SEISMIC PERFORMANCE OF TERRACED REINFORCED CONCRETE FRAME

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ABSTRACT :

Terraced reinforced concrete frame located at hillside with terraced substructure is a special structure form of mountainous area buildings. Two simplified model are built in two ways of connection with hillside, then to adopt elastic and static elastic-plastic earthquake analysis method to analyze those designed examples by 3D finite element analysis software. The seismic performance of terraced reinforced concrete frame is researched in paper. There are three parties on the analysis, firstly, to study on the seismic performance of terraced reinforced concrete frame when retraining wall is not main structure together; secondly, to study on the seismic performance of terraced reinforced concrete frame when retraining wall is main structure together through bolt connecting, wherein the bolt and retraining wall providing to lateral restraint; thirdly, to analyze and compare above two conditions with the common frame by their seismic performance at different work stage besides dynamic property and weak story and so on. Based on analysis and study, the seismic performance of terraced reinforced concrete frame is explored to adopt designed measures of ensuring the seismic performance. The analysis result will be basis to design similar structure for engineers.

KEYWORDS: Terraced reinforced concrete frame; seismic performance; common frame

1. INTRODUCTION

More than 65 percent of land areas in china are mountainous areas and many cities are mountainous cities (Dai 2006). The terraced structure is a common form of mountainous architectural structure (Lu and Wang 2001). It is built on hill slope, its bottom basement is located on different elevation site and height of terraced part equal to layer height or multiple of layer height in Figure 1 and figure 2.

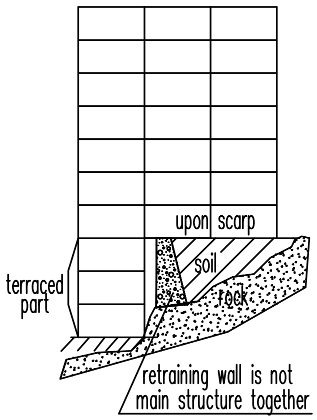


Figure 1Terraced structure diagram(Retaining wall is not connected with the main structure)

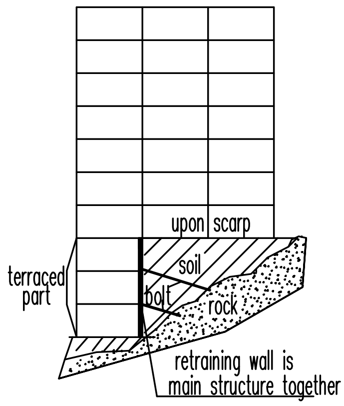


Figure 2 Terraced structure diagram(Retaining wall is connected with the main structure)

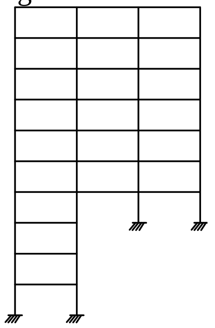
The changes of bottom stiffness of terraced reinforced concrete frame (terraced frame for short) and different ways of connection with hillside lead to some special problem comparing with the common frame. Liu et al. (1996) analyzed the seismic performance of terraced structure thinking over interaction of soil and structure.

Yang et al. (2007 and 2005) built whole model thinking over the interaction of soil and structure with only the influence of properties and thickness of soil layer considered. However, the influence of seismic performance on the structure with different ways of connection with hillside r is neglected.

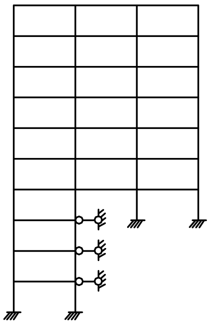
So the simplified model is built in two ways of connection with hillside in the paper and the elastic and static elastic-plastic earthquake analysis method is used to analyze their seismic performance, which is expected to provide theoretical basis for design of terraced structure.

2. SIMPLIFIED MODEL FOR TERRACED REINFORCED CONCRETE FRAME

Based on two treated ways of connection with hillside for terraced reinforced concrete frame in engineering presently, firstly, retraining wall is not main structure together (see Figure 3a); secondly, retraining wall is main structure together through bolt and retraining wall providing to lateral restraint(see Figure 3b). The two methods are applied and engineers can choose one of them.



(a) Model 1



(b) Model 2

Figure 3 Simplified model for terraced frame

Aiming at Figures 1 and 2, tow simplified models for terraced frame are built, meanwhile it is considered whether retraining wall reacted to main structure and how to simplify when it is reacted. According to Figures 1and 2, the simplified models 1 and 2 are built in the paper.

1) For simplified model 1, the influence of retraining wall is not considered beacause retraining wall is not main structure together, however c are treated as fixed end (Figure3a).

2) For simplified model 2, the retraining wall is main structure together through bolt, to suppose lateral displacement of terraced part is constrained, then bolts are simplified lateral supports. the bearings of column base are treated as fixed end too (Figure3b).

Based on the simplified models, different examples are designed and their seismic performances are predicted. In the following parts, the seismic performances of two simplified models are compared with the commmon frame performance.

3.COMPARATIVE ANALYSIS OF EXAMPLES

For convenience of depiction, stories of connection with hillside are called as terraced part, longitudinal stories are called as terraced longitudina stories, transverse stories are called as terraced transversal spans, for example Figure 3a is ten-story frame, terraced three stories and terraced one span are simplified as 31a. thereinto 3 indicates terraced story number and 1 indicates terraced span number, a or b shows separately the simplified model 1 or the simplified model 2, in addition 00 indicates common reinforced concrete frame (common frame for short).

Three reinforced concrete 10-story frames are designed in this paper. First frame is three stories terrace and three spans; the second is four stories terrace and four spans and third one is a common frame. The simplified model 1 and the simplified model 2 are denoted as 33a, 44a and 33b, 44b respectively. The story height considered to be 3 m, the space between columns is 6 m. X direction contains 5 spans and Y direction contains 6 spans. A typical frame is taken from X direction to study the seismic performance. Section size and material of example members are shown in table 3.1.

Table 3.1 Section size and material of members

Member type	story	Section size (h×b)	Concrete grade
column1	1-2 story	700mm×700mm	C30
colunm2	3-10 story	600mm×600mm	C30
beam	1-10 story	600mm×300mm	C30

Following to adopt elastic and static elastic-plastic earthquake analysis method to analyze those designed examples by 3D finite element analysis software. The seismic performance of terraced frame is researched, besides dynamic property and weak story and so on.

3.1 Analysis on Dynamic Property of Structure

The natural period of structure for different examples is given through analysis of examples (Table 3.2). There are following some characteristic. Firstly, the direction of first main vibration mode makes a change for terraced frame contrast with common frame. The span number in X direction is less than the span number in Y direction so that the stiffness in X direction is less than the stiffness in Y direction, lead to first main vibration mode in X direction for common frame in example. However it is found that first main vibration mode in Y direction for terraced frame through calculation of some examples. Secondly, common frame 00 has not torsion period, but terraced frame has torsion period due to vertical stiffness irregularity. Thirdly, the natural period of simplified model 1 and simplified model 2 are near, however lateral stiffness is added because of lateral support in the simplified model, so that the natural period of simplified model 1 is less than that of simplified model 2 in the same situation.

Table 3.2 Natural periods of different examples

Frame type	T_1 (s)	Direction	T_2 (s)	Direction	T_3 (s)	Direction
00	1.2841	X	1.2691	Y	0.4146	X
33a	1.0653	Y	0.9914	X	0.8795	torsion
33b	1.0209	Y	0.9365	X	0.8521	torsion
44a	1.0749	Y	0.9407	X	0.7852	torsion
44b	0.9504	Y	0.7997	X	0.7229	torsion

3.2 Analysis of Story Displacement

It is found the story displacement of two simplified models are not big difference in Y direction, however they in X direction are difference for those examples, due to lateral displacement is constrained by lateral support in the simplified model 2. From the change curve of story displacement in X direction (Figure 4), there are some rules.

On the one hand, for the example 33a and the example 44a represented the simplified model 1, the story displacement of terraced part is less than that of corresponding part of common frame, but the story displacement of part upon the scarp for terraced frame is more than that of corresponding part for common frame. And the maximum story displacement is first story upon the scarp for the example 33a and the example 44a represented the simplified model 1, to show abrupt change in stiffness makes abrupt change in displacement, which occurred at the first story upon the scarp for the simplified model 1. on the other hand, for the example 33b and the example 44b represented simplified model 2, the story displacement of terraced part is zero, because lateral displacement of terraced part is constrained by lateral supports. And the maximum story displacement is the second story upon the scarp for the example 33b and the example 44b. Moreover the story displacement of part upon the scarp, for the example 33a and the example 44a represented the simplified model 1, is slightly more than that, for the example 33b and the example 44b represented simplified model 2.

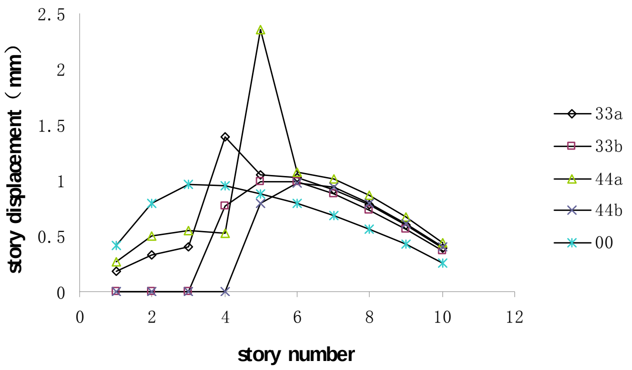


Figure 4 Change curve of story displacement in X direction

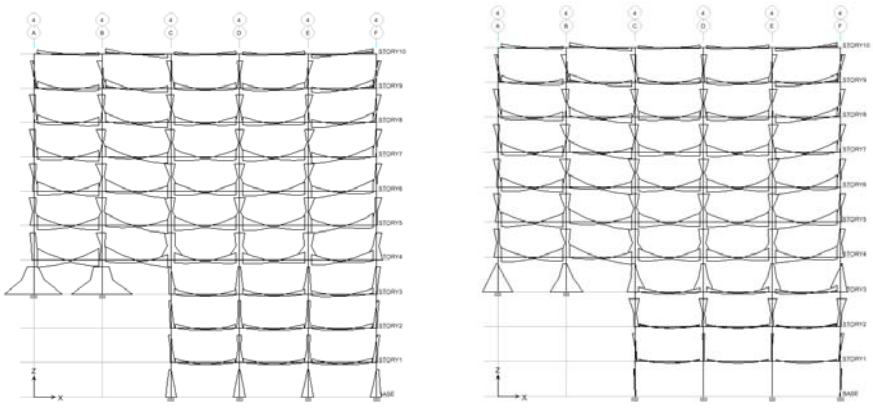
3.3 Calculation Analysis of Internal Force

Through the internal force figure of beams and columns for two simplified models, it is found the changes occur in the columns mostly, however the changes of beam internal force is small. The comparative results of column internal force are given for one frame in the text. To adopt the formula of relative error, namely (the simplified model 1－the simplified model 2)/ the simplified model 2, to account the error value range of the same column internal force for two simplified model (Table 3.3).

Table 3.3 Error value range of the same column internal force for two simplified models

Story number	Relative error for moment of column base		Relative error for shear of column base		Relative error for axial force of column base	
	33	44	33	44	33	44
1	6.72~47.03	12.7~381.0	1.96~16.28	3.8~132.3	-0.004~0.004	-0.012~0.012
2	0.74~6.87	1.59~74.1	0.26~2.58	1.09~31.9	-0.002~0.002	-0.010~0.010
3	-0.09~0.41	0.94~9.42	-0.59~-0.32	0.59~4.79	-0.001`0.001	-0.006~0.007
4	-0.57~0.90	0.01~1.00	-0.61~1.11	-0.05~-0.08	-0.003`0.003	-0.001~0.001
5	-0.37~0.33	-0.56~2.09	-0.39~0.24	-0.6~2.35	-0.001~0.001	-0.006~0.007
6	-0.07~0.14	0.22~1.36	-0.05~0.09	0.17~0.49	-0.001~0.001	-0.001~0.001
7	-0.02~0.02	-0.07~0.35	-0.03~0.003	-0.06~0.21	-0.001~0.001	-0.001~0.001
8	0.01~0.04	-0.01~0.02	0.003~0.009	-0.03~0.01	-0.001~0.001	-0.001~0.001
9	0.03~0.05	-0.003~0.01	0.02~0.03	0.004~0.015	-0.001~0.001	-0.001~0.001
10	-0.02~0.03	-0.03~-0.01	0.01~0.04	-0.01~0.002	-0.001~0.001	-0.001~0.001

First, the story shear and moment of terraced part in the simplified model 2 are much less than that in the simplified model 1, owning to the most shear of terraced part is born by the lateral supports in the simplified model 2. Second, the most of internal force are born by column upon the scarp, and the moment of column base upon the scarp in the simplified model 1 is more than that in the simplified model 2, but in the same story the other columns in the simplified model 1 are less than that in the simplified model 2. And even the changes are obvious as the adding story and span. The column moment of two simplified models is less different for the higher stories upon the scarp. Third, the changes of shear are similar to the changes of moment for two simplified models. However the change range of axial force is much less for two simplified models. The envelop moment figures in the load combination besides earthquake load are given for two simplified models (figure 5). Combining to different value in table 2, it is found that the weak part is the columns upon the scarp for terraced frame, and the simplified model 1 is weaker than the simplified model 2.



33a 33b
Figure 5 Envelop of bending moment graph

3.4 Analysis of Weak Story

The rectangle distribution mode of lateral load is used in pushover analysis in the paper. The aim is to find the weak story and pay attention to hinge in the different models. Firstly, as the common frame 00, the hinges appear most early in the beam of the first story, to the beam of tip story, then to two side column base of bottom story, finally to the end of all the column base of bottom story. Namely the first story is weak story for the common frame. Secondly, as the example 33a and 44a, the hinges appear in the beam of the first story upon the scarp, to the most of beams except the beams of tip story, to the column base upon the scarp, to all the beams, then to the column base of the second story upon the scarp more and more serious, finally, to the end of the failure of column base upon the scarp. And the degree of damage for the example 44a is more serious than that for the example 33a. Thus for the simplified model 1, the weak story is in the column upon the scarp and the second story upon the scarp. Thirdly, as the example 33b and 44b, the hinges appear in the beam of the first story upon the scarp, to the most of beams, then to the column base upon the scarp, finally to the end of the column base of the first story upon the scarp. From above the result of static elastic-plastic analysis, contrasted with the common frame, the weak story of terraced frame transfers up, due to the stiffness abrupt change for the terraced frame.

5. CONCLUSIONS

According to two ways of connection with hillside for terraced frame, to build the simplified model 1(retraining wall is not main structure together) and the simplified model 2(retraining wall is main structure together), and to design the examples, through comparative analysis of seismic performance following conclusions are drawn.

1) The torsion mode appears in the terraced structure due to the vertical stiffness irregular.

2) Compared with the common frame, the position of the maximum story displacement angle for terraced frame is varied; however the change is different as the different ways of connection with hillside. Under the same conditions, , the maximum value of story displacement lies in the simplified model 1.

3) Contrasted with the common frame, the weak story of terraced frame transfers up, the weak story is in the first and the second story upon the scarp for the simplified model 1, the weak story is in the first story upon the

scarp for the simplified model 2.

4) In the same situation, the internal force of column upon the scarp is more than that of the others in the same story for two simplified models; however that of column upon the scarp for the simplified model 1 is more than that for the simplified model 2.

5) Above all, as selecting the terraced structure to design, the strengthening measures should be taken for the first story upon the scarp, in order to ensure the whole seismic performance.

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