Journal of Southeast University (English Edition) Vol. 28, No. 1, pp. 73 - 78 Mar. 2012 ISSN 1003—7985

Shear resistance performance of steel-concrete-steel composite shear wall

Wei Fangfang Zha Bin Zhao Haibo Ma Xin

(College of Civil and Transportation Engineering, Hohai University, Nanjing 210098, China)

Abstract: For a deeper understanding of the shear resistance performance of the steel-concrete-steel composite shear wall, the main influence factors such as the thicknesses of the steel plates and the concrete, the strength grades of the concrete and the span-depth ratios of the composite wall, which have impacts on the shear resistance performance of the composite shear wall, are analyzed by the numerical simulation method. Meanwhile, the simplified calculation formulae of the initial elastic lateral-resisting stiffness and the shear bearing capacity of the composite shear wall are also proposed. The research shows that with the increase in the thicknesses of the steel plates and the concrete and the increase in the strength grades of the concrete, the shear performance of the shear wall improves obviously; the span-depth ratios of the composite wall have a significant effect on the initial elastic lateral-resisting stiffness, but a small effect on the shear bearing capacity. Comparing the results of the simplified calculation formulae with those of the nonlinear finite element method, it is obvious that the presented formulae are reasonable and meet the real force state of the structure. These conclusions can serve as a preliminary design reference for the steel-concrete-steel composite shear wall.

Key words: steel-concrete-steel composite shear wall; shear resistance performance; influence factor; calculation formula

doi: 10. 3969/j. issn. 1003 - 7985. 2012. 01. 013

The lateral load resisting system is one of the most important parts in the design of a high-rise building structure[1]. The steel-concrete-steel composite shear wall is a new kind of high-rise lateral-force-resisting structure. The structure combines the merits of the steel and the concrete and has high anti-shear and anti-lateral stiffnesses, so the composite shear wall is suitable for use in high-rise buildings and skyscrapers which require high anti-lateral stiffness[2]. Up till now, the steel-concrete-steel composite shear wall has been applied in dozens of buildings to resist the lateral load. Those buildings are mainly located in high earthquake intense places such as North America and Japan. In China, there are some buildings using this composite shear wall system, including the Yancheng broadcast and television tower[3], the Guangzhou east tower[4] and the Buddha statue[5]. However, the development of this system is still at the early stage. So far, only a few comprehensive researches have been done on such a type of structure in the shear resistance mechanism and the failure mode, and there is no related design specification in China. Therefore, it is necessary to study it systematically and in-depth.

The ANSYS finite element software is utilized in this paper to analyze the nonlinearity behavior of the composite shear wall, and the formulae of initial elastic lateral resisting strength and anti-shear strength are studied by finite element analysis.

1 Finite Element Analysis

1.1 Model construction

The steel-concrete-steel composite shear wall proposed by Corus is used as the research object, as shown in Fig. 1[6]. Shear link rods are welded between two steel plates by high-speed friction welding, and the concrete is cast in the space after the installation of the plates are in place, which forms the composite shear wall structure.

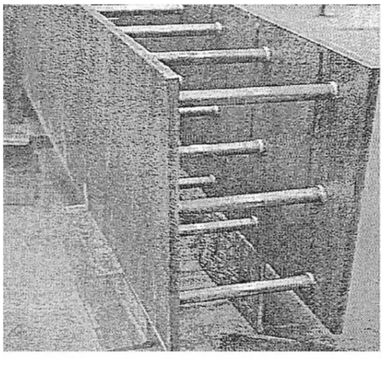

Fig. 1 Steel-concrete-steel composite shear wall

In order to study the shear resistance properties of the steel-concrete-steel composite shear wall, the structure is simplified with the following assumptions[7]: 1) Between the composite shear wall and the beam-column frame, the nodes at the four corners are hinged connections; 2) The flexural rigidities of the beam-column frame are infinitely great; 3) The axial deformations of the beam-column frame are ignored. And the simplified model is shown in Fig. 2.

Received 2011-12-08.

Biography: Wei Fangfang (1978—), female, doctor, associate professor, weifangfang@ vip. sina. com.

Foundation item: The Basic Scientific Research Funds of Hohai University (No. B1020133).

Citation: Wei Fangfang, Zha Bin, Zhao Haibo, et al. Shear resistance performance of steel-concrete-steel composite shear wall. [J]. Journal of Southeast University (English Edition), 2012, 28(1): 73 - 78. [doi: 10. 3969/j. issn. 1003 - 7985. 2012. 01. 013]

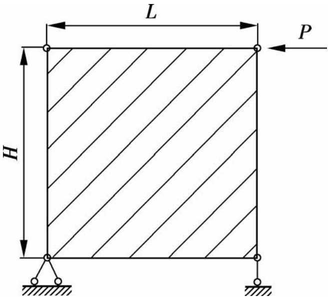

Fig. 2 Simplified model

The finite element model is shown in Fig. 3. The model consists of the surrounding framework, two steel plates and the filled concrete. The dimension of the composite wall is 3 m × 3 m[5].

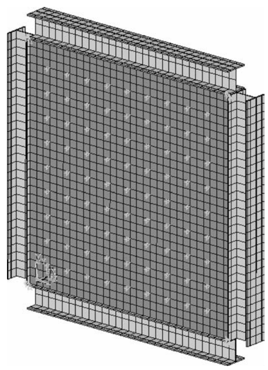

Fig. 3 Model of composite shear wall

The constitutive model of the concrete in GB 50010—2002[8] is adopted and the concrete is simulated by the element Solid65. The steel constitutive model uses the ideal elasto-plastic model, and the steel plate is simulated by the element Shell181. The yield strength of the steel plate is 235 MPa, and the elastic modulus is 206 GPa. Beams and columns are simulated by the element Solid45, and their flexural rigidities in plane are infinitely great.

The nodes between the composite shear wall and the beam-column frame at four corners are hinged connections, and the others are coupled by sharing nodes. The mutual effect of the concrete and the steel is realized by the face-to-face element. CONTA173 is used in the internal surfaces of the two steel plates and TARGE170 is used in the external surfaces of the concrete slab, which makes up the contact pairs. The contact surfaces are assumed to be smooth and have no mutual infiltration, and they transfer normal pressure to each other without normal tension.

The shear link rods connecting the concrete and the steel are simulated by the nonlinear spring element COMBIN39. The spacing is 200 mm.

The displacement loading method is used in this paper and the maximal horizontal displacement is 60 mm[7].

1.2 Analysis of finite element result

The shear performance of the steel-concrete-steel wall is studied through these main factors including the thicknesses of the steel and the concrete, the strength grade of the concrete and the span-depth ratio of the composite wall. The curves of the load-displacement are shown in Fig. 4. The results show that: 1) With the increase in the thicknesses of the concrete and the steel plate and the in-

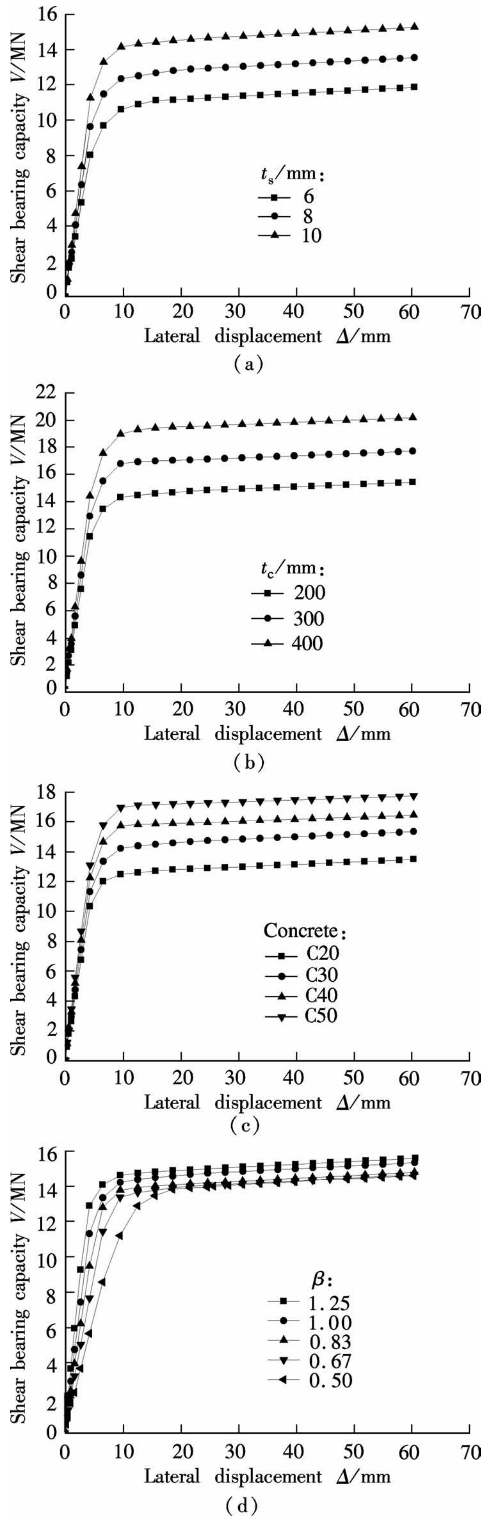

Fig. 4 Curves of load-displacement of the composite wall by considering influence factors. (a) Effect of various thicknesses of steel; (b) Effect of various thicknesses of concrete; (c) Effect of various strength grades of concrete; (d) Effect of various depth-span ratios

crease in the strength grades of the concrete, the initial elastic lateral resisting strength and shear bearing performance improve accordingly; 2) As the joints of the framework are hinged connections and the flexural rigidities of the beam-column frame are infinite, only the lateral load is taken into consideration. The changes in span-depth ratios significantly influence the initial elastic lateral resisting strength, but they have a trivial effect on the shear bearing capacity.

2 Simplified Formulae

2.1 Formula of initial elastic lateral resisting strength

Fig. 5 shows the deformation of the composite shear wall under the horizontal load. The vertical displacement Δ_y is tiny, so Δ_y can be ignored, and we only calculate the horizontal displacement Δ_x caused by the horizontal load.

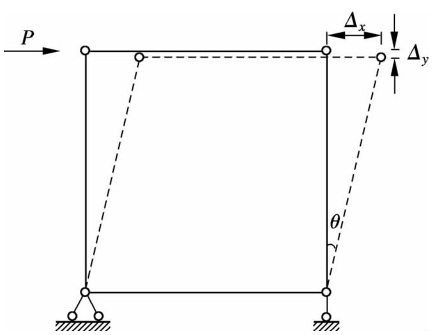

Fig. 5 Calculation diagram

According to the virtual work principle, with the effect of the lateral load on the top of the structure, the displacement on the top of the structure can be expressed as

$$\Delta = \sum \int \frac{\overline{M}M_p}{EI}\mathrm{d}s + \sum \int \frac{\overline{N}N_p}{EA}\mathrm{d}s + k \sum \int \frac{\overline{Q}Q_p}{GA}\mathrm{d}s \quad (1)$$

Because only the lateral load is taken into consideration, the influence of the axial load can be ignored. Besides, it is assumed that the flexural rigidities of the beam-column frame are infinitely great, and the additional bending moment caused by the lateral load is supported by two columns at the two ends. So, the effect of the bending moment on the displacement can also be ignored. The horizontal displacement can be computed by

$$\Delta_x = k\frac{VH}{G_z A_z} \quad (2)$$

where H, G_z, A_z are the height, the shear modulus and the cross section area of the wall along the span, respectively; k is the coefficient related to the section shape when the section is rectanglar[9], and it can be 1.2.

It is assumed that the steel and the concrete can satisfy the deformation compatibility conditions during the initial elastic stage. $G_z A_z$ can be calculated as

$$G_z A_z = G_s A_s + G_c A_c \quad (3)$$

where G_s, A_s are the shear modulus and the total cross section area of the steel plate along the span, respectively; G_c, A_c are the shear modulus and the total cross section area of the concrete slab along the span, respectively.

Substituting Eq. (3) into Eq. (2), we can obtain

$$\Delta = 1.2\frac{VH}{G_s A_s + G_c A_c} \quad (4)$$

The Poisson ratio of the steel and the concrete are 0.3 and 0.2, respectively, so the horizontal displacement can be written as

$$G_s = \frac{E_s}{2(1+\nu_s)}, \quad G_c = \frac{E_c}{2(1+\nu_c)}$$
$$A_s = Lt_s, \ A_c = Lt_c, \ L = H\beta$$
$$\Delta = \frac{V}{\left(\frac{E_s t_s}{3.12} + \frac{E_c t_c}{2.88}\right)\beta} \quad (5)$$

where E_s, t_s are the elastic modulus and the total thickness of the two steel plates, respectively; E_c, t_c are the elastic modulus and the total thickness of the concrete slab, respectively; β is the span-depth ratio of the composite wall.

The horizontal displacement on the top of the wall caused by a unit load can be computed by

$$\delta = \frac{1}{\left(\frac{E_s t_s}{3.12} + \frac{E_c t_c}{2.88}\right)\beta} \quad (6)$$

The initial elastic lateral-resisting stiffness K_0 can be obtained as

$$K_0 = \frac{1}{\delta} = \left(\frac{E_s t_s}{3.12} + \frac{E_c t_c}{2.88}\right)\beta \quad (7)$$

Tab. 1 shows the comparison of the results calculated by the finite element method and Eq. (7). The comparison indicates that the maximum error between the results in the two ways is within ±10%, so the results fit well with each other.

2.2 Design formula of shear bearing capacity

The shear bearing capacity of the steel-concrete-steel wall is provided by two external steel plates and the concrete. The contribution of the inside concrete to the shear bearing capacity of the composite wall is reflected in two ways: the plane-section resisting shear and the inclined compression bar mode.

2.2.1 Shear bearing capacity provided by steel plates

According to the results of the finite element analysis, the average shear stress of the cross section of the steel can reach 135 MPa, so the steel can be considered as the total cross-section shear yield. According to Ref. [10], the shear bearing capacity of the steel plates can be computed by

Tab. 1 Comparison of the results calculated by the finite element method and formula

Strength grade of concrete	t_s/mm	t_c/mm	β	Results of Eq. (7) K_0/(MN · mm^{-1})	Results of finite element method K_{01}/(MN · mm^{-1})	$\frac{K_0 - K_{01}}{K_0}$/%
C30	12	200	1.00	2.87	2.71	5.57
C30	16	200	1	3.14	2.93	6.69
C30	20	200	1.00	3.40	3.28	3.53
C30	20	300	1.00	4.45	4.19	5.84
C30	20	400	1.00	5.49	5.04	8.20
C20	20	200	1.00	3.09	2.97	3.88
C40	20	200	1.00	3.58	3.71	-3.63
C50	20	200	1.00	3.72	3.98	-6.99
C30	20	200	1.25	4.25	4.11	3.29
C30	20	200	0.83	2.84	2.72	4.23
C30	20	200	0.67	2.27	2.17	4.41
C30	20	200	0.50	1.70	1.62	4.71

$$V_s = 0.6 f_y L t_s \tag{8}$$

where f_y is the yield strength of the steel; L is the span of the composite wall.

2.2.2 Shear bearing capacity provided by concrete

The compression strength and the tensile strength of the concrete can be measured by the standard experiment. But the shear strengths of the concrete obtained by different tests are different. The shear stress-strain curve equation obtained by data discretization and regression analysis[11] is adopted in this paper. The shear strength and the shear deformation of the concrete are

$$\tau_p = 0.39 f_{cu}^{0.57} \tag{9}$$

$$\gamma_p = (176.80 + 83.56\tau_p) \times 10^{-6} \tag{10}$$

where τ_p and γ_p are the peak shear stress and the peak shear strain, respectively.

The concrete slab is restrained by two external steel plates and the surrounding beam-column. It is assumed that the distribution of the shear stress on the cross section of the concrete is uniform, and the shear stress will not change when approaching τ_p (see Fig. 6). The shear bearing capacity of the concrete can be expressed as

$$V_{c1} = \tau_p A_c = 0.39 f_{cu}^{0.57} L t_c \tag{11}$$

where f_{cu} is the compressive strength of the concrete cube.

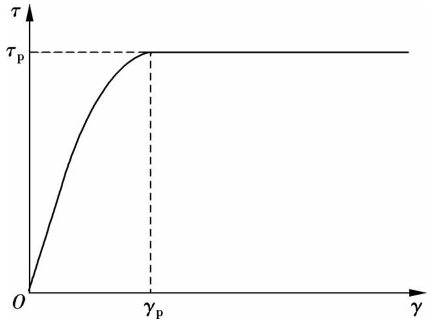

Fig. 6 The shear stress-strain curve of the concrete

2.2.3 Shear bearing capacity of inside concrete under inclined compression bar mode

For the four-side-connected shear composite wall, the concrete slab is restrained by two external steel plates and the surrounding beam-column. So when the shear composite wall bears the horizontal load, it is easy to form an inclined pressure bar to resist the lateral shear force. The mechanism of the inclined pressure bar is shown in Fig. 7. The columns and steel plates work as the pull bar to balance the vertical load of the inclined pressure bar, and the horizontal component of the inclined pressure bar resists the lateral shear force.

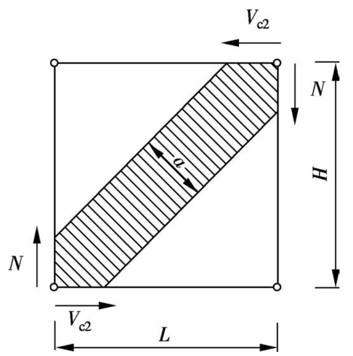

Fig. 7 Mechanism of inclined pressure rod

Owing to the pull-pressure stress state of the concrete in the actual state, a reduction factor β' of the compression strength of the concrete should be taken into account[12],

$$\beta' = \frac{1}{0.85 + 0.27k'} \tag{12}$$

The shear bearing capacity of the inside concrete slab under the inclined compression bar mode can be computed by

$$V_{c2} = \beta' f_c a t_c \cos\theta \tag{13}$$

where β' is the reduction factor of the compression strength of the concrete. Generally, when the concrete is restrained by the surrounding beam-column, $k' = 1.5$ and $\beta' = 0.8$. f_c, θ and a are the concrete axial compressive strength design values, the intersection angle between the axes of the inclined compression bar and the horizontal plane, and the equivalent width of the inclined compression bar, respectively. According to Ref. [13],

$$a = 0.3\sqrt{L^2 + H^2} \tag{14}$$

The shear bearing capacity of the steel-concrete-steel composite shear wall can be obtained on the basis of the strength superposition principle,

$$V = V_s + V_{c1} + V_{c2} = 0.6 f_y L t_s + 0.39 f_{cu}^{0.57} L t_c + 0.24 f_c \sqrt{L^2 + H^2}\, t_c \cos\theta \tag{15}$$

Tab. 2 shows that the errors between the results computed by the finite element method and the results computed by Eq. (15) can be controlled in the range of 20% to 30% . The main factors causing errors are as follows: 1) The crashed concrete is not considered in the finite element analysis in order to guarantee the calculation convergence of the model; 2) The influences of the connections and the surrounding beam-column on the composite shear wall are not taken into consideration in the deduction of Eq. (15). Therefore, the results of Eq. (15) are reasonable and can meet the real force state of the structure compared with the results of the finite element method.

Tab. 2 Comparison between results computed by finite element method and results computed by formula

Strength grade of concrete	t_s/mm	t_c/mm	β	Results of Eq. (15) V/MN	Results of finite element method V_u/MN	$\frac{V_u - V}{V}$/%
C30	12	200	1.00	8.58	11.85	38.11
C30	16	200	1.00	10.21	13.53	32.52
C30	20	200	1.00	11.84	15.25	28.80
C30	20	300	1.00	13.68	17.53	28.14
C30	20	400	1.00	15.53	19.98	28.65
C20	20	200	1.00	10.83	13.40	23.73
C40	20	200	1.00	12.81	16.35	27.63
C50	20	200	1.00	13.63	17.63	29.34
C30	20	200	1.25	11.84	15.50	30.91
C30	20	200	0.83	11.83	14.70	24.16
C30	20	200	0.67	11.84	14.56	22.97
C30	20	200	0.50	11.84	14.51	22.55

3 Conclusions

The shear performance analysis of the steel-concrete-steel wall is conducted through the main factors including the thicknesses of the steel and the concrete, the strength grade of the concrete and the span-depth ratios of the composite wall, and the formulae of the initial elastic lateral resisting stiffness and shear bearing capacity are discussed. By comparison, the following conclusions are obtained:

1) With the increase in the thicknesses of the concrete and the steel plates and the increase in the strength grade of the concrete, the initial elastic lateral resisting strength and shear bearing performance improve accordingly.

2) The changes in span-depth ratios can significantly influence the initial elastic lateral resisting strength. But when the joints of the framework are hinged connections and the flexural rigidities of the beam-column frame are infinitely large, only the lateral load is taken into consideration. The influence made by the change in span-depth ratios on the shear bearing capacity is not significant.

3) Through theory analysis and finite element computation, the initial elastic lateral resisting strength and shear bearing capacity are reasonable and fit the real force state of the structure. These conclusions can serve as preliminary design references of the steel-concrete-steel composite shear wall.

References

[1] Li Guoqiang. *Design of multi-storey and high-rise steel structure*[M]. Beijing: China Architecture and Building Press, 2003. (in Chinese)

[2] Wang Min, Cao Wanlin, Zhang Jianwei. Seismic research and development of composite shear wall[J]. *Earthquake Engineering and Engineering Vibration*, 2007, **27**(5): 80 − 87. (in Chinese)

[3] Chen Jinshi, Zhang Jun. Construction technology of composite structure of double steels and shear wall in Yancheng broadcast and television tower[J]. *Construction Technology*, 2011, **40**(15): 17 − 20. (in Chinese)

[4] Nie Jianguo, Tao Muxuan, Fan Jiansheng. Research advances of composite shear walls with double steel plates and filled concrete[J]. *Building Structure*, 2011, **41**(12): 52 − 60. (in Chinese)

[5] Zhu Wenjun, Ma Jun, Huang Huiping. Research and application of the bi-steel plate shear wall in special structure [J]. *Special Structure*, 2010, **27**(2): 14 − 16. (in Chinese)

[6] Clubley S K, Moy S S J, Xiao R Y. Shear strength of steel-concrete-steel composite panels. Part Ⅰ—testing and numerical modeling[J]. *Journal of Constructional Steel Research*, 2003, **59**(6): 781 − 794.

[7] Guo Yanlin, Zhou Ming, Dong Quanli. Research of elastic-plastic shear limit bearing capacity and hysteretic behavior on buckling-resisting steel plate shear wall [J]. *Engineering Mechanics*, 2009, **26**(2): 108 − 114. (in

Chinese)
[8] Ministry of Construction of the People's Republic of China. GB 50010—2002 Code for design of concrete structures[S]. Beijing: China Architecture and Building Press, 2002. (in Chinese)
[9] Long Yuqiu, Bao Shihua. *Structural mechanics* (Ⅰ): *basic tutorial*[M]. Beijing: Higher Education Press, 2006. (in Chinese)
[10] American Institute of Steel Construction (AISC). Seismic provisions for structural steel buildings[S]. Chicago, IL, USA: American Institute of Steel Construction Inc, 2002.
[11] Nie Jianguo, Xu Guigen. Shear deformation of concrete filled square tubular column connections[J]. *Journal of Tsinghua University: Science and Technology*, 2009, **49**(6): 782 - 786. (in Chinese)
[12] Parra-Montesinos G, Wight J K. Modeling shear behavior of hybrid RCS beam-column connections[J]. *Journal of Structural Engineering*, 2001, **127**(1): 3 - 11.
[13] Tang Jiuru. *A seismic design of reinforced concrete frame joint*[M]. Nanjing: Southeast University Press, 1989. (in Chinese)

双层钢板混凝土组合剪力墙的抗剪性能

韦芳芳　查　斌　赵海波　马　欣

(河海大学土木与交通学院, 南京 210098)

摘要:为深入了解双层钢板混凝土组合剪力墙的抗剪性能,采用数值模拟的方法研究了钢板厚度、混凝土厚度、混凝土强度及组合剪力墙的跨高比等主要参数对该组合剪力墙抗剪性能的影响规律,并提出了该组合剪力墙弹性抗侧刚度及抗剪极限承载力的简化计算公式. 研究表明:随着钢板厚度、混凝土厚度、混凝土强度等级的增加,组合剪力墙的抗剪性能均有较显著的提高;组合剪力墙跨高比的变化对其弹性抗侧刚度影响较大,而对其抗剪极限承载力的影响并不明显. 通过将公式计算结果与有限元计算结果进行对比分析,发现提出的简化计算公式较合理,能较好地反映双层钢板混凝土组合剪力墙的实际受力状态. 该结论可作为双层钢板混凝土组合剪力墙初步设计的参考建议.

关键词:双层钢板混凝土组合剪力墙;抗剪性能;影响参数;计算公式
中图分类号:TU398.9