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Theoretical Research on Octagon Reinforcement Method in Reinforced Concrete Frame Node

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Abstract: Research on frame joint has an important practical significance because it has an important impact of the bearing capacity of the whole frame structure. Based on the reinforcement engineering of a super transfinite office, this paper has presented octagon reinforcement method. By using the numerical simulative analysis of one-time loading and low reversed cyclic loading for the six different reinforced frame joints, the stress of reinforcements and steel plates, the deformation of joints, the figure of cracks, the load-displacement curve and the hysteresis curve have been obtained. The failure model of the frame joints reinforced by octagon reinforcement method mainly is ductile fracture in beam end, which has been presented through analyzing the developing process of cracks. By analyzing the load-displacement curve and hysteresis curve of the frame joints under three kinds of axial compression ratio which is 0.2,0.5and 0.8, octagon reinforcement method has increased the core concrete area of frame joint, the shear strength of frame joint and the ductility and seismic performance of frame joint. Octagon reinforcement method is more significant than enlarging section method when the axial compression ratios are larger.

Key words: Frame joints reinforcement, octagon reinforcement method, ductility, load-displacement curve, finite element modeling

INTRODUCTION

The frame node which includes the intersecting core area of column and beam, column ends and beam ends is one of important frame structure members. Under the load, it will be bearing the axial force, bending moment and shear force from column ends and beam ends. So the node is more likely to be broken with the complex stress relative to the general components such as beam, column (He and Ou, 2007). Under the seismic action, frame nodes often are the weakest link in the whole structure. Once the node damage occurs, it will result in the plastic hinge which can't be formed at the beam end and the influence of internal force redistribution (Jiang, 1998). Finally it will affect the bearing capacity of frame structure. Therefore the reinforcement theory and experimental research of frame node has important practical significance (Liang and Ye, 2007).

ENGINEERING BACKGROUND

The style of the transfinite high-rise office building is frame-shear wall structure with building height of 144 m, 29 floors and underground 2 layers (Fig. 1). The structural seismic grade of frame and shear wall is secondary. The designable concrete strength of shear wall and column is C60 and that of beam and slab is C40 Under three layers. When it comes to the third construction floor, the actual concrete strength of shear wall and column is C40 by the core method and the rebound method. This study

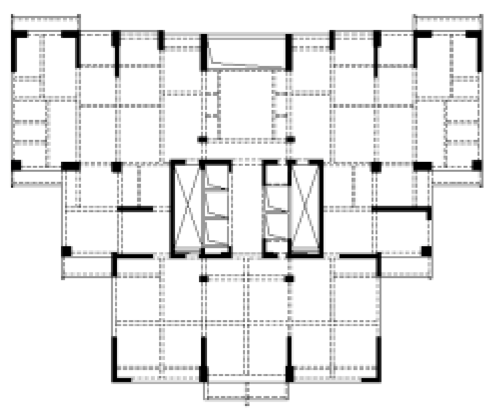

Fig. 1: Structure plan of standard layer

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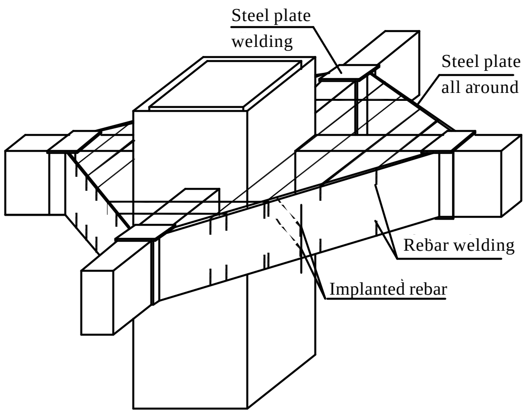

Fig. 2: Schematic diagram of octagonal reinforcement

presents a new method of reinforcement named octagonal reinforcement method which is to constrain the new concrete in the eight directions of framework by steel plate (Fig. 2). The simulation analysis of six different reinforcement models has been done by using ANSYS software.

REINFORCEMENT DESIGN

The middle node of the first layer was selected as the calculation model of framework according to a quarter of the size of the original model (Fig. 3).

Layout of reinforcement: The specific ways of octagonal reinforcement method are the follows.

Firstly, the frame column is strengthened by enlarging section. Secondly, Planting bar and scrabbling is processed between the old and new concrete. Thirdly, the octagonal steel template has done between four beams in order to connect the node. Finally, shear reinforcements are welded on the steel plate (Fig. 4).

Calculation model: The six different model of reinforcement analysis is shown in Table 1.

The unidirectional compressive concrete constitutive model of Hognestad is chosen. The rise of stress-strain curve is quadratic parabola and the decline of it is straight lines. Steel bars, rigid block and steel plate are simulated by LINK8 unit, SOLID45 unit and SHELL181 unit respectively (Wang, 2007). The blocks in loading parts are added in order to reduce the stress concentration.

There are two steps for unreinforced node. Firstly, a constant pressure is added on the top of column. Finally, under the original constant pressure anti-symmetry load and anti-symmetric low reversed cyclic loading are applied on the beam end by the displacement control (Sun, 1995).

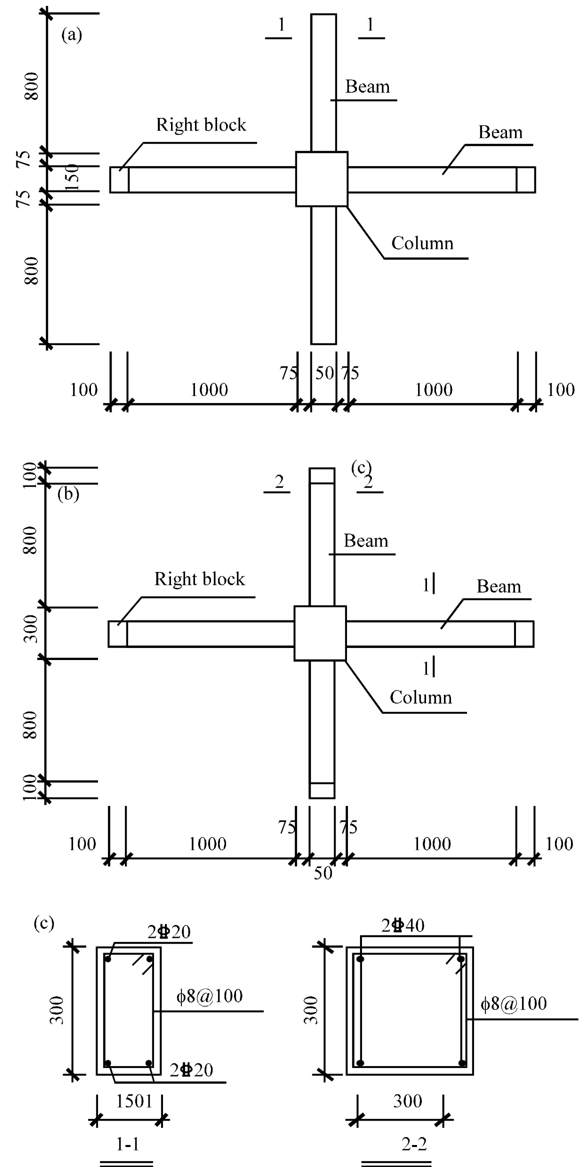

Fig. 3(a-c): Structural diagram of unreinforced node (a) Method (b) Planar graph and (c) Vertical graph

There are three steps for reinforced node. Firstly, a constant pressure which is equal to 80% of unreinforced model is added on the top of column. And new added reinforced concrete will not be involved by EKILL command. Secondly, we let the new added reinforced concrete to work by EALIVE command and make the axial compression ratio of reinforced column as the same of contrast specimens. The third step is the same to the second step of unreinforced node.

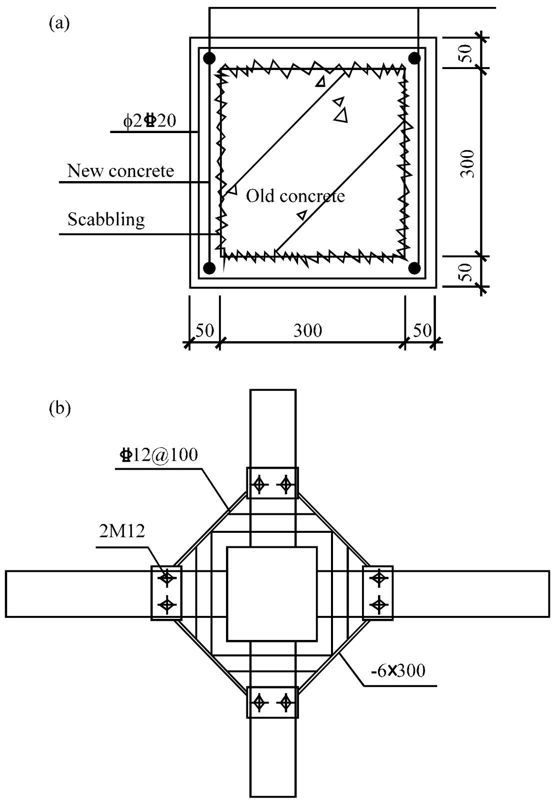

Fig. 4(a-b): Structural diagram of reinforced node (a) Planar graph of column and (b) Planar graph of node

Table 1: Reinforcement analysis model

Number	Describe
OM	Original member
SRM	Sectional reinforced member
ORM-0	Octagonal reinforced member without steel plate
ORM-3	Octagonal reinforced member with steel plate of 3mm thickness
ORM-5	Octagonal reinforced member with steel plate of 5mm thickness
ORM-8	Octagonal reinforced member with steel plate of 8 mm thickness

RESULTS AND DISCUSSION

Load-displacement curve: The load-displacement curve of framework node is obtained by one-time load simulation with the axial compression ratio of 0.2, 0.5 and 0.8 as shown in Fig. 5. We can calculate the ultimate load, ultimate displacement, stiffness and ductility of framework node from these curves (Lu *et al*., 2004).

Ultimate load: Under the condition of same axial compression ratio, octagonal reinforcement method can significantly improve the ultimate bearing capacity of the frame node (Table 2). The grown rate is from 77.7-120.2% with the different thickness of steel plate. But the thickness of the steel plate has less effect in improving the contribution of ultimate load.

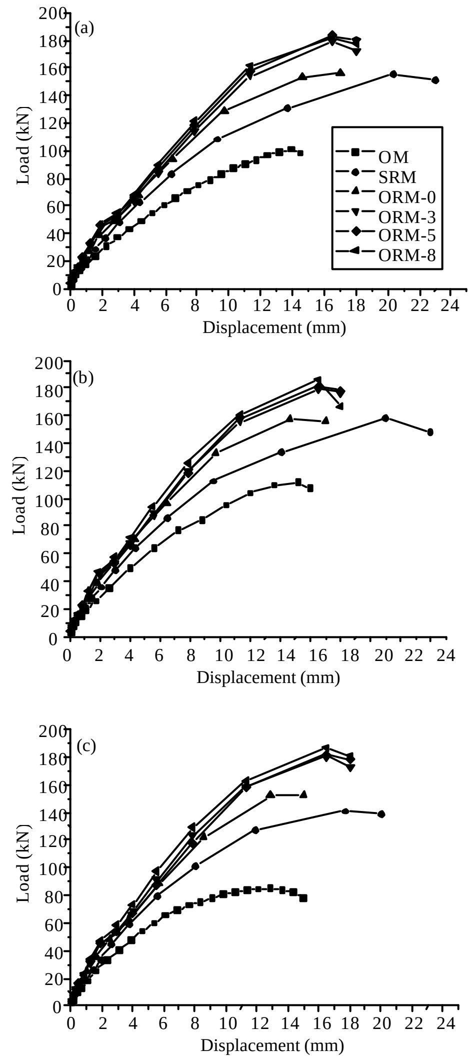

Fig. 5(a-c): Load-displacement curve of OM~ORM-8 (a) 0.2 Axial compression ratio (b) 0.5 Axial compression and (c) 0.8 Axial compression ratio

Under the condition of different axial compression ratio, the growth rate trend of octagonal reinforcement method is the same. When the axial compression ratio is 0.8, the growth rate of octagonal reinforcement method has a high value which is 120.2%.

Ultimate displacement: Under the condition of same axial compression ratio, octagonal reinforcement method can improve the ultimate displacement value of the frame node (Table 3). The grown rate is from 20.0 to 31.0% with the different thickness of steel plate. But the thickness of the steel plate has no effect in improving the contribution of ultimate load.

Table 2: Ultimate load of node

Axial compression ratio (Ratio)	Number	OM	SMR	ORM-0	ORM-3	ORM-5	ORM-8
0.2	ultimate load/kN	100.90	155.39	155.96	179.24	183.18	181.54
	growth rate/%	/	54.0	54.6	77.7	81.6	79.9
0.5	ultimate load/kN	111.58	157.69	158.5	179.15	181.17	185.79
	growth rate/%	/	41.3	42.1	60.6	62.8	66.5
0.8	ultimate load/kN	84.69	140.76	151.8	180.56	181.84	186.46
	growth rate/%	/	66.2	79.2	113.2	114.7	120.2

Table 3: Ultimate displacement of node

Ratio	Number	OM	SMR	ORM-0	ORM-3	ORM-5	ORM-8
0.2	ultimate displacement/mm	14.5	23.0	22.0	19.0	19.0	19.0
	growth rate/%	/	58.6	51.7	31.0	31.0	31.0
0.5	ultimate displacement/mm	16.0	24.0	22.0	19.0	19.0	19.0
	growth rate/%	/	50.0	37.5	18.8	18.8	18.8
0.8	ultimate displacement/mm	15.0	20.0	19.0	18.0	18.0	18.0
	growth rate/%	/	33.3	26.7	20.0	20.0	20.0

Table 4: Stiffness of node

Ratio	Number	OM	SMR	ORM-0	ORM-3	ORM-5	ORM-8
0.2	stiffness/kN•mm^{1}	9.23	10.69	13.59	14.09	14.48	14.88
	growth rate/%	/	15.8	47.2	52.7	56.9	61.2
0.5	stiffness/kN•mm^{-1}	9.51	12.32	13.72	14.88	14.94	15.08
	growth rate/%	/	29.6	44.3	56.5	57.1	58.6
0.8	stiffness/kN•mm^{-1}	9.18	12.24	13.30	14.45	14.93	15.02
	growth rate/%	/	33.3	44.9	57.4	62.6	63.6

Table 5: Ductility of node

Ratio	Number	OM	SMR	ORM-0	ORM-3	ORM-5	ORM-8
0.2	ductility	1.39	1.62	1.51	1.73	1.74	1.74
	growth rate/%	/	16.6	8.6	24.5	25.2	25.2
0.5	ductility	1.47	1.68	1.56	1.88	1.86	1.89
	growth rate/%	/	14.3	6.1	27.9	26.5	28.6
0.8	ductility	1.45	1.66	1.55	1.7	1.74	1.72
	growth rate/%	/	14.5	6.9	17.2	20.0	18.6

Under the condition of different axial compression ratio, the growth rate trend of octagonal reinforcement method is the same. When the axial compression ratio is 0.2, the growth rate of octagonal reinforcement method has a high value which is 31.0%.

Stiffness: Under the condition of same axial compression ratio, octagonal reinforcement method can increase the stiffness of the frame node (Table 4). The grown rate is from 52.7 to 63.6% with the different thickness of steel plate. And the thickness of the steel plate is thicker, the stiffness of node is bigger.

Under the condition of different axial compression ratio, the growth rate trend of octagonal reinforcement method is the same. When the axial compression ratio is 0.8, the growth rate of octagonal reinforcement method has a high value which is 63.6%.

Ductility: The ductility of the structure refers to the deformation ability of the component or the cross section of the component from yield to the maximum bearing capacity. And during this process, bearing capacity is not decreased obviously. Its value is equal to the ratio between ultimate displacement and yield displacement.

Under the condition of same axial compression ratio, octagonal reinforcement method can increase the ductility of the frame node (Table 5). The grown rate is from 17.2 to 28.6% with the different thickness of steel plate. And the thickness of the steel plate has a little effect in improving the contribution of ductility of node.

Under the condition of different axial compression ratio, the growth rate trend of octagonal reinforcement method is the same. When the axial compression ratio is 0.5, the growth rate of octagonal reinforcement method has a high value which is 28.6%.

As a whole, Octagonal reinforcement method can increase the core area and the shear capacity of the frame node. It can help to significantly increase the ultimate bearing capacity, ultimate displacement, stiffness and ductility of the frame node.

Energy-dissipating capacity: Hysteretic curve can be obtained by the low reversed cyclic loading (Fig. 6). The energy-dissipating capacity of component can be calculated by area size of the peripheral hysteretic loop in hysteretic curve. The area size of the hysteretic loop is

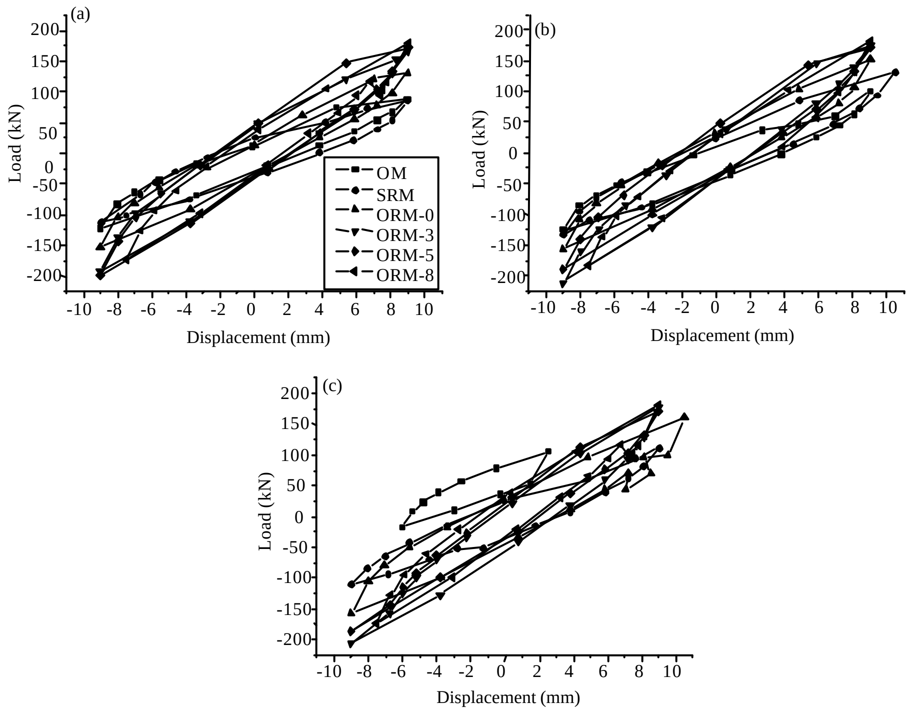

Fig. 6(a-c): Peripheral hysteretic loop (a) 0.2 Axial compression ratio (b) 0.5 Axial compression ratio and (c) 0.8 Axial compression ratio

Table 6: Data of hysteretic curve

Ratio	Number	OM	SMR	ORM-0	ORM-3	ORM-5	ORM-8
0.2	Energy-dissipating Area/kN•mm^{-1}	716.14	788.20	848.60	1104.56	1163.58	1028.14
	growth rate/%	/	10.1	18.5	54.2	62.5	43.6
0..5	energy-dissipating Area/kN•mm^{-1}	744.64	977.58	1017.74	1124.31	1257.42	1088.72
	growth rate/%	/	31.3	36.7	51.0	68.9	46.2
0.8	energy-dissipating Area/kN•mm^{-1}	304.75	711.69	866.53	955.80	1068.16	875.30
	growth rate/%	/	133.5	184.3	213.6	250.5	187.2

greater; the energy-dissipating capacity of frame node is better (Guo, 2011).

Same axial compression ratio: The trend of the node energy dissipation capacity is consistent. Octagonal reinforcement method has the biggest energy-dissipating Area (Table 6). So octagonal reinforcement method can significantly improve the node plastic deformation ability and enhance the capacity of node's energy consumption. The grown rate is from 43.6 to 250.5% with the different thickness of steel plate. The thickness of the steel plate has big effect in improving the energy-dissipating area.
Different axial compression ratio: When the axial compression ratio is 0.5 and other conditions are the same, the energy-dissipating area has a biggest value. And when the axial compression ratio is 0.8, the energy-dissipating capacity of node is smallest. So the proper axial compression ratio can improve the energy performance of the node.

CONCLUSION

Octagonal reinforcement method is a new good method for strengthening.

Octagonal reinforcement method can effectively increase the core area and significantly improve the shear bearing capacity, ultimate displacement, ultimate load, energy dissipation, stiffness and ductility of frame node.

The grown rate of the ultimate bearing capacity is from 77.7-120.2%. The grown rate of the ultimate displacement is from 20.0-31.0%. The grown rate of the stiffness is from 52.7-63.6%. The grown rate of the ductility is from 17.2-28.6%. The grown rate of energy-dissipating area is from 43.6-250.5%

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