Seismic performance study for reinforced concrete–steel plate composite coupling beam

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Abstract. With finite element software ADINA, numerical models were presented for reinforced concrete-steel plate composite coupling beams, under span-depth ratio of 2.5:1,2.0:1 and 1.5:1, plus steel thickness of 8mm and 12mm, in order to study its seismic performance. Results show that reinforced concrete-steel plate composite coupling beams exhibit good seismic performance in ductility, energy dissipation capacity. It is considered that good effect could be expected for reinforced concrete-steel plate composite coupling beams when span-depth ratio is less than 1.5.

Introduction

Coupling beams is the first protecting line in a shear wall structure system. It could strength the shear walls and could dissipate the seismic energy. The loading bearing capacity, rigidity, ductility and energy dissipating capacity should be ensured in the designing works. The reinforced concrete coupling beams with relative small span-depth ratio often exhibits brittle cracking modes, which could result the sudden decreasing in loading bearing capacity, rigidity, increasing in shear wall internal forces, or collapsing of the whole structure[1-7].

Many researchers have concluded that the seismic behavior could be improved with a steel plate embedded in the concrete. Zhang Gang, Ma Si-wen and Ma Yi had demonstrated the effectiveness of the conclusion, through structural numerical simulation with finite element software MARC and ABAQUS.[8][9]. But, on the hand, a contradiction might be resulted in the position of the embedded steel plate and the in-place horizontal stirrup in shear wall boundary members. It is widely known that stirrup in boundary members play an important role not only in bearing shear in the wall, but also in providing the horizontal bonding upon the vertical main reinforce bars to protect them from buckle bending. The stirrup also makes the boundary members concrete be in a state of 3D compression and ensure the ductility of shear wall.

A feasible solution to this problem is to weld the semi-opened stirrup onto the both sides of the steel plate before its installation. The steel plate is installed before the main reinforce bar in shear wall, then the main reinforce bar is placed going through the semi-open stirrup loop, and then is connected with the main reinforce bar bellow, which constitute the semi-opened welded stirrup steel plate coupling beams, as is shown in figure1.

When the structure is subjected to seismic action, the semi-loop stirrup will deform following the steel plate, which will probably cause the concern of worsening of the deform distribution field of wall-coupling joint, which make its detail research necessary. In this paper, with finite element software ADINA, numerical models were presented for reinforced concrete-steel plate composite coupling beams, under span-depth ratio of 2.5:1,2.0:1 and 1.5:1, plus steel thickness of 8mm and 12mm, in order to study its seismic performance.

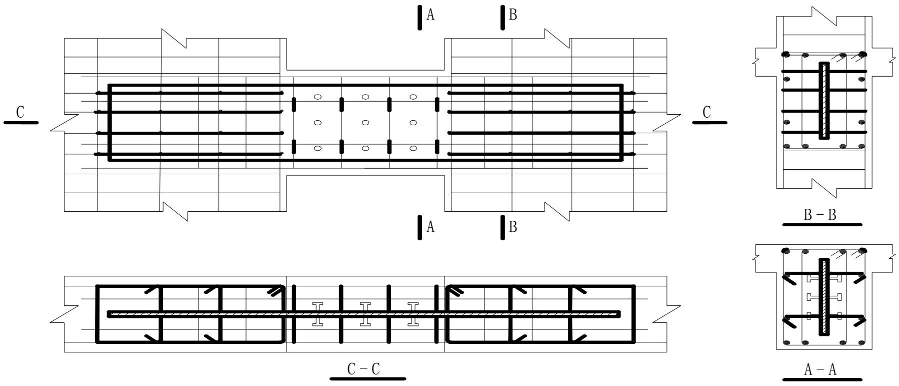


Fig1 Schama of steel plate with semi-opened welded stirrup

Computation Model

A double-nib shear wall specimen is applied as the analyzed numerical structural model, with the scale 1:2. Each of the 2 nibs is with a flange at the end, in order to fix the specimen and the loading parts. On each flange two column holes (8 in each column) with diameter of 48mm were set apart. In coupling beam of every of the 6 specimens, a steel plate with length of 1350mm was embedded, which were numbered as S1, S2, S3, S4, S5, S6. The geometric parameters are listed in table1. The semi –opened loop of steel bar welded on to end area of steel plate, as the horizontal stirrup of shear wall bonding members. The reinforcement ratio of main reinforce bar and stirrup take the value of medium level. The geometric dimension and reinforcement layout are shown in figure 2, with the unit of mm. In Adina software, the structural model of 3 parts: concrete, steel plate and reinforce bar.

Table 1. geometrical dimension of coupling beam models

No,	Cross section dimension (height×breadth)/mm	Span-depth ratio	Steel plate thickness//mm	Anchored length of steel plate/mm
S1	300×150	2.5:1	8	250
S2	300×150	2.5:1	12	250
S3	375×150	2.0:1	8	250
S4	375×150	2.0:1	12	250
S5	500×150	1.5:1	8	250
S6	500×150	1.5:1	12	250

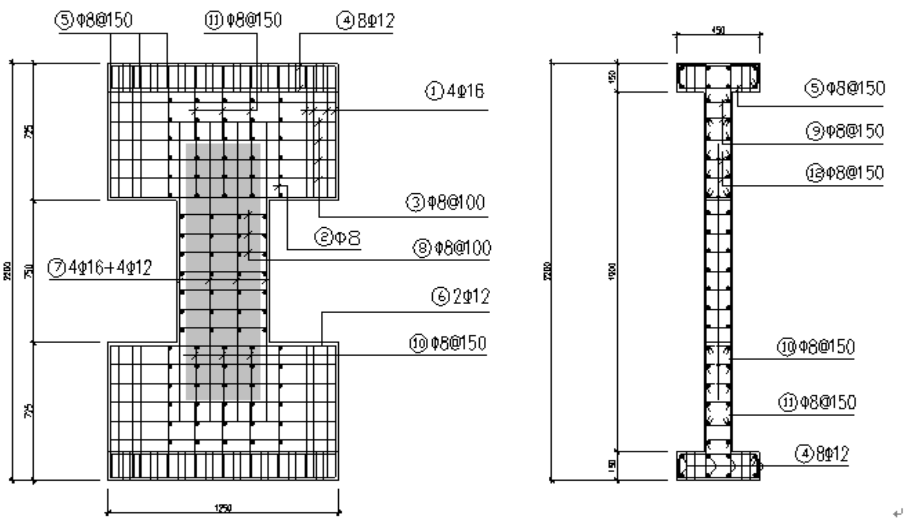


Fig2 steel plate reinforced composite coupling

The ADINA software was applied to establish the numerical models. Because of the unsatisfactory behavior of concrete material models in the analysis process, the MULTIPLE-LINEAR material model in ELASTRO-PLASTIC was taken as the concrete material model, while the BILINEAR material model was taken as the steel plate material and the reinforce bar material model.

The 3D solid element was applied for concrete and steel plate. While the rebar element was applied for main reinforce bar and stirrup, which was formed by meshing the lines representing the reinforce bar in the numerical model. When the concrete part was meshed, this lines could be meshed automatically[10]. At last, a composite finite element model was established to represent the specimen.

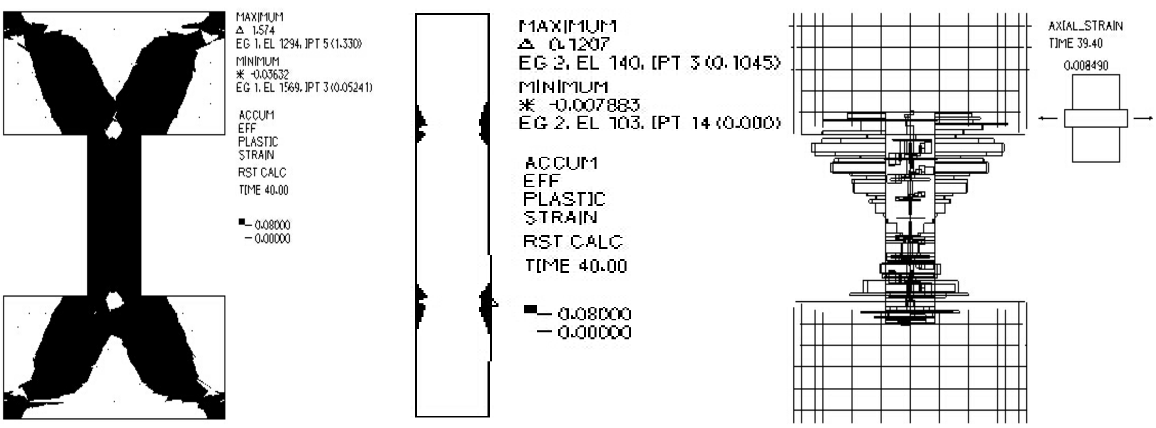
On the other hand, because the anchored bolts were installed o the surface of the steel plate, the relative slipping between concrete and steel plate could be neglected on their contacting surface. The FACE-LINK linking elements were set on their contacting surface.

The low frequency cyclic loading scheme was applied. It is expected that the seismic performance such as rigidity degradation, ductility, energy dissipation, load bearing capacity etc., be under overall observation during the loading process.

Result analysis

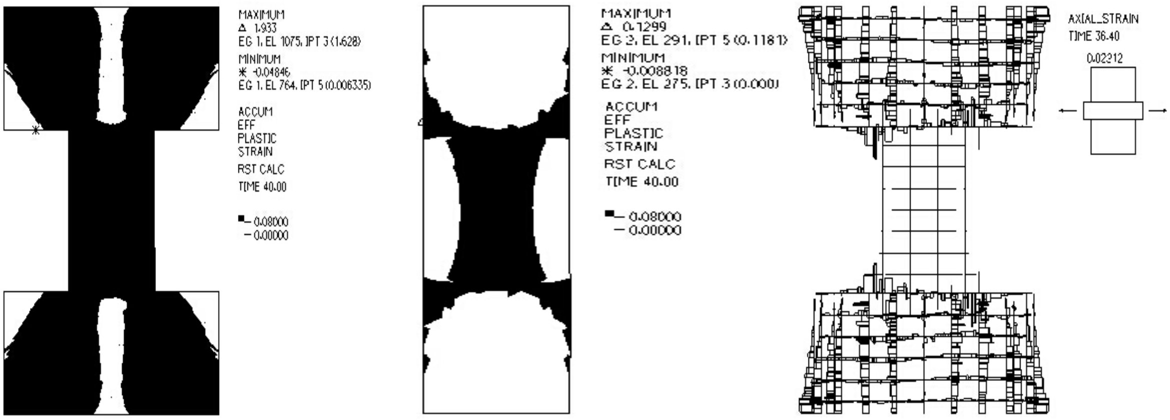
During cyclic loading process, in some ways, the accumulated plastic strain (ACCUM_PLASTIC_STRAIN)could represent the quantity of accumulated damage and energy dissipated. It is considered that energy dissipation capacity of concrete is low, its accumulated plastic strain should represent the cracking phase, while for steel plate, the accumulated plastic strain should represent the quantity of energy dissipation (which is the hardening work done during the loading process). And for reinforce bar, the most important parameter should be the axial strain (including both elastic strain and plastic strain). If the axial strain exceeds 0.025(defined in material model), it means that the reinforce bar have broken.

At the end of loading process(the maximum displacement amplitude is 60mm), part of the computation results for 6 specimens are shown in fig3-fig4. In the strain figures for concrete and steel plate, the black areas means that accumulated plastic strain $e_{aps} > 0.08$ (about 40 times of yield strength for steel). In axial strain figures for reinforce bar, vertical line are applied to represent its axial strain.



concrete steel plate reinforce bar

Fig3 Accumulated plastic strain for concrete and steel plate, axial strain for reinforce bar in S1 Span –depth ratio 2.5:1, steel plate thickness 8mm



concrete steel plate reinforce bar

Fig4 Accumulated plastic strain for concrete and steel plate, axial strain for reinforce bar in S5
Span –depth ratio1.5:1, steel plate thickness 8mm

If the span-depth ratio of coupling beams becomes smaller, the shear strain will relatively increase in total strain. It is clear that a smaller span-depth ratio will correspond to a larger accumulated plastic area specified in the way above ($e_{aps} > 0.08$), which means the enhancement of shear bearing capacity from the embedded steel plate. For example, there is no accumulated plastic strain area ($e_{aps} > 0.08$) on the central area of steel plate, which means the small proportion of shear strain. On the contrary, the accumulated plastic strain area ($e_{aps} > 0.08$) occurs on internal central area of steel plate means the large proportion of shear strain. The steel plate should be embedded when the span-depth is small, for a high effectiveness. At the same time, it should be noted that pull-out failure could not be simulated with in the steel plate anchored area, attention should be paid to this problem.

It is clear that there is little difference among the distribution of concrete accumulated plastid strain, but large difference for the steel plate accumulated plastic strain. The plastic strain will decrease with the growth of steel plate thickness. For S1,S2,S3,S4, there is even not specified accumulated plastic strain in central area of plastic steel, but only a small amount of accumulated plastic strain at corner position of coupling beams, which means for a large span-depth ratio, the damage of steel plate will decrease, but ductility will increase. It is also seen that proportion of accumulated plastic area on steel plate is far less than proportion of concrete. That means there still is potential deformation capacity for steel plate, which is necessary for its ductility and energy dissipation. It is clear that the seismic performance could be improved with steel plate.

It is clear that a large span-depth ratio corresponds to a large axial strain of main reinforce bar, which means, at this time, the flexure bending deformation dominant the whole deformation. On the contrary, the shear deformation will dominant the whole. In both occasion, the axial strain of stirrup in walls are in low level, which means the existence of steel plate will exert little affect to stirrup in wall nibs, and means the ensuring of restriction from stirrup to concrete and main steel bar.

It clear that for both of the two kinds of steel plate thickness (8mm and 12mm), the hysteresis loops are plump, which means satisfied energy dissipation capacity of the composite coupling beams.

At last, it must be mentioned that because MULTIPLE-LINEAR material model was applied approximately for concrete material model, the rigidity degradation performance could be expressed in bond curve of hysteresis loops in fig10, which means the probably significant difference between the numerical results and the experiment results. But it could seen from fig6 to fig9 that the area for the specified accumulated plastic strain are rather small at the end of loading process. The elastic strain dominants the whole strain in steel plate. On the other hand, the Young’s modulus of steel is about 7-8 times of the Young’s modulus of concrete, it could be concluded that composite coupling beams will not exhibit notable rigidity degradation, which means the further load bearing capacity and good ductility etc.

Conclusions

(1) In concrete-steel plate composite coupling beams, the thickness of steel plate exerts little influence to steel plate damage (accumulated plastic deformation) . The concrete part will exhibit cracking in a large area.

(2) The deformation in steel plate is mainly elastic deformation. The area for specified accumulation is mainly elastic deformation. The area for the specified accumulated plastic in steel plate is rather smaller than in concrete. It could be expected that there is no notable rigidity degradation for composite coupling beams. When span-depth ratio is smaller than 1.5, it is effective to set composite coupling beams.

(3) The hysteresis loops are plump, which means satisfied energy dissipation capacity of the composite coupling beams. The axial strain of stirrup in walls are in low level, which means the existence of steel plate will exert little affect to stirrup in wall nibs, and means the ensuring of restriction from stirrup to concrete and main steel bar.

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References

[1]Fan Chen, Quanfeng Wang,Some Problems in Design of Coupling Beam of Shear Wall Structure, J. Fujian Architecture & Construction. 91(2005) 47-49(In Chinese).

[2] Stafford Smith B, Coull A, Tall building structures: analysis and design, John Wiley& Sons, Inc, London, 1991.

[3] Surkl, Yong Zhu, Experimental and numerical analyses of external steel plate strengthened reinforced concrete coupling beams, J. Engineering Structures .27(2005)1537-1550.

[4] Oehlers D J, Bradford M A, Elementary behavior of composite steel and concrete structural Members, Butterworth Heinemann, Oxford, 1999.

[5] Oehlers D J, Sved G, Flexural strength of composite beams with limited slip capacity shear Connectors,J. Journal of Structural Engineering, ASCE. 121(1995)932-938.

[6] Yong Zhu , Qicai Yu , Mechanics analysis of strengthened RC coupling beam,J. Journal of Guangzhou University:Natural Science Edition,J. 6(2005)81-84(In Chinese).

[7] Junhai Zhou, Embedded steel girder length - restoring force model experimental study and analysis of concrete shear wall concrete composite coupling beam joint-points, Central South University, Changsha, 2008(In Chinese).

[8] Huoshui Peng, Application Study of Steel plate Reinforced Concrete Coupling Beams, J. Fujian Building, Fujian Architecture & Construction, J. 129 (2009) 33-35(In Chinese).

[9] Gang Zhang. Experimental Study on Seismic Behavior of Steel plate Reinforced Concrete Coupling Beams, Tsinghua University, Beijing, 2005(In Chinese).

[10] Siwen Ma, Yi Ma, Study of Steel plate concrete beams and concrete shear wall joints performance, Science and Technology Information, J. 15(2011)356-387(In Chinese).

[11] Jianjing Jiang， Xinzheng Lu, Lieping Ye, Finite Element Ansysis of Concrete Structures, Press of Tsinghua University, Beijing, 2005(In Chinese).