horizontal seismic effect coefficient corresponding to fundamental period of isolated building shall be determined by the following formula:

$$\alpha_1 = 0.7\Psi\alpha \tag{2}$$

Where Ψ – the expected horizontal seismic decrease coefficient.

(3). Natural vibration period of base isolation structure shall be determined by seismic effect coefficient curve. Where, seismic isolation degree I [Zhou, et al, 2002] is introduced to evaluate the seismic decrease effect (Table 2, Table 3).

$$I = T_1 / T \quad (3)$$

Where I – Seismic isolation degree,

T_1 – Natural vibration period of isolated building,

T – Natural vibration period of non-isolated building

Table.1 The classification of seismic decrease effect

Ratio of maximum story shears	Horizontal seismic decrease coefficient	Seismic decrease effect
0.53	0.75	drops 0.5 degree
0.35	0.50	drops 1.0 degree
0.26	0.38	drops 1.5 degree
0.18	0.25	drops 2.0 degree

When $0.1 < T < T_g$, where T_g – characteristic period, the relationship between seismic isolation degree and horizontal seismic decrease coefficient is as follow Table 2:

Table.2 The relationship between seismic isolation degree and horizontal seismic decrease coefficient

Ψ	Seismic decrease effect	I
		$T_g < T_1 < 5T_g$
0.75	drops 0.5 degree	$2.046\ T_g/T$
0.50	drops 1.0 degree	$3.211\ T_g/T$
0.38	drops 1.5 degree	$4.355\ T_g/T$
0.25	drops 2.0 degree	$6.935\ T_g/T$

When $T_g < T < 1.0$, the relationship between seismic isolation degree and horizontal seismic decrease coefficient is as follow Table 3:

Table.3 The relationship between seismic isolation degree and horizontal seismic decrease coefficient

Ψ	Seismic decrease effect	I
		$T_g < T_1 < 5T_g$
0.75	drops 0.5 degree	2.046
0.50	drops 1.0 degree	3.211
0.38	drops 1.5 degree	4.355
0.25	drops 2.0 degree	6.935

(4). Because the much great stiffness than isolation layer and usually unification translation under earthquake action, superstructure is regarded as a rigid body. The total horizontal stiffness of isolation layer shall be determined by the following formula:

$$K_1 = \frac{4\pi^2 G_{eq}}{T_1^2 g} \quad (4)$$

Where K_1 – the total horizontal stiffness of isolation layer.

2.2 Primary Reasonableness Check of the Expected Horizontal Seismic Decrease Coefficient

The reasonableness check of the expected horizontal seismic decrease coefficient lies between the first step and the second step.

After the first step, base isolation device was tentatively selected based on the total horizontal stiffness of isolation layer, called seismic isolator selected according to the total horizontal stiffness of isolation layer. In addition, seismic isolator can also be selected according to vertical bearing capacity of seismic isolator. If the expected horizontal seismic decrease coefficient is reasonable, two kinds of selection will be quite close, then entering the second step. Contrarily, if there is big difference between the two results, the coefficient is unreasonable, and then the coefficient needs to be re-determined, returning the first step.

2.3 The Second Step Design Method for Seismic Isolation Structure

In order to calculate earthquake resistant capacity of base isolation structure and optimize arrangement and parameters of base isolation device, the step-by-step time history analysis has been adopted in the second step.

The calculation model used is in accordance with Code, including seismic isolator, beam and slab structure of isolation layer roof and superstructure, which is simplified as shear-type structure of multi-lumped particles. The horizontal seismic decrease coefficient is determined according to the ratio of maximum story shears made in the two situations of isolated building and non-isolated building, and the maximum displacement of isolation layer should be checked under rare earthquake.

Table.4 Type of bearing and calculation parameters

Item	Type			
	PXΦ300-53	PXΦ400-70	PXΦ500-85	PXΦ600-107
Vertical bearing capacity (kN)				
Average compressive stress 15Mpa	924	1702	2715	3963
Average compressive stress 12Mpa	739	1307	2171	3171
Average compressive stress 10Mpa	616	1089	1810	2642
Ultimate bearing capacity (kN)	9300	16000	25000	38000
General horizontal displacement designed R=50% (mm)	26.5	35.0	42.5	53.5
Maximum horizontal displacement designed R=250% (mm)	132.5	175.0	212.5	267.5
0.55 times of the diameter (mm)	154	209	264	319
Horizontal stiffness (kN/mm)				
R=50%	0.85	1.48	1.86	2.1
R=250%	0.62	0.83	1.119	1.26
Vertical stiffness (kN/mm)	827	1210	1697	2100
Equivalent damping ratio (%)				
R=50%	23	22	23	24
R=250%	15	14.5	16	15.6
The first shape coefficient S_1	15.84	16.3	16.9	18.23
The second shape coefficient S_2	5.28	5.4	5.62	5.61

3. EXAMPLE OF ISOLATION STRUCTURE DESIGN

3.1 Engineering Survey

There is a 7-story reinforced concrete frame structure in area of 9 degree intensity, without basement. It is built on Ⅲ site category, and classification of design earthquake is the first group. It is 41.4m long and 17.7m wide, and the height is 26m.

3.2 The Concrete Design Contents and Procedures

3.2.1 The first step design

(1). The representative value of the total gravity load is 81338.265kN, natural vibration period of non-isolated building is 0.65s, and characteristic period of site is 0.45s. The initial expected horizontal seismic decrease coefficient is 0.50. The horizontal seismic effect coefficient corresponding to fundamental period of isolated building is calculated in accordance with the formula (2):

$$a_1 = 0.7 \times 0.50 \times 0.230 = 0.080$$

(2). Natural vibration period of base isolation structure is determined by seismic effect coefficient curve, and that is 2.087s. The total horizontal stiffness of isolation layer is determined by the formula (4), and that is 75.280kN/mm.

(3). Average horizontal stiffness demand of single isolator is 1.711kN/mm. Two kinds of seismic isolators are arranged, including diameter 400mm and 500mm. The number of isolator of 400mm is 12, of 500mm is 32, respectively. Under frequently-occurred earthquake action, the total horizontal stiffness of isolation layer is 77.28kN/mm, and equivalent damping ratio is 22.7%.

3.2.2 Primary reasonableness check of the expected horizontal seismic decrease coefficient

(1). when Ψ is equal to 0.5, the number of seismic isolator selected according to vertical bearing capacity for 400mm is 48 independently, and for 500mm is 30 independently. Two kinds of selection are quite close results, and then the coefficient is reasonable.

(2). when Ψ is equal to 0.75, the total horizontal stiffness of isolation layer is 185.34kN/mm, average horizontal stiffness demand of single isolator is 4.212kN/mm. According to given mechanical properties of isolators, it can not make selection, and then the coefficient is unreasonable.

(3). when Ψ is equal to 0.38, the total horizontal stiffness of isolation layer is 40.910kN/mm, average horizontal stiffness demand of single isolator is 1.023kN/mm. The number of seismic isolator selected according to vertical bearing capacity for 300mm is 88 independently, and for 400mm is 48 independently. Obviously, there is big difference between the two results, and then the coefficient is unreasonable.

(4). when Ψ is equal to 0.25, the total horizontal stiffness of isolation layer is 16.131kN/mm, average horizontal stiffness demand of single isolator is 0.403kN/mm. According to given mechanical properties of isolators, it can not make selection, and then the coefficient is unreasonable.

3.2.3 The second step design

Based on Code and Technical specification for seismic-isolation with laminated rubber bearing isolators [CECS 126, 2001], base isolation structure is calculated with 3D-BASIS-ME.

The calculation results are as follows (Table.5, Table.6):

Table.5 Calculation of horizontal seismic decrease coefficient

Wave	1	2	3	4	5	6	7	8	Maximum ratio	Decrease coefficient
Synthesized	0.474	460	0.446	0.438	0.427	0.408	0.371	0.336	0.351	0.50
Natural 1	0.369	0.351	0.344	0.336	0.324	0.311	0.290	0.283		
Natural 2	0.212	0.198	0.186	0.189	0.202	0.208	0.216	0.245		
Average	0.351	0.336	0.325	0.321	0.317	0.309	0.293	0.288		

Table.6 Maximum base displacement, maximum base shear and overturning moment

Wave	Synthesized seismic wave		Natural seismic wave 1		Natural seismic wave 2	
	X	Y	X	Y	X	Y
Maximum displacement of base (m)	0.2072	0.1859	0.1282	0.1308	0.0853	0.0823
Maximum base shear (kN)	1.96E04	1.72E04	1.22E04	1.24E04	8.67E03	8.25E03
Overturning moment (kN.m)	3.10E05	2.95E05	1.81E05	1.99E05	1.21E05	1.41E05

The representative value of time history analysis is the average value of maximum value under three seismic waves, main results are as follows:

$$K_{eq50} = 77.28\text{kN/mm}, \xi_{eq50} = 22.7\%, K_{eq250} = 45.67\text{kN/mm}, \xi_{eq250} = 15.6\%;$$

$$\Psi = 0.5; \quad \delta_{max} = 136.6mm$$

4. COMPUTER SOFTWARE FOR BASE ISOLATION STRUCTURE

Computer software based on above method with user-friendly interface, pre-processor and post-processor was developed for practical engineering design of superstructure and foundation. It can export the Excel worksheet of the analysis result and save calculation time and reduce the workload greatly. It is beneficial for the extension and application of seismic isolation technique.

5. CONCLUSION

(1). The computation result shows that two step design method is simple and practical, and its concept is clear and easy for further expansion and application. The method is advantageous to enhance design quality and reduce design period.

(2). The simplified method is suitable for multi-storey isolation structure. With the increase of the layer number, influence of higher modes increased, the method is not adapted for high-rise isolation structure.

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