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Anti-seismic Property of Recycled Concrete Middle-high-rise Shear Wall

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ABSTRACT: In order to study the different recycled fine aggregate content of concrete and anti-seismic property of reinforcement ratio shear wall, the thesis conducts seven low frequency cyclic loading experiments with 1.5 shear span ratio. Based on the experiments, the thesis analyses the bearing capacity, ductility, rigidity as well as its degenerative process, hysteretic characteristics, energy dissipation and failure mechanism. The experiments show that: compared to the normal concrete high-rise shear wall, the anti-seismic property of recycled concrete high-rise shear wall is little poorer; with the increase of amount of recycled aggregate, the anti-seismic property of recycled concrete high-rise shear wall is decline; with the increase of reinforcement ratio, bearing capacity, ductility and energy dissipation of recycled concrete high-rise shear wall will be improved; with the increase of axial compression ratio, bearing capacity of recycled concrete high-rise shear wall will be increased and the elastic-plastic deformability will be decreased. Through the rational design, the recycled concrete high-rise shear wall can meet the seismic requirement of multilayer shear wall house construction.

KEYWORDS: Recycled concrete; Reinforcement ratio; Axial compression ratio; Middle high rise shear wall; Anti-seismic property; Experimental study.

INTRODUCTION

Resource and environment are the basic condition for survival and development of human being and the foundation for the development of economy and society. The lack of resource and the environmental degradation have restricted China’s quick, sustainable and sound development. The strategy of sustainable development facing the future can ensure that economy is a significant strategy of social long-term sustainable development, related to the survival and development of China nation.

At present, the amount of construction waste has occupied 30%~40% of total municipal waste. At the same time, lots of natural gravel aggregate has been exploited so that the natural aggregate goes to the exhaustion. In recent years, China has carried out the change of economic growth pattern, striving to the development of circular economy. However, realizing the reduction and reutilization of construction waste and comprehensive treatment of resources economy are significant ways to enhance the efficiency of utilization of construction waste. Because the wasted concrete contains lots of gravel aggregate, they can be recycling and reusing. Through the smashing, washing and grading, the wasted concrete can be blended into recycled concrete aggregate according to the certain proportion and grading.

The technology of recycled concrete can renew some original property of wasted concrete and create new building materials that can save the natural aggregate resource and reduce urban environmental pollution owning economic, environmental and social benefits. The research on recycled concrete has become one hot issue in academic world and engineering world.

There are many papers about the material property of recycled concrete at home and abroad. But there are few researches on the structure of recycled concrete and mechanical property of component. This paper introduces the replacement rate, and axial compression stress reinforcement ratio of seven different recycled fine aggregates, and the experimental research on the anti-seismic property of high-rise shear wall. The thesis emphatically analyzes the influence of replacement rate and axial compression stress reinforcement ratio of different fine aggregates on the anti-seismic property of shear wall.

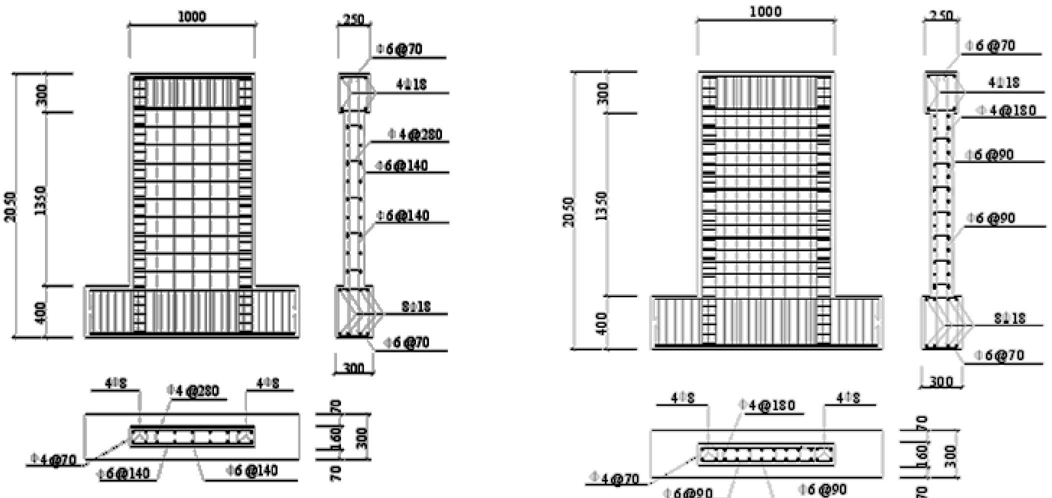
THE GENERAL SITUATION OF EXPERIMENT

Seven test pieces of middle-high recycled concrete shell wall with 1.5 shear span ratio are designed and their serial numbers are SW0, RCSW1-RCSW6. Here, SW0 is the normal concrete shell wall. The coarse aggregates of RCSW1-RCSW6 are concrete shell wall of recycled coarse aggregate; the replacement rates of recycled fine aggregate of RCSW1, RCSW2, RCSW3 are concrete shell walls with 100%, 50%, 0. The reinforcement ratios of distributing bar between RCSW4 and RCSW1 are same, but the axial compression ratios are different, 0.4 and 0.2; RCSW5, RCSW6 and RCSW1 have the same aggregate and different reinforcement ratios of distributing bar. The reinforcements are shown in Figure 1, and the detailed design parameters of test pieces are in Table 1.

The thickness of wall in each test piece is 160 mm, and the width is 1000 mm and the height is 1500 mm which are all poured by C30 concrete. The measured value of the normal concrete cube crushing strength and the coarse aggregate in SWO are recycled coarse aggregate. And measured values of the cube crushing strength of recycled concrete with 100%, 50%, 0% replacement ratios of fine aggregate are shown in Table 2. The measured value of the yield strength and the ultimate strength of φ 6, φ 8 rebar are shown in Table 3. The loading device is shown in Figure 2. The distance from the horizontal loading point to the basic top surface is 1500 mm adopting low cycle repetitive loading form. Rebar strain, horizontal displacement, horizontal load and vertical load are collected by on-line data collection system on line and the crack is drawn by hand.

Table 1. Detailed design parameters of test pieces.

Serial number	SW0	RCSW1	RCSW2	RCSW3	RCSW4	RCSW5	RCSW6
Replacement rate of recycled coarse aggregate/ (%)	0	100	100	100	100	100	100
Replacement rate of recycled fine aggregate/ (%)	0	100	50	0	100	100	100
Reinforcement ratios of distributing bar ρ/ (%)	0.25	0.25	0.25	0.25	0.25	0.4	0.15
Axial compression ratio	0.20	0.20	0.20	0.20	0.40	0.20	0.20
Horizontal and vertical distribution bar	φ6 @140	φ6 @140	φ6 @140	φ6 @140	φ6 @140	φ6 @90	φ6 @230
Edge member embedded column longitudinal bar	4φ8	4φ8	4φ8	4φ8	4φ8	4φ8	4φ8



(a) SW0、RCSW1—RCSW4 (b) RCSW5

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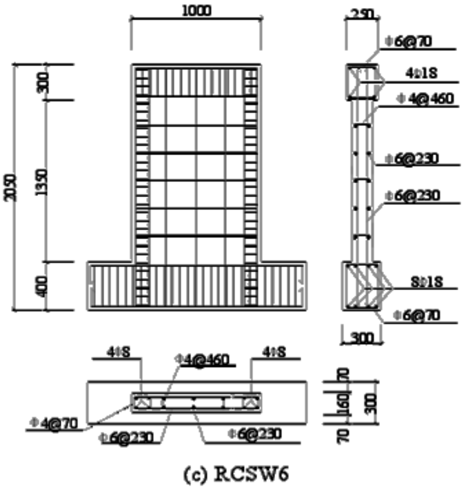

Figure 1. Reinforcement of test piece.

Table 2. The mechanical properties of concrete materials.

Level of concrete	Replacement of recycled fine aggregate	cube crushing strength/Mpa
C30		34.84
RC30	0	33.57
RC30	50%	33.13
RC30	100%	31.97

Table 3. The mechanical properties of rebar

Standard of rebar	yield strength/Mpa	ultimate strength/Mpa
φ6	535.82	590.64
φ8	338.2	492.88

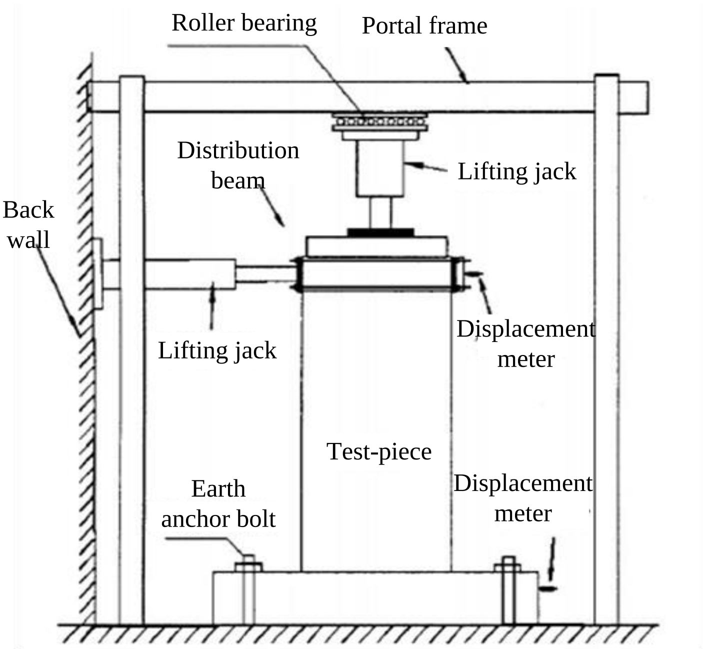

Figure 2. Testing apparatus.

THE RESULT AND ANALYSIS OF EXPERIMENT

Actual Measured Result and Analysis about Bearing Capacity

The measured value of obvious craze horizontal load, obvious yield horizontal load and ultimate load of each shear wall test piece and their specific value are shown in Table 4.

Table 4. The measured value of bearing capacity of shear wall test piece.

Test piece	Craze load/kN		Yield load/kN		Ultimate load/kN	
	Actual measurement	Relative value	Actual measurement	Relative value	Actual measurement	Relative value
SW0	94.51	1.000	203.33	1.000	237.80	1.000
RCSW1	91.03	0.963	193.57	0.952	221.95	0.933
RCSW2	92.43	0.978	197.78	0.973	232.27	0.977
RCSW3	92.97	0.984	202.60	0.996	233.27	0.981
RCSW4	142.59	1.509	302.36	1.487	336.84	1.416
RCSW5	90.94	0.962	204.20	1.004	247.98	1.043
RCSW6	91.02	0.963	195.31	0.961	227.16	0.955

We can find from Table 4:

1) Compared to the normal shear wall SWO, the bearing capacity of recycled concrete shear wall with the same axial compression ratio would decline under 7%.

2) WhenRCSW3 is compared to RCSW2, RCSW1. Its cracking loads, obvious yield load and ultimate load are all declining, which implies that as for the bearing capacity, the recycled concrete middle high-rise shear wall mixed with recycled fine aggregate is worse than the normal concrete low shear wall.

3) Compared to RCSW1, the cracking loads, obvious yield load and ultimate load of RCSW4 increase 56.6%, 56.2%, 51.8%，which shows that with the increase of axial compression ratio, the bearing capacity of recycled concrete middle high-rise shear wall can be increased.

4) The cracking loads of RCSW5, RCSW6, RCSW1 are close to each other. With big reinforcement ratio, yield load and ultimate load of RCSW5 are comparatively high; yield load and ultimate load of RCSW6 are little bit higher than ones of RCSW1. The reason is that with the low reinforcement ratio, the damage of test piece is mainly the curve damage and its bearing capacity mainly depends on margin embedded column longitudinal bar. However, with the same margin embedded column longitudinal bar, bearing capacity of RCSW6 with low distributing bar reinforcement ratio is higher than the other one because of the discreteness of concrete. In a word, under the condition that minimum reinforcement ratio distributing bar meeting the standard, bearing capacity of recycled concrete middle high-rise shear wall is improved with the increase of reinforcement ratio.

Property and Analysis of Ductility

The measured value of the horizontal displacements and the ductility factor of each shear wall test pieces are shown in Table 5.

Here, U_c is the cracking horizontal displacement; U_y is the average value of yield displacement; U_d refers to the maximum displacement for the 85% of ultimate bearing capacity; θ_p refers to the maximum elastic-plastic displacement; $\mu = U_d/U_y$ is the displacement ductility factor.

From the Table 5:

1) Compared to the normal shear wall SWO, its cracking displacement is close to the yield displacement, elastic-plastic maximum displacement, elastic-plastic angle of displacement, less ductility factor declining within 15%. It means that the ductility of recycled concrete middle high-rise shear wall has little differences from the normal

Table 5. The measured value of top displacement and ductility factor in each test piece.

Test piece	Uc/mm	Uy/mm	Ud/mm	θp	μ
SW0	0.84	6.09	42.74	1/35.1	7.02
RCSW1	1.08	6.69	40.07	1/37.4	5.99
RCSW2	1.06	6.46	41.82	1/35.9	6.47
RCSW3	1.05	6.07	41.02	1/36.6	6.76
RCSW4	0.83	5.13	31.11	1/48.2	6.06
RCSW5	1.08	6.70	42.17	1/35.6	6.29
RCSW6	1.09	6.65	40.01	1/37.5	6.02

concrete wall that is satisfied with the requirement of the design.

2) Compared to the RCSW1, under the function of high axial compression ratio, yield displacement, elastic-plastic maximum displacement, elastic-plastic angle of displacement and ductility factor of RCSW4 are all declining considerably, which implies that ductility of recycled concrete shear wall is influenced much by high axial compression ratio. The elastic-plastic deformation ability of recycled concrete shear wall becomes lower with the increase of axial compression ratio.

3) Compared to SW0, RCSW3, RCSW2, RCSW1 has lower elastic-plastic maximum displacement, elastic-plastic angle of displacement and ductility factor, which means that the recycled concrete high-rise shear wall mixed with recycled aggregate has lower ductility than the normal concrete wall. When compare RCSW3, RCSW2 and RCSW1, the ductility factor declines successively that means the ductility of recycled concrete high-rise shear wall rises with the decrease of recycled fine aggregate.

4) Compared to RCSW1, the ductility factor of RCSW5 is rising with the increase of reinforcement ratio that implies the big influence of lower reinforcement ratio on the ductility of recycled concrete high-rise shear wall.

The Measured Value of Rigidity in Each Stage and Damping Analysis

The rigidity of shear wall is decreasing with the increase of angle of displacement, and the degradation law of test piece is mainly divided into three stages: firstly, the prompt dropping of rigidity from hair-cracking to the macroscopic fissure; secondly, the sub prompt dropping of rigidity from the obvious structural cracking to obvious yield; thirdly, the slow descent of rigidity from the obvious yield to the maximum elastic plastic deformation.

The measured value of rigidity of test piece in each stage and their damping factors are shown in Table 6. Here, $K_0$is the initial elastic rigidity of test piece; K_c is the obvious cracking secant rigidity of concrete; K_y is the obvious yield secant rigidity; β_{c0} is the specific value K_c/K_o between the cracking rigidity and the initial elastic rigidity that shows the damping from the initial phase to the obvious cracking; β_{y0} is the specific value K_y/K_c between the yield rigidity and obvious cracking rigidity that shows the damping of rigidity from the obvious cracking to the yield.

Table 6. The measured value of rigidity of test piece in each stage.

Test piece	K0/(kN/mm)	Kc/(kN/mm)	Ky/(kN/mm)	βc0	βyc	βy0
SW0	300.00	112.51	33.41	0.375	0.297	0.111
RCSW1	292.12	84.29	28.93	0.289	0.343	0.099
RCSW2	295.41	87.20	30.62	0.295	0.351	0.104
RCSW3	296.63	88.54	33.38	0.298	0.298	0.113
RCSW4	292.12	171.80	58.94	0.588	0.343	0.202
RCSW5	292.53	84.20	30.50	0.288	0.362	0.104
RCSW6	291.45	83.50	29.37	0.286	0.352	0.101

From Table 6 we can find:

1) The initial elastic rigidities of each test piece are close that means it depending on the strength of concrete and the size of test piece.

2) When compare RCSW3, RCSW2, RCSW1, the damping factors of each rigidity are all decreasing, that implies that with the increase of recycled fine aggregate, speed of the damping of the rigidity of test piece rises.

3) The rigidity of each recycled concrete high-rise shear wall test piece is damping evenly without sudden change.

Hysteretic Curve and the Analysis of its Features

Hysteretic curve is a load-deformation curve of structure under the repeated functions and is also called resilience curve. Hysteretic curve reflects test piece's carrying capacity, plastic deformation capacity and energy-dissipating capacity etc. It is a significant evidence for the dynamic analysis of the anti-seismic elastic-plastic of structure and is the comprehensive reflect of anti-seismic property of structure.

The area encircled by hysteretic loop reflects the energy-dissipating capacity of the test piece, which means that the bigger the area is, the stronger the energy-dissipating capacity is. The more obvious the knead gathering effect is, and the smaller the area is, the weaker the energy-dissipating capacity is.

The hysteretic curve "horizontal load F-peak horizontal displacement U" actually measured by each test piece is shown in Figure 3, which comprehensively reflects the bearing capacity, rigidity, ductility and energy-dissipating capacity.

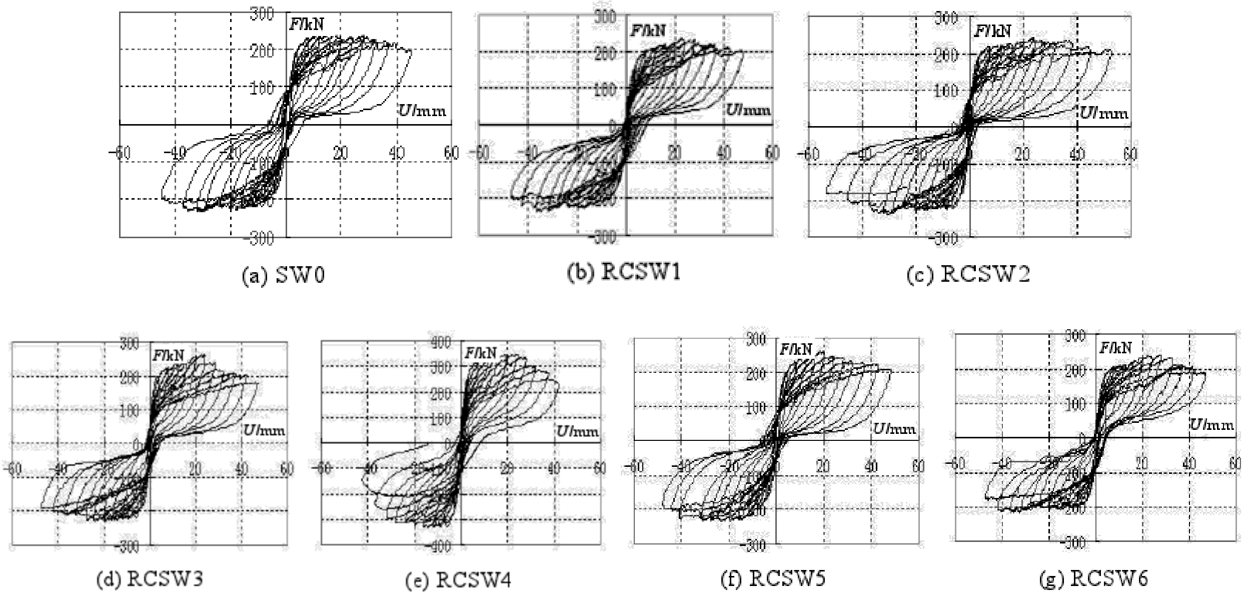

Figure 3. The hysteretic curves of test pieces.

Form the Figure 3, we find that:

1) The shapes of the hysteretic curves of test pieces have almost no differences. The hysteretic curve of normal concrete shear wall seems fuller that implies the slower rigidity degeneration and the better ductility of normal concrete shear wall.

2) Compared to RCSW1, the hysteretic curve of RCSW4 with higher axial compression ratio has an obvious knead gathering effect in the middle part, which implies that with the increase of axial compression ratio, ductility and anti-seismic property of recycled concrete high-rise shear wall would decline.

3) In the test piece of recycled concrete shear wall, RCSW5 with higher reinforcement ratio has a fuller hysteretic curve than RCSW6 with lower reinforcement ratio that shows with the increase of reinforcement ratio, ductility and anti-seismic property of recycled concrete high-rise shear wall would rise.

4) The hysteretic curves of RCSW1, RCSW2 and RCSW3 have no difference that shows the recycled fine aggregate has less influence on the ductility and anti-seismic property of concrete.

Energy Dissipation

The energy-dissipating capacity of structure refers to capacity that the structure can absorb and dissipate energy through its own elastic-plastic deformation when structure suffers the sudden large horizontal force or the earthquake force. The energy dissipation of structure or component can be measured by the area circled by hysteretic curve: the bigger area is, the better energy-dissipating capacity is, vice versa. The area circled by skeleton curve of hysteretic curve in first quadrant and third quadrant is considered as the comparative energy dissipation. The comparison of energy dissipation of test pieces is shown in Table 7.

Table 7. The comparison of energy-dissipating capacity of test pieces.

Test pieces	Energy dissipation Ep/(kN·mm)	Relative value
SW0	15998.35	1.000
RCSW1	14454.71	0.904
RCSW2	14636.66	0.915
RCSW3	15020.56	0.939
RCSW4	20523.90	1.283
RCSW5	16372.33	1.023
RCSW6	13057.74	0.816

From Table 7, we can see:

1) Compared to the normal shear wall SWO, energy-dissipating capacity of recycled concrete shear wall is worse and decline within the 10% with the same reinforcement ratio. It shows that with the increase of recycled fine, recycled concrete high-rise shear wall would decline.

2) Compared to RCSW1, the energy-dissipating capacities of RCSW3, RCSW2 decline a little that means the increase of recycled fine, energy-dissipating capacity of recycled concrete high-rise shear wall would decline.

3) When compares RCSW4 and RCSW1, under the high axial compression ratio, energy-dissipating capacity of recycled concrete high-rise shear wall would rise.

4) When compares RCSW5, RCSW1 and RCSW6, under the same replacement rate of recycled aggregate, with the increase of reinforcement ratio of wall distributing bar, its energy-dissipating capacity will rise. So if the reinforcement ratio is increase, the energy-dissipating capacity of recycled concrete shear wall will rise.

Failure Mode and Analysis

Figure 4 is the final failure crack of seven test pieces. The test pieces mainly have bending failure in the end.

1) In SW0, RCSW3 and RCSW6, there are only horizontal linking curve cracks on the root but no curved scissors diagonal crack which implies the lower flexural capacity than shear capacity.

2) The wall curved scissors crack of RCSW3, RCSW2, RCSW1 decline successively that implies with the decline of replacement rate of recycled fine aggregate, shear capacity of recycled concrete shear wall will increase.

3) When RCSW1, RCSW5 and RCSW6 are compared, the lower the reinforcement ratio is, the higher the shear capacity of recycled concrete is. So if the reinforcement ratio is low, the shear capacity of recycled concrete will increase.

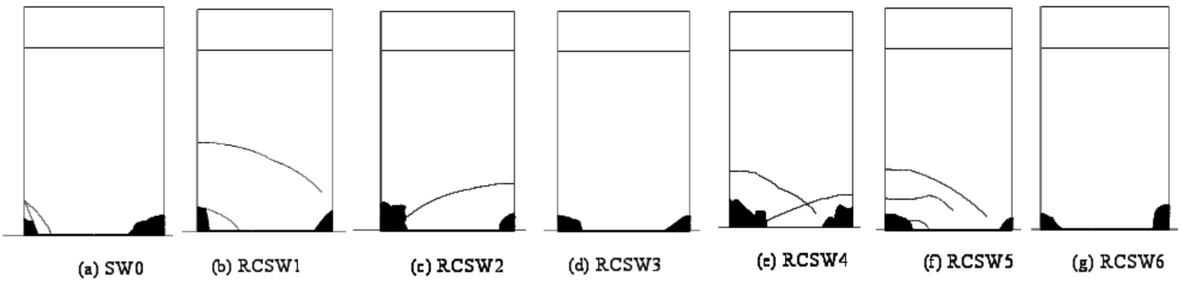

Figure 4. The crack figures of test piece.

CONCLUSION

(1) Compared to the normal concrete high-rise shear wall, the comprehensive anti-seismic property of recycled concrete high-rise shear wall declines a little, which meets the requirement of the aseismic design.

(2) With the increase of the mixing amount of recycled fine aggregate, bearing capacity, ductility, energy dissipation of recycled concrete high-rise shear wall will decline but the rigidity degeneration will rise.

(3) The axial compression ratio has great influence on the performances of recycled concrete high-rise shear wall. The appropriate increase of axial compression ratio can improve the bearing capacity of recycled concrete high-rise shear wall but reduce the ductility, energy dissipation of recycled concrete high-rise shear wall.

(4) With the increase of reinforcement ratio, bearing capacity, ductility, energy dissipation of recycled concrete high-rise shear wall will increase.

(5) With the same reinforcement ratio, compared to the normal concrete high-rise shear wall, the bearing capacity of recycled concrete high-rise shear wall is a little lower that meets the requirements of the standard.

REFERENCES

[1] L. Belagraa and M. Beddar, “Study of the Mechanical Performance of a Recycled Aggregate Concrete with Admixture Addition”, *Open Journal of Civil Engineering*, vol. 3, no. 2, pp. 99-103, February 2013.

[2] M. Silva, M. Mota, A. Gadea, M. Leite, and K. Nagahama, “The Behavior of Recycled Concrete through the Application of an Isotropic Damage Model”, *Open Journal of Civil Engineering*, no. 5, pp. 339-351, May 2015.

[3] R. Fang, *Fatigue test and simulation study of cold-recycling basic level mixture*, Shenyang: Shenyang Architectural University, 2010.

[4] C. X. Li, T. R. Lu, and Y. L. Liu, “key technology of recycling of cement concrete pavement”, Beijing: China Communications Press, 2010

[5] W. L. Cao, Q. Liu, and J. W. Zhang, “A Experimental study on seismic performance of high–rise recycled aggregate concrete shear wall”, *Journal of Beijing University of Technology*, vol. 37, no. 3, pp. 409-416, April 2011.

[6] B. K. Liu, L. H. Chen, and A. Zhou, “Research on the anti-seismic property of recycled concrete frame beam-column joints”, *Journal of architectural structure*, no. 11, pp. 109-115, November 2011.

[7] H. P. Yin, *Test and theoretical research of anti-seismic property of the recycled concrete frame-shear wall*, Beijing: Beijing University of Technology, 2010.

[8] C. Yu, L. H. Chen, and B. K. Liu, “Seismic performance of recycled concrete frame under cyclic loading”, *Engineering and Construction*, vol. 25, no. 3, pp. 356-358, March 2011.

[9] N. Singh, S. Dutta, “Reinforcement of Polypropylene Composite system via Fillers and Compatibilizers”, *Open Journal of Organic Polymer Materials*, vol. 3, no. 1, pp. 6-11, January 2013.

[10] J. H. Zhou, J. W. Zhu, and X. H. Meng, “Experimental research on seismic behavior of concrete lattice walls”, *Journal of Shenyang Jianzhu University (Natural Science)*, vol. 26, no. 6, pp. 1095-1100, June 2010.

[11] H. T. Yang and S. Z. Tian, “The experimental study of the compressive strength size effect of recycled concrete material”, *Railway Engineering*, no. 6, pp. 166-168, June 2013.