SEISMIC RESPONSE OF STEPPED BUILDING SUPPORTED BY STEPPED FOUNDATION ON HILLSIDE

Liping Liu[(1)], Cunxiong Wu[(2)], Yingmin Li[(3)], Nina Zheng[(4)], Qiang Xie[(5)]

[(1)] *Professor, school of civil engineering, chongqing university, chongqing, china, liuliping@cqu.edu.cn*
[(2)] *Graduate student, school of civil engineering, chongqing university, chongqing, china,469538566@qq.com*
[(3)] *Professor, school of civil engineering, chongqing university, chongqing, china, liyingmin@cqu.edu.cn*
[(4)] *Professor, school of civil engineering, chongqing university, chongqing, china, Zhengnina@cqu.edu.cn*
[(5)] *Professor, school of civil engineering, chongqing university, chongqing, china, xieqiang2000@hotmail.com*

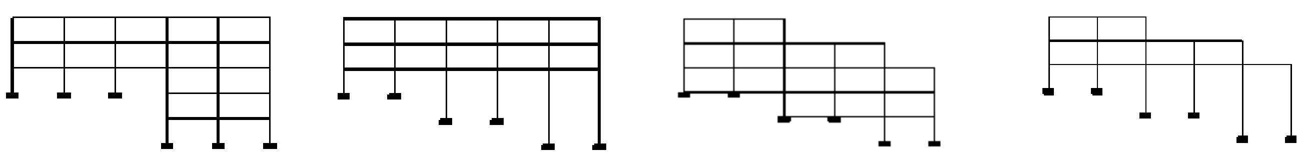
Abstract

The step back-set back building is supported by stepped foundation where the foundation elevation and roof elevation are different. The complexity of seismic input of stepped site and the irregularity of this building make seismic response of this structure has its own particularity. In this paper, a model of identical inputting wave and a model of soil-structure interaction suitable for seismic response of step back-set back buildings were developed. The dynamic response of this structure, i.e. period, storey drift, storey shear, and the shear distribution characteristic of columns have been studied by using elastic seismic response analysis method. The distribution of plastic hinges and the yield mechanism of the structures were studied by using elastoplastic analysis method. Some suggestions on seismic design for step back-set back building were presented. The conclusion will be beneficial to improve the seismic resistance capability, and promote the application of step back-set back building.

Keywords: stepped foundation; stepped building; building built on hillside; soil-structure interaction

1. Introduction

With the increasing demands of people's living environment, building on hillside combined with natural environment and mountainous terrain is increased. The hillside building structures are usually divided into four categories, i.e., step back building (Fig.1a), suspending building (Fig.1b), step back-set back buildin g (Fig.1c), suspending-set back building (Fig.1d), depending on the mode of connection between foundation and soil and the mode of setback.



(a) Step back building (b) Suspending building (c) Step back-set back building (d) Suspending-set back building

Fig.1 Type of hillside building structures

Researchers pay more attention to the research of hillside buildings. In 1990, Valts [1] proposes a structure of combines stepped structures with brace, and applied for a patent. In 1996, the seismic behavior of the step back-set back building was analyzed by Kumar [2], and then an elastic seismic analysis method for the step back-set back building was proposed [3]. A multi-storey residential building with unequal foundation was applied by Stewart [4], and the connection modes about structures and slopes was given. The torsional response of step back-set back structures was analyzed by Birajdar [5]. These studies only aimed at the analysis of the seismic performance characteristics of the hillside building structure, systemic theories have not been formed. Liu Liping [6] clearly stated the concept of the hillside building structure, analyzed the special problems in seismic design of hillside building structure. Dr. Sanjaya Kumar Patro[7] and Haider Abdulazeez Ibrahim[9] analyzed the seismic performance of the hillside building structures through establishing suspending-set back structures with variable column heights. The research shows that many situations with short column effect arise in buildings. Ajay Kumar Sreerama[8] studied the behavior of building on varying slope angles i.e., 15°, 30°, 45° and 60°. It was observed that as the slope angle is increasing, building is becoming stiffer. Liu Liping [10-13] analyzed the seismic performance of soil structure interaction on hillside building structures, compared with soil structure interaction models, the results of traditional structure models is not safe and much attention should be given. Pandey A.D[14] analyzed the hillside structure with pushover method, and proposed pushover analysis for type of irregularity considered requires modification. R. M. Jenifer Priyanka [15] studied the effect of soil structure interaction on step back structure. It was observed that the dynamic response of structures increases when the type of soil changes from hard to soft.

At present, seismic performance of step back structures are mainly carried on the theoretical research, and mainly for the two steps back buildings, for multi-steps back-set back buildings and on the basis of considering soil-structure interaction research is very few. In this paper, step back structures were as the study object, the identical inputting wave model and soil-structure interaction model were established in SAP2000, analyzed the storey drifts, storey shear force, column shear force and plastic deformation appearance concentrated area of the beams and columns under seismic action, and based on the analysis results, some seismic design suggestions were presented.

2. Analysis model

Taken the step back structures as the study object, considered the types of stepped and not stepped structural, and identical inputting wave models and soil-structure interaction models were established. The seismic response and yield mechanism of these models were comparatively analyzed.

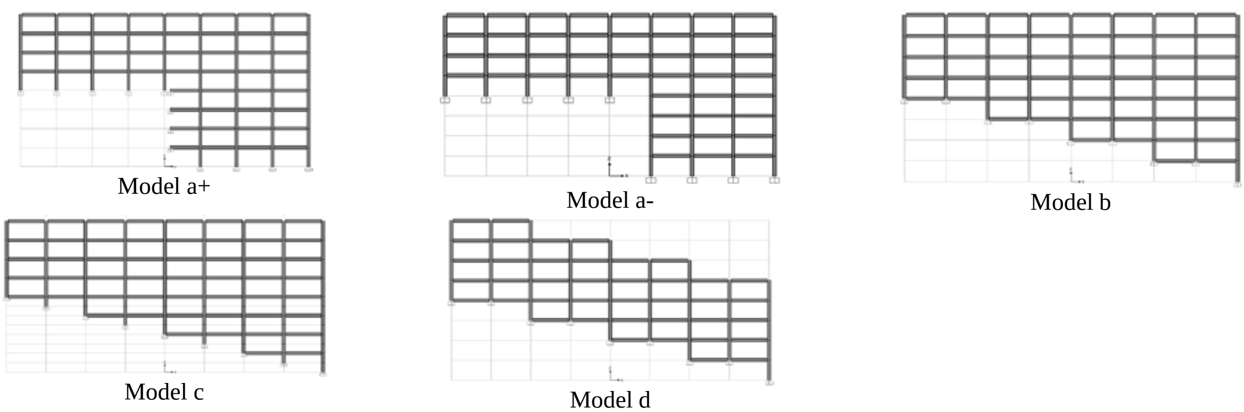


Fig.2 Identical inputting wave models

In this paper, the floor height and column spacing of each structure model are 3 meters and 6 meters respectively. The beam section is 0.2m x 0.5m. The column section is 0.5m x 0.5m. The concrete strength is C30. The earthquake intensity is VII degree (0.1g). The design earthquake group is 1 and the site class is II. The linear load of beam is 12kN/m. The dead load of slabs including the dead weight and additional load of 1.5 kN/m^2. The live load of slabs is 2kN/m^2.

2.1 Identical Inputting Wave Model

The models with different grounding methods are established based on the principle of using area approximation are shown in Fig. 2. Taking the influence of setting pull beam in the off layers of the step back structure, the modal "a+" and modal "a-" were established. It can be observed from figure 2 that modal "a+" and modal "a-" have two-steps, modal "b" has four-steps, modal "c" has eight-steps and modal "d" has four-steps.

2.2 Soil-Structure Interaction Analysis Model

The soil-structure interaction model was established based on model "d" in Fig2.d. The proposals of the structure design are proposed through changing site conditions and by analyzing the effect of different site condition on seismic response of structure. The soil-structure interaction model is shown in Fig. 3. The beams and piles are simulated with beam element. The soil layers are simulated with plane strain element and the thickness of the soil is 1meters. The soil boundary simulated by using simple and effective remote border. As long as the boundary is relatively far away, it can be used without any treatment. The literature [11] show that the width of remote border is not less than 10H (H is the thickness of the soil) when soil harden gradually from top to bottom. The width of remote border is not less than 20H when soil is identical from top to bottom. In this paper, the simulation of the soil boundary with remote border and the width is 600 meters. The parameters of the structure are similar to the model “b”. The type of foundation using a column corresponding to a pile and the diameter of the pile is 0.8 meters. The site conditions have three types, and the soil is identical from top to bottom. The depth of soil at the bottom of the structure is 12 meters. The parameters of foundation soil are given in Table 1.

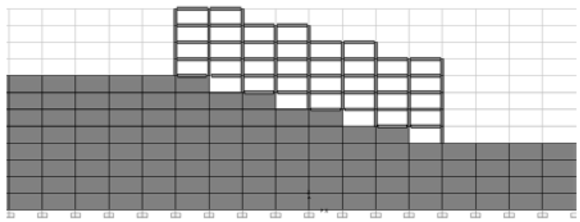


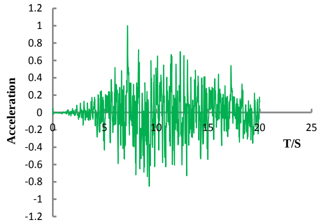
Fig.3 Soil-structure interaction model for step back-set back building

Table 1 Soil parameters of soil-structure interaction model

Models	**A soil （b-1）**	**B soil（b-2）**	**C soil（b-3）**
Elastic Modulus /MPa	1152	288	72
Poisson Ratio	0.3	0.3	0.3
Density /（kg/m^3)	2000	2000	2000
Damp Ratio	0.05	0.05	0.05
Shear wave velocity /（m/s）	471	235	118

2.3 Inputting seismic wave

Two seismic records and an artificial seismic wave were selected to analyze the seismic behaviors of the identical inputting wave model and soil-structure interaction model by using time-history analysis method. The seismic waves are selected based on the first group of earthquake group, site II, characteristic period 0.35s, and structure period 0.65s. To facilitate the analysis, the peak value of seismic waves were to adjusted to unit 1. The seismic waves are shown in Fig. 4.



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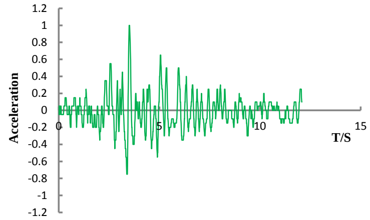

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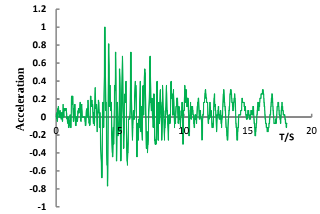

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Fig.4 Seismic waves for time-history analysis

3. Seismic response analysis based on identical inputting wave model

The models under identical inputting are simulated by using the plane model, and elastic time-history analysis and elastoplastic time-history analysis are carried out. The dynamic response, i.e. the period of structures, storey drifts, storey shear, and the yield mechanism of the structure under the condition of elastoplastic analysis have been studied.

3.1 Elastic seismic response analysis

1) Structure periods

From Table 2 shows that different grounding methods of step back structures have different period, and the difference of upper structure significantly differentiated in period. Compared with the model "a-", the model "a+" is connected with the slope by the beam, and the period decreases with the constraint increasing. According to the period changes of model "a+", model "b" and model "c", the more number of stepped, the smaller the slope constraint is, the larger the period is. Compared with the model "b", the period of model "d" is obviously decreased.

Table 2 The 1st an 2nd Structure periods of models

Period/s	Model a+	Model a-	Model b	Model c	Model d
T1	0.637	0.658	0.659	0.675	0.496
T2	0.187	0.304	0.197	0.201	0.195

2) Storey drift and storey shear

The value of storey drifts can be represented by the relative displacement differences of the upper and lower node of side column. Floors "-1, -2, -3, -4" respectively means "stpset 1, stpset 2, stpset 3, stpset 4". As shown in the figure 5 and figure 6, the storey drifts and storey shear of the structures are the average value under the response of three seismic waves.

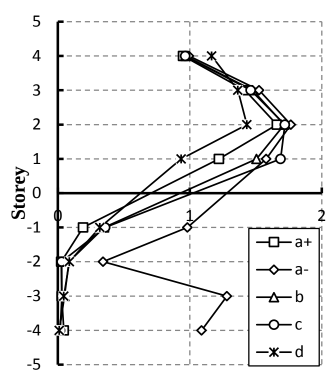


Fig.5 Distribution of storey drift

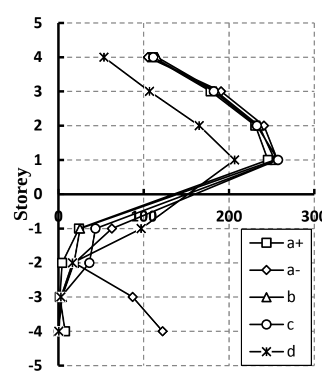


Fig.6 Distribution of storey shear force

From Fig.5 and Fig.6, the change rules of storey drifts among the five models are basically the same, and the maximum value of storey shear appears in the layer located on the upper ground. Comparing with the other models, the storey drift and storey shear of model "d" are smaller.

The storey drift and storey shear of model "a-" in the off layers of the step back structure are larger than other models. The main reason lies in that the lateral deformation is constrained by the pull beam in the off layers, and most of the horizontal force was transmitted directly to the slop through the pull beam, which causes the storey drift and storey shear reduced. Therefore, for this very irregular and unsymmetrical in horizontal and vertical planes structures, the pull beams are set in the off layers of the step back structure can make the seismic response of the off layers reduced.

3) Shear of the columns located on the upper ground storey

The model “a-”as shown in the Fig. 7, the columns are numbered consecutively from left to right, and divided into ground and not ground based on the actual situation. The number of the brackets behind each model names in Fig. 8 represents the total shear value of the layer located on the upper ground.

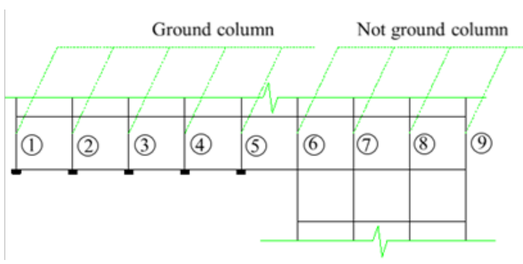


Fig.7 The numbers of columns

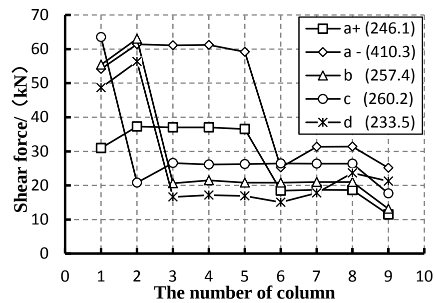


Fig.8 Distribution of each column shear force

From Fig. 8, it is indicated that the shear distribution rules of the layer located on the upper ground under different grounding methods are basically the same. The shear of the ground column is obviously larger than the not ground column of the same layer. The main reason is that the larger the stiffness of the ground column is, the more the shear is. Thus the ground column should be strengthened during the process of design.

Comparison of the distribution of shear in model “a+” and model “a-” shows that the distributive ratio of shear in ground column and not ground column are basically the same. The ratio is usually in the range of 2. But the value of shear has great difference. The main reason is that the horizontal force of the upper structure under seismic was transmitted to scarp through the pull beam and the upper ground column. It makes the storey shear of the layer located on the upper ground and the shear of column become smaller.

4) Shear of ground column of each layer

Taking the model “b” as an example, the columns are numbered consecutively from left to right and shown in Fig. 9.

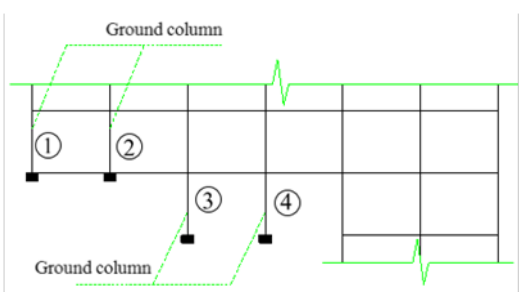


Fig.9 The numbers of columns

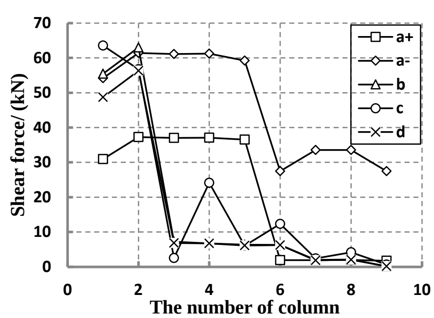


Table.10 Distribution of column shear

From Fig. 10, it is shown that the shear of the ground column located on the off layers decreases obviously by setting pull beam in the off layers. For different models, the shear distribution rules of the ground column from top to bottom are basically the same. The shear of ground column was getting smaller from top to bottom. Due to variable column heights, the shear of ground column is difference in model “c”. If short and tall columns exist within the same storey level, the short columns attract larger earthquake force and suffer more damage as compared to taller ones. Thus the short column should be strengthened during the process of design. The shear of ground column has little difference between model “b” and model “d”.

3.2 Elastoplastic seismic response analysis

The values of the elastoplastic storey drifts and storey shear of the structures under rare earthquake are shown in Fig. 11 and Fig. 12 respectively. Compared with frequent earthquake, only the position of the maximum storey drift of model "a-" and model "d" have changed .The maximum storey drift of model "a-" appears in the column located on the upper ground and the maximum storey drift of model "d" appears at the top layer.

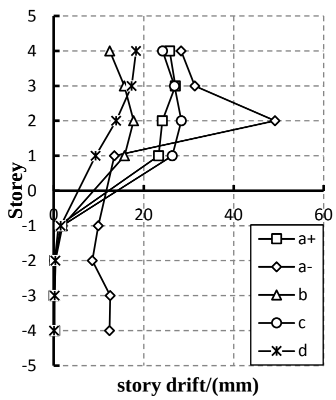


Fig.11 Distribution of storey drift

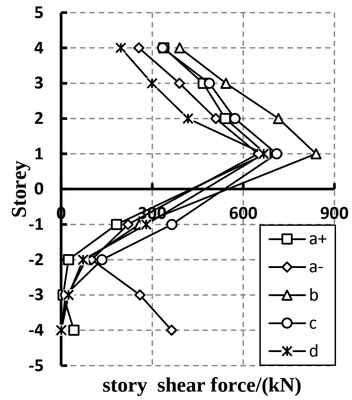
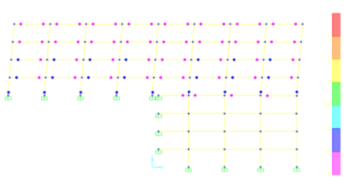


Fig.12 Distribution of storey shear force

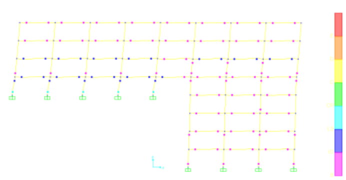
A research is studied about analyzing the elastoplastic deformation and the distribution of plastic hinges under the seismic waves TAI00039, the results are shown in Fig. 13.

By comparing the distribution of plastic hinges under the seismic shows that the column located on the upper ground always appears plastic hinge. Compared with other models, the plastic hinges in the bottom floor and the second floor of the off layers are emerged only in model "a-".

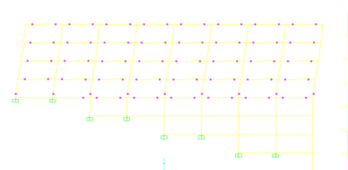
Compared with model "a-", the off layers of modal "a+" are connected with slope by setting the pull beam. It is beneficial to reduce the damage degree of the upper ground column. In model "d", the column hinges are mainly emerged in the upper ground column, and the upper layers mainly emerge beam hinges. The damage degree of model "d" was lighter, which has a good dissipation capacity as well as great seismic performance.



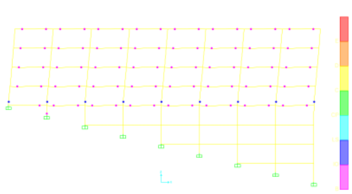
Model a+



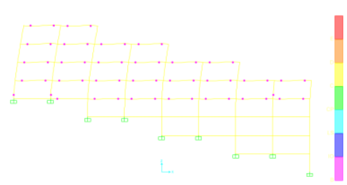
Model a-



Model b



Model c



Model d

Fig.13 Plastic hinges concentrated area of the beams and columns

4. Seismic response analysis based on soil-structure interaction model

The soil structure interaction model of step back-set back building is simulated by using the plane model is shown in Fig. 2. The seismic inputting position of soil-structure interaction model based on the bottom of soil. The basis for the structural design was proposed through the elastic time historey analysis and by comparison the difference in the periods of structures, storey drifts and storey shear force.

For ease of expression, using the model of "b-1", "b-2" and "b-3" respectively represent the model with different type of foundation soil are shown in Table 1. Table 3 shows that the periods of the soil-structure interaction model is bigger than the model under identical inputting, and the soil become softer, the vibration period of structure become bigger.

Table 3 The vibration period of models

Period/s	Model b	Model b-1	Model b-2	Model b-3
T1	0.495701	0.56629	0.660137	0.973201
T2	0.194723	0.248139	0.451384	0.802062

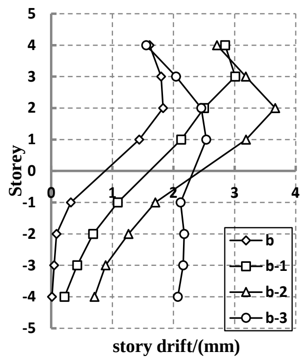


Fig.14 Distribution of storey drifts

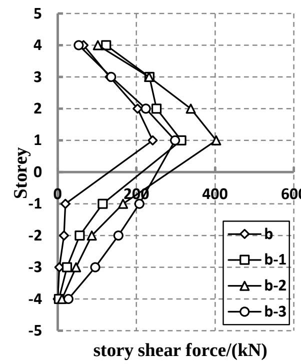


Fig.15 Distribution of storey shear force

Fig.14 and Fig.15 clearly shows that the change rules of storey drifts and storey shear among the four models are basically the same. The bigger the soil stiffness, the storey drifts and storey shear of soil-structure interaction were closer to the model under identical inputting. The smaller the soil stiffness, the greater the increment magnitude of the storey drifts and storey shear in the off layers. It showed that the storey drifts and storey shear of the model under identical inputting is smaller than the soil-structure interaction model. When the slope is soil condition, the effect of the soil and soil-structure interaction should be considered during the design process. If the model under identical inputting is used during the design process, it is necessary to multiply an amplification factor for the storey drifts and storey shear of the structure, and the factor differs with the form of structure and the nature of soil.

5. Conclusion

Based on dynamic analysis of different configurations of buildings, the following conclusions can be drawn.

The shear of the ground column is obviously larger than the not ground column of the same layer. Thus the ground column should be strengthened during the process of design.

For this very irregular and unsymmetrical in horizontal and vertical planes structures, the pull beams are set in the off layers of the step back structures can make the seismic response of the off layers reduced.

By comparing the distribution of plastic hinges under the earthquake shows that the damage degree of step back-set back building structure was lighter, which has a good dissipation capacity as well as great seismic performance.

When the slope is soil condition, the effect of the soil and soil-structure interaction should be considered during the design process. If the model under identical inputting is used during the design process, it is necessary to multiply an amplification factor for the storey drifts and storey shear of the structure, and the factor differs with the form of structure and the nature of soil.

6. Acknowledgements

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