SHAKING TABLE TEST OF HIGH PERFORMANCE RAC FRAME STRUCTURE UNDER RARE EARTHQUAKE

DU Yuan-fang[1,a] WANG She-liang[2,b]

[1]Xi'an University of Architecture and Technology, Xi'an, China

[2]Xi'an University of Architecture and Technology, Xi'an, China

[a]36362803@qq.com, [b]wanshel@aliyun.com,

Key words: recycled aggregate concrete; frame structure; enhanced performance; shaking table test; seismic resistance capacity;

Abstract. The high performance recycled aggregate concrete(RAC)is a kind of RAC mixed in proportion of hybrid fiber and silica fume.Its main characteristic is to make up for the imperfections of RAC.In order to study the frame seismic performance,a 1:4 scale high performance RAC frame model was made.With the replacement of 100%,the model simulated earthquake shaking table tests.The study measured dynamic characteristics and the seismic response of the model structure under earthquake excitations of EL-Centro wave,Taft wave and Lanzhou artificial wave.The natural frequency,earthquake acceleration response,the maximum displacement response and inter-storey drift ratio were obtained.The data of statistics revealed that the performance enhancing materials had a good effect on relieving seismic damage,enhanced the seismic resistance capacity of the RAC frame and can meet the seismic resistance requirements in eight seismic degree area.

Introduction

Recycled Aggregate Concrete(RAC) refers to using discarded waste Concrete, waste brick, mortar to form the new concrete.In recent years,scholars at home and abroad have done related researches for recycled concrete materials,components and structure and have obtained certain achievements.The test research of Nixon[1-4] shows that the compressive strength of RAC is 15% lower than that of ordinary concrete.In terms of tensile and bending properties, Ravindrajah r.'s [5]research has shown that RAC reduced about 10% compared with normal concrete.At present the research for compound high performance recycled concrete is less and focused on material performance study phase.In view of this,it is necessary to study the seismic performance of composite recycled high performance recycled concrete framework.

Based on the excellent properties of HF(hybrid fiber) and SF(silica fume),the reinforced material add both in a certain proportion to make reinforced performance RAC.It can effectively improve the seismic performance of ordinary recycled concrete framework.In this paper,the frame are 1/4-scale three-story, one-bay by two-bay.The experiment tested the dynamic characteristics and seismic response of high performance RAC frame.

The material properties

Before the test,the fundamental mechanical properties of high performance RAC have been reseached.The effection of mixed fibers and silica fume on RAC was discussed.The two materials together improved the overall mechanical properties of RAC and provided the basis for simulated

earthquake shaking table test research of high-performance recycled concrete frame model .

Experiment

In the guarantee to satisfy the requirement of vibration table size and the maximum load,the model geometric similarity relation is 1/4.Compound high performance RAC frame work model design is shown in chart 1.Considered the live load of prototype and gravity load of Non structural components,the total weight of model is 6.38 t.

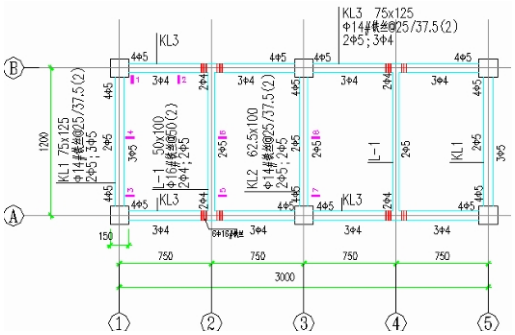

Fig.1 Dimension of frame model (unit：mm)

The model is made of 100% all recycled aggregate concrete which the strength grade is C30,the cement use 42.5 YaoXian cement and sand use river sand.The aggregate particle size range for 5~10 mm.The material ratio as follows:Water, cement, sand and gravel mass ratio is 0.38:1:1. 13:1.92,6%of silicon powder 2.00%,water reducing agent and 1.0% hybrid fiber.Hybrid fiber regeneration of crude TANK by modified polypropylene fiber and recycled steel fiber.

shaking table test

According to the construction site conditions and structural dynamic characteristics,we selected two actual seismic record and a set of artificial simulation as input earthquake shaking table mesa wave.Two of a natural wave were EL Centro wave and Taft wave,for artificial wave we selected Lanzhou wave.

In the experiment,two-way seismic wave were loaded,the main measurement of the structure were the displacement,acceleration and shearing deformation in joint core area.Acceleration sensor arrangement:acceleration sensor according to the X,Y,two directions to decorate,based at the top of the X,Y direction each 1,1~3 layer on each floor to decorate,a total of 10 accelerometer.Displacement sensor placement in the center of the model 1~3 layers,in X,Y direction,decorated a total of eight.Strain gauge:1~3 layers each layer column root and pillars X,Y direction each 1,decorate a total of 36.As shown in figure 2.

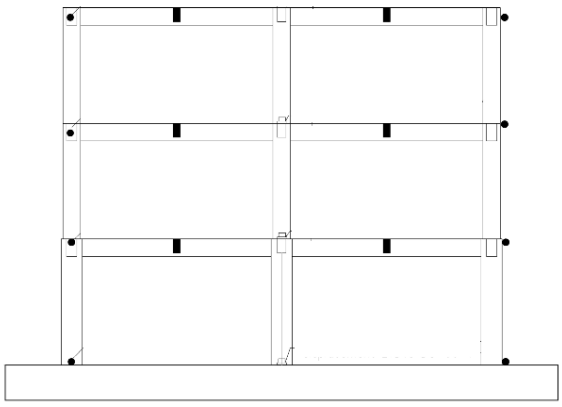

Fig.2 Arrangement of accelerometers and displacement LVDTs

In the experiment,for the EL Centro wave and Taft wave, working condition of each input X,Y,two-way at the same time.EL Centro wave navier-stokes component as X to input,original record acceleration time intervals of 0.02 seconds.For Taft wave we chose E-W component as X input,the original record acceleration time intervals was 0.02 seconds;Input Lanzhou wave unidirectionally,original record acceleration interval was 0.02 seconds.According to "norm for seismic design of buildings (GB50011-2010)[10],acceleration amplitude is level 1,level 2:vertical=1:0.85:0.65.Earthquake simulation test was going on under the rare earthquake of magnitude of 7 (220gal)and 8(400 gal).According to JGJ 101-96:white noise spectrum should be able to cover the specimen natural vibration frequency.So the acceleration is 0.05 g in this test.Test conditions are shown in table 1.The total number of test Conditions is 29.

Tab.1 The model conditions on the test

Sequence number	Operating mode number	Intensity	Seismic excitation	Earthquake level (g) Main direction	X set point	Y set point	Remarks
1	W-1	first white noise		/	0.05	0.05	Bidirectional white noise
2	R7-E-Xy	7degree rare earthquake	EL Centro	X	0.22	0.19	bidirectional earthquake
3	R7-E-Yx			Y	0.19	0.22	
4	R7-T-Xy		Taft	X	0.22	0.19	bidirectional earthquake
5	R7-T-Yx			Y	0.19	0.22	
6	R7-L-X		Lanzhou	X	0.22		unidirectional earthquake
7	R7-L-Y			Y		0.22	
8	W-2	second white noise		/	0.05	0.05	Bidirectional white noise
9	R8-E-Xy	8degree rare earthquake	EL Centro	X	0.4	0.34	bidirectional earthquake
10	R8-E-Yx			Y	0.34	0.4	
11	R8-T-Xy		Taft	X	0.4	0.34	bidirectional earthquake
12	R8-T-Yx			Y	0.34	0.4	
13	R8-L-X		Lanzhou	X	0.4	0.34	unidirectional earthquake
14	R8-L-Y			Y		0.4	
15	W-3	third white noise		/	0.05	0.05	Bidirectional white noise

test phenomenon description

In the previous experiment,composite material made of hybrid fiber and silicon powder has good performance.hybrid fiber played an obvious inhibitory effect on structure crack,postpone the emerge of cracks.With hybrid fibers and silica fume's effect to the promotion of structural strength, the structural natural vibration frequency decrease is little.But under the 7 degree rare earthquake:as the input seismic acceleration increases gradually, structural response increased obviously.This phase,the structure has a significant crack,structural deformation,structural natural frequency decrease.Structural cracks first appeared in the second floor near the beam node core,then appear in the top node core.At the end of column ,the crack appears late gradually.

Under the 8 degree rare earthquake:cracks of all structure developed obviously.The cracks in joint core area became deeply,on floor surface appeared along the beam side and plastic hinge appeared at beam-column joints in the end.Because of the enhancement effect of hybrid fiber and silicon

powder,the severe damage is not apparent.Through experiment,it`s renewable that hybrid fibers and silica fume increase significantly the performance of recycled concrete frame structure.The damage is less compared with the more common recycled concrete frame structure under the same conditions,crack and development is lighter, earthquake damage is significantly lighter than common RAC frame and satisfy the ordinary concrete frame structure in the 8 degrees seismic requirements.

Seismic response analysis of model test

In different levels , the white noise frequency swept before and after the seismic wave input.It get the dynamic characteristic parameters such as natural frequency, vibration mode and damping ratio.Using the measured data acquisition and analysis system, the natural frequency of vibration of the model structure is in the following table 2.

Tab.2 Natural frequencies of the model

W1			W2			W3		
Vibration mode	direction		Vibration mode	direction		Vibration mode	direction	
	X	Y		X	Y		X	Y
first vibration mode	4.37	3.57	first vibration mode	3.50	3.31	first vibration mode	3.46	3.07
Second vibration mode	13.96	13.74	Second vibration mode	11.89	13.16	second vibration mode	11.76	10.06
third vibration mode	24.86	24.23	third vibration mode	18.50	23.73	third vibration mode	18.39	21.03

From table 2 it is evident that the model structure of each order natural frequency of vibration are decreased with seismic amplitude increases.And the drops more apparent which in rarely met earthquake excitation.Overall decline is not large,the results show that Performance Enhancement Material(hybrid fibers and silicon powder)reinforced RAC frame.It really have played an important role in improving seismic performance.

Piezoelectric acceleration sensor signal of earthquake response in each level can be got through the MTS data acquisition system.After processing we get the acceleration response of model structure.The acceleration response peak ratio of different floor and input mesa is the acceleration amplification factor(AF)for each floor.AF has relationship with storey stiffness,strength of each layer,the development of inelastic deformation and input characteristics of the seismic waves, and so on.In this experiment,earthquake acceleration amplification factor of each layer structure model is shown in figure 5.Analysis the model acceleration amplification factor graph under different seismic waves,it can be seen:

1. For floors of the model structure,the maximum acceleration response abide by the consistent change law along the height.In the process of all test conditions, the lower part of the structuret is upper strong motivation, model layer 2 acceleration response is the largest.Different input seismic waves cause different acceleration of the model,and the acceleration responses degree is also different.

2.In general,model Y direction acceleration response is bigger than X direction and the maximum acceleration response appeared on the top of first layer.According to the design of the model,it is

weak because of the column size changed,so the acceleration response is more apparent. 3.In frequent earthquake condition,the acceleration amplification factor increase gradually but model stiffness decrease is so little.But the trend is very obvious under the condition of rare earthquake.This shows that Performance Enhancement Material has better control of the frequent earthquake effect, structure damage is tiny under small earthquakes.In the model's Y direction,the acceleration amplification factor decreases along the floor height.And with the increase of earthquake acceleration peak,the AF for each layer is gradually reduced in the general trend.

Model displacement response is obtained by displacement sensor.The model's maximum inter-storey drift ratio are shown in table 3.

Tab.3Maximum inter-storey drift ratio (DR) of RAC frame structure model under rare earthquake

Earthquake level (g)	X as the main direction			Y as the main direction		
	first layer	second layer	third layer	first layer	second layer	third layer
0.220	1/363	1/257	1/727	1/173	1/131	1/301
0.400	1/277	1/235	1/667	1/162	1/98	1/291

Table 3 shows that for high performance RAC frame,the deformation under small earthquakes is smaller than ordinary RAC frame, satisfy the strength requirement and there's micro cracks by and large.In the large earthquake condition, the structure model satisfies the Code for seismic design of buildings GB50011-2010[10].Deformation and cracking are less than those of normal concrete.

the seismic performance analysis

Under rare earthquake impact,the structure entered the elastic-plastic stage.Model's largest DR occurred in y direction, DR =1/98,less than 1/50 of the specification limits.At this time,the model façade was intact and more slender crack appeared at the edge of the beam.The shear crack appeared in the joint core area in the ead.The model is still in not severe secondary damage.

Compared with ordinary RAC,the characteristics of high performance RAC frame is as follow:deformation is less,model under strong earthquake performance enhanced,crack resistance was better.So high performance RAC frame meet the requirements of seismic code and reached the requirements of normal concrete frame.In the whole experiment process,no serious damage happened to the model.No concrete block dropped and beam-column serious damaged.Performance Enhancement Material is good enough to control the deformation of the model,delay the cracking of model,slow down the damage.It makes the structure completely sustain the bi-directional earthquake excitation in rare earthquake.By white noise frequency sweep,acceleration analysis, maximum inter-storey drift and Maximum inter-storey drift ratio analysis,we can found that the seismic performance of high-performance RAC frame is superior to the ordinary RAC framework and reach the requirement of complex high performance.

Conclusion

Through experiment,it is known that the natural vibration frequency of model structure,acceleration response,displacement response,the interlayer deformation ability were studied.The seismic evaluation of the high-performance RAC frame was made in rare earthquake.By comparing test of high-performance RAC frame with ordinary RAC,it can be found that:

(1)The Performance Enhancement Material(composed of hybrid fibers and silica fume) obviously improved the RAC seismic performance.The inter-storey drift and DR is lesser than ordinary RAC.the Performance Enhancement Material effectively suppresses the lateral displacement of the structure.

(2) Beam is the main energy dissipation member throughout the whole process.and the main members are basically intact in rare earthquake.In the rare earthquake stage, frame nodes only appear a part of the crack, no leakage of tendon,or falling phenomenon.

This shows that as a result of the hybrid fiber added,the crack development was effectively restrained and it increases the model intensity, improves the overall ductility of frame model.By adding silicon fume etc.,it is avoided the decrease of strength of components caused by its high fiber content (1.0%). From the test results, after adding Performance Enhancement Material,RAC frame has a good ability of deformation and seismic capacity.It meet the requirement of code and make up for the deficiency of the ordinary RAC frame.

References

[1] P.J.Nixon.Recycled concrete as an aggregate for concrete a review[J].Materials and structures,1978.11(65):371-378.

[2] Corinaldesi.V. Recycled aggregate concrete under cyclic loading[C].Proceedings of the International Symposium on Role of concrete in Sustainable Development.University of Dundee,Scotland,2003:509-518.

[3] M.C.Limbachiya,T. Leelawat and R.K.Dhir,Use of recycled concrete aggregate in high-strength concrete[J].Materials and Structures,2000,33(233):574-580.

[4] Mandal S,Gupta A.Strength and durability of recycled aggregate concrete[C].IABSE Symposium Melbourne,Melbourne,Australia,2002.

[5] Ravindrajah R.,Tam C T.Recycled concrete as fine and coarse aggregates in concrete[J]. Magazine of Concrete Research.1987,39(141):214-220.

[6] Li Jiabin Mechanical properties of recycled aggregate concrete[D].Shanghai:Tongji University College of Civil Engineering,2005.(in Chinese)

[71]XIAO Jian-zhuang Recycled aggregate concrete[M].Beijing:China Architecture and Building Press,2008:30-37.(in Chinese)

[8] Andrze Ajdukiewicz,Alina Kliszcewicz.Influence of Recycled Aggregate on Mechanical Properties of HS/HPC[J].Cement and Concrete Composites,2002,24(2): 269-279.

[9] WANG Chan qing XIAO Jian zhuan Experimental Study on Recycled Aggregate Concrete Frame Structure Model[J] Journal of TONGJI university(natural science,2012,40(12):1767-1771.(in Chinese)

[10]GB 50011-2010 Code for seismic design of buildings[S].Beijing:China Architecture and Building Press,2010.(in Chinese)