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STUDY ON FIRE RESISTANCE OF BOX-TYPE COMPOSITE WALLS

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ABSTRACT

The fire resistance limit value of box-type composite walls is one of the important parameters for applying this system. To this end, this article selects different refractory structural measures for the composite wall and analyzes the parameters in each part of the fire-resistant structure, including rock wool thickness, keel spacing, number of opening rows in the keel, gypsum board layers and thickness, etc. The results show that the thickness of rock wool, gypsum board layers and thickness, type of cladding plates and the number of layers, the axial compression ratio have significant influence on the fire endurance. The keel distance and the number of openings rows are almost unaffected. Based on the above analysis, the fire resistance optimization design method and fire resistance calculation formulas of the composite wall are proposed to provide theoretical support for the fire protection design of the box-type steel structural system.

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1. Introduction

In the seismic structural system, steel plate shear walls, as the lateral force-resisting member, have advantages of lightweight, good ductility and powerful energy consumption capability, which play a pivotal role in the safety of structural system. To follow the development trend of the construction industry, combining the design concept of assembled steel structure and steel plate walls, the box-type assembled steel structural system emerges as the times require, the structural system is shown in Fig.1. The box-type assembled steel structural system consists of the stiffening plate which is not constrained by the peripheral frame, with advantages of production industrialization, assembled construction, etc. In particular, as a novel type of assembled steel structural system, this structure can give full play to the advantage of steel material and assembled structure, reduce the construction time greatly, and has been applied to the practical engineering.

Through the experimental study of module units and shaking table of box-type assembled steel structural system, it has been found that this structural system has good ductility and seismic performance under seismic load by Lan and Men [1]~[3]. In the module unit experiment, when the corners of the structure are reinforced, the ductility and bearing capacity of the structure is improved greatly. In the shaking table experiment, the maximum elastic-plastic story drift angle of this structure is 1/52 under the 9th intensity rare earthquake, which meets the requirement of the code of seismic design for buildings (GB 50011-2010) [4], indicating the excellent seismic performance. However, this structural system is a pure steel structure with poor fire resistance, for the popularization and application of this structure system, the effect of fire on buildings can't be ignored.

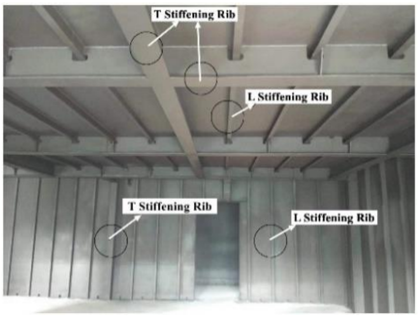


Fig. 1 Box-type assembled steel structural system

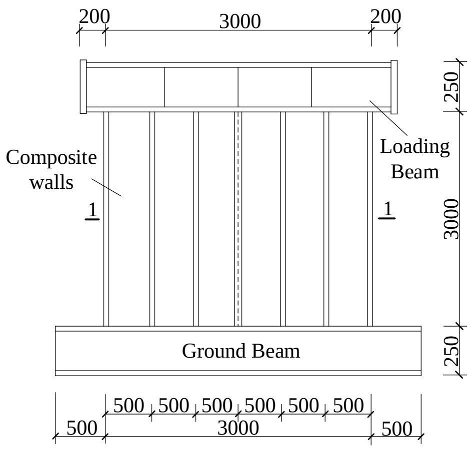
For these reasons, this paper will conduct the relevant analysis and research on the fire-resistance of box-type assembled composite walls, including the design of fire-resistance structure and finite element analysis of the fire resistance. Finally, based on the analysis result, a method for designing the fire-resistant of composite walls is presented, which provides the basis for the application of the box-type steel structural system.

2. Structural design for fire resistance

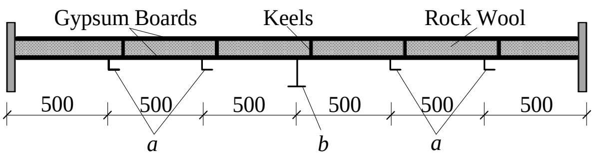
2.1. Structural design and stress mechanism

2.1.1. Structural design for composite walls

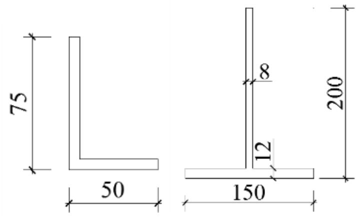
This paper mainly analyzes the fire-resistance of the box-type assembled composite wall under the one-side fire, the specimen is shown in Fig. 2.In the figure, a joist steel beam with large stiffness is set at the top of the wall, which is used to simulate the uniform load transferred by the floor. Additionally, considering the effect of partial fixing, the box-section ground beam is set at the bottom of the wall.



(a) Front elevation of specimens



(b) 1-1 Section



(c) Size of stiffeners (a and b)

Fig. 2 Fire-resistance structure of box-type assembled composite walls.

2.1.2. Stress mechanism of composite walls

Steel plate walls are divided into thick steel plate walls and thin steel plate walls. In literature [5], Zhao provided the stress mechanism of steel plate walls, for thick steel plate walls, it occurred shear deformation under seismic load, and formed the tensile band. The effect of stiffeners is to restrict the deformation of steel plate, until the tensile band reached the ultimate strength. Thick steel plate walls occurred shear failure, the failure deformation is shown in Fig. 3(a). For thin steel plate walls, its failure mode is the same as thick steel plate walls, when concrete slabs are covered on the steel plate wall. The tensile band is mainly distributed in the area enclosed by the concrete slab and the stiffener, the failure deformation is shown in Fig. 3(b).

(a) Thick steel plate walls (b) Thin steel plate walls

Fig. 3 Failure modes of specimens

2.2. Proposal for fire-resistant structure

The fire-resistant structural design of composite walls mainly includes: the covering thickness, the keel distance and row numbers of openings, types of cladding plates, the thickness of walls and the number of stiffeners. The details are as follows:

(1) Design of covering thickness. The covering thickness is mainly related to the layer numbers and thickness of the filling material and the cladding plate. If the covering thickness is too thin, the protective layer is easy to fall off under fire condition, leading to contact directly between steel and fire, and reducing the safety of members. Therefore, in designing the fire-resistant structure, the thickness and layer numbers of rock wool and gypsum board, which are used as filling material and cladding plates, should be chosen reasonably.

(2) Keel distance and row numbers of openings. In the fire-resistant structure, the presence of lightgage steel joist can keep the stability of walls under fire load, but the fire resistance of composite wall is greatly reduced. To reduce this influence on the fire resistance, opening in the keel reasonably is crucial.

(3) Types of cladding plates. When selecting the cladding plate, the fire resistance, applicability and economy of the material must be considered. Common materials include fire-retardant gypsum boards (FRGB), glass magnesium boards (GMB), as well as calcium silicate boards (CSB). Analyze the fire resistance of composite walls of the three-faced board, and select the appropriate cladding plates.

(4) Depth-thickness ratio and number of stiffeners. The load of the box-type composite wall is mainly subjected by steel plates and stiffeners. Stiffeners limit the deformation of the steel plate, but also bear horizontal shear force. Therefore, determining the appropriate depth-thickness ratio and the number of stiffeners is critical to the fire resistance of composite wall.

3. Analysis of fire resistance

3.1. Judgment standard for fire resistance

According to “The Fire Resistance Design Of Steel Structure And Steel-concrete Composite Structure” [6], there are two judgment standard for reaching the fire resistance of composite wall[7]. The first is the out-plane deformation rate of the wall exceeds the specified limit l2/15hx; the second is the out-plane displacement of the wall reaches l/800hx, which l is the length of the wall(mm); hx is the section height of the wall(mm).

3.2. Establishment of finite element model

In the establishment of finite element models, the C3D8R element was used for rock wool plate, cladding plate and steel plate, S4R element was used for keel, and the calculation model proposed by Lie and Chabot[8]was used for constitutive relation of steel. The test method refers to “The Fire-resistance Tests-elements Of Building” (GB/T 9978-2008)[9], two analysis steps are set up in the finite element analysis. In the first step, the constant axial load N at the top of the wall is applied to the rigid beam in the form of equivalent uniformly distributed load. In the second analysis step, the ODB result file obtained from the temperature field analysis was imported into the mechanical model for thermodynamic coupling calculation, and the fire resistance limit was solved. The bottom of the specimen was completely consolidated; the initial temperature was set at 20℃.

In order to verify the reliability of the above model, finite element simulation was carried out on some specimens of the fire resistance test[10] and the simulated values were obtained and compared with the experimental values, as shown in Table 1. The maximum deviation was 8.1%, and the minimum deviation was 4.3%, which was small enough to indicate that the above model could be used in subsequent fire resistance research.

Table 1
Comparison of fire resistance with simulated value and test value

Specimen number	Construction measures（from the fire surface to the backfire surface）					Fire resistance（min）		
	B1 layer	B2 layer	Keel	B3 layer	B4 layer	Test value	Simulated value	Deviation
S1	FRGB	FRGB	C89	FRGB	FRGB	71	67	-5.6%
S2	FRGB	GMB	C140	GMB	FRGB	94	90	-4.3%
S3	FRGB	GMB	C89	GMB	FRGB	98	90	-8.1%
S5	CSB	CSB	C89	CSB	CSB	58	62	6.8%

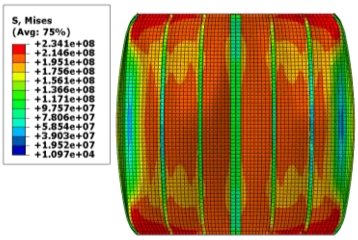
3.3. Stress distribution and failure mechanism

To study the stress distribution and failure mechanism of composite walls under fire condition. According to the technical specification for concrete structures of tall buildings (JGJ 3-2010)[11], the shear wall was designed with an axial compression ratio limit of 0.5. It was compared with axial compression ratio of 0.2 and 0.8. Specimen parameters were shown in Table 2, which a1, a2 is the thickness of FRGB on the fire surface and the backfire surface, respectively; n is the axial compression ratio.

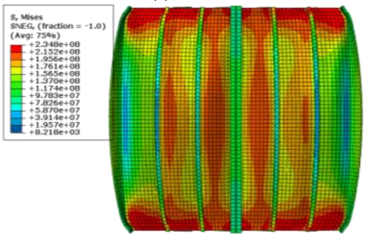
Table 2
Parameters of specimens

Specimen number	Thickness of rock wool(mm)	Keel distance(mm)	Thickness of FRGB		Axial compression Ratio, n
			a1(mm)	a2(mm)	
Q1	100	60	10	10	0.2
Q2	100	60	10	10	0.5
Q3	100	60	10	10	0.8

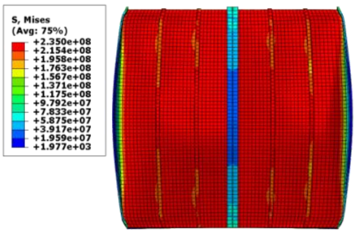
The stress distribution of specimens with different axial compression ratio is shown in Fig. 4. When the axial compression ratio n is 0.2 (Fig. 4a), the deformation of the entire steel plate is like a pumpkin, the plastic yield mainly distributes symmetrically in the four corners. Stress concentration occurs in the area near the loading beam and the bottom fixed end. The stress of the steel plate, L-type and T-type stiffeners is relatively small. For the edge constrained steel plate, since the constrained steel plate is not a load-bearing member, and the model only considers the internal heat conduction effect, the stress in the area near the edge restrained steel plate not closed to the end is little.



(a) n=0.2



(b) n=0.5

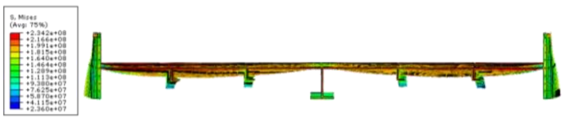


(c) n=0.8

Fig. 4 Stress distribution of composite walls

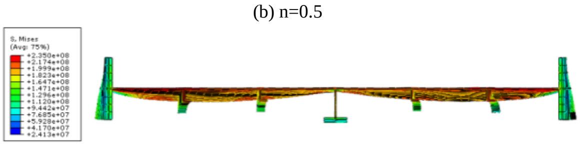
When the axial compression ratio n is 0.5 (Fig. 4b), the stress concentration area at the upper and lower end of the wall increases, and gradually extends from the corner to the middle of the steel plate. The stress in the middle of the wall is great, but the stress of the L-type and T-type stiffener is still little.

When the axial compression ratio n is 0.8 (Fig. 4c), the stress concentration area of the specimen develops from the end to the whole wall, the stress of the T-type stiffener is still small, but the stress of steel plate and L-type stiffeners increases and the yield is uniform. The edge steel plate is mainly deformed by expansion, but the stress near the edge steel plate increases greatly, and the whole wall almost reaches the yield strength.



(a) n=0.2

(b) n=0.5



(c) n=0.8

Fig. 5 Deformation of composite walls with different axial compression ratio

The deformation of composite walls with different axial compression ratio as shown in Fig. 5, the deformation of the steel plate was symmetrically distributed along the axis of T-type stiffener. On the initial heating stage, the steel plate of composite walls bulged, the L-type stiffener bent, but the T-type stiffener had almost no distortion. With the increase of heating time, the lateral displacement in the upper end of steel plates increased. Finally, the deformation of the steel plate reached the limit, the composite wall was damaged.

3.4. Parametric analysis

The fire resistance of composite wall is affected by various parameters, such as the thickness of rock wool and keel distance, etc. In order to research the influence of various parameters on the fire resistance of composite walls, select the main parameters to analyze the fire resistance. The values of the main parameters are shown in table 3, which a1, a2 is the thickness of cladding plates on the fire surface and the backfire surface, respectively; b1, b2 is the layer number of FRGB on the fire surface and the backfire surface, respectively.

Table 3
The value of specimen parameters

The main parameters	The value
Thickness of rock wool（mm）	50, 100, 150
Keel distance（mm）	No keel, 1000, 600
Layer numbers of FRGB b1+b2（layer）	1+1, 1+2, 2+1, 2+2
Row numbers of opening(row)	1, 3, 5, 7
Thickness of cladding plates a1+a2（mm）	10+10, 10+12, 10+15, 12+10, 15+10
Types of cladding plates	FRGB、GMB、CSB
Depth-thickness ratio	300, 400, 500, 600

3.4.1. Thickness of rock wool

The relationship between the thickness of rock wool and fire resistance is shown in Fig. 8. As the thickness of rock wool increases, the fire resistance of composite walls increases. When the thickness of rock wool exceeds 100mm, the straight slope increases from 0.62 to 1.62, and the fire resistance increases more. Increasing the thickness of rock wool can effectively improve fire resistance. When the thickness of rock wool exceeds 100mm, the effect of increasing the fire resistance is better.

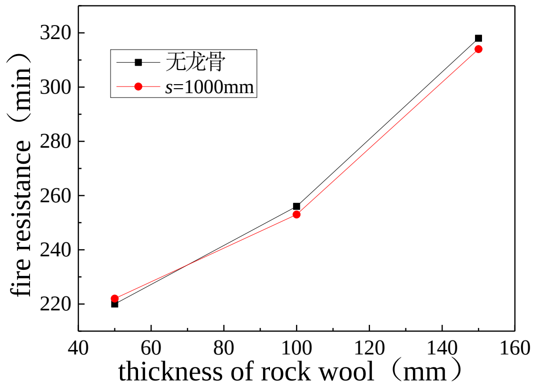


Fig. 6 Relationship between thickness of rock wool and fire resistance

3.4.2. Keel distance

The relationship between keel distance and fire resistance is shown in Fig. 7. With the increase of keel distance, the fire resistance gradually decreases, but the range is little, which means that the influence of keel distance on the fire resistance is little. In practical engineering, considering the convenience of construction and the size of walls, the recommended value for keel distance is 600 mm, which does not affect the use of the building but also can meet the requirements of fire resistance.

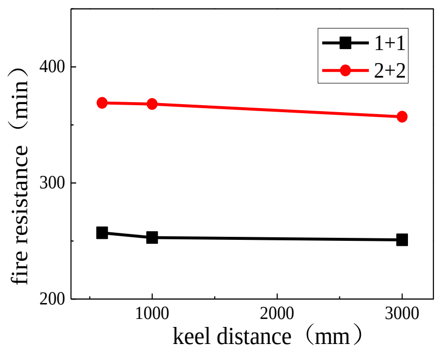


Fig. 7 Relationship between the keel distance and fire resistance

3.4.3. Layer numbers of gypsum boards

The fire resistance of specimens with different layer numbers of gypsum boards is shown in table 4, which b1, b2 is the layer number of cladding boards on the fire surface and the backfire surface, respectively, and c is the thickness of rock wool. It can be seen that as the layer number of gypsum boards increases, the fire resistance of specimens increases. When the total layers of gypsum boards are unchanged, The more gypsum boards layers on the fire surface, the more improvement of fire resistance. Therefore, it can be seen that increasing layer numbers of gypsum boards is economic and effective measures to improve fire resistance.

Table 4

The fire resistance of specimens with different layer numbers of gypsum boards

Layer numbers of FRGB b1+b2（layer）	Fire resistance（min）	
	c=100mm	c=150mm
1+1	257	359
1+2	309	363
2+1	335	387
2+2	368	483

3.4.4. Row numbers of keel openings

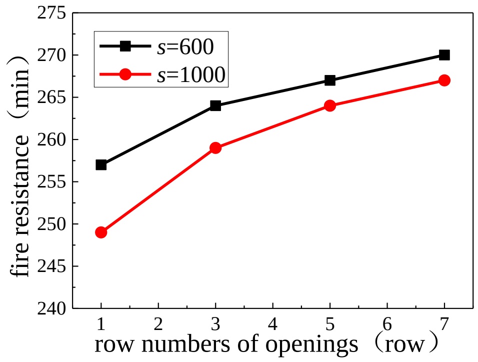
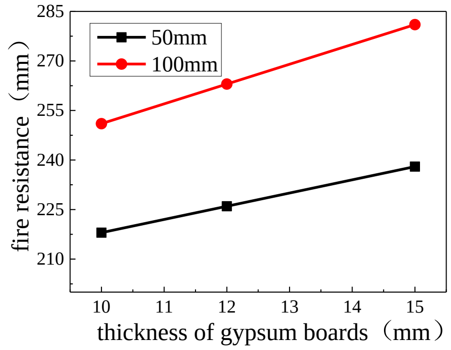


Fig. 8 Relationship between row numbers of openings and fire resistance

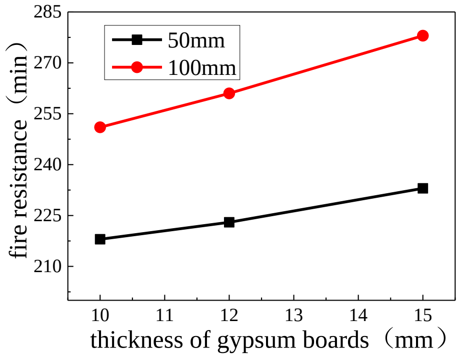
The relationship between row numbers of keel openings and the fire resistance is shown in Fig. 8. As the row number of keel openings increases, the fire resistance of specimens increases. When the keel distance s is 600mm, and the row number of keel openings m exceeds 5, the effect on the fire resistance is not obvious, although the heat conduction path of the keel is extended. When the keel distance s is 1000mm, the fire resistance is the same as when keel distance is 600mm. Therefore, in the practical application, we should pay attention to the selection of appropriate keel opening row, avoid too much keel opening.

3.4.5. Thickness of gypsum boards

The relationship between the gypsum board thickness and fire resistance is shown in Fig. 9. Regardless of the fire surface and the backfire surface, with the thickness of gypsum boards increasing, the fire resistance of specimens increases. When the thickness of rock wool is 50 mm and 100mm, the thickness of gypsum board on backfire surface increases by 5mm, the fire resistance of specimens increases by 3.0% and 6.0% on average. When the thickness of plasterboard on fire surface increases by 5mm, the fire resistance of specimens increases by 7.0% and 9.0% on average, indicating that the thickness of plasterboard has a great influence on the fire resistance of specimens.



(a) the backfire surface



(b) the fire surface

Fig. 9 Relationship between thickness of gypsum boards and fire resistance

3.4.6. Types of cladding plates

The fire resistance of composite walls with different cladding plate is shown in table 6, which b1, b2 is the layer number of cladding boards on the fire surface and the backfire surface, respectively. It can be seen that under different layer numbers of cladding plates, the fire resistance of glass magnesium boards is greater than the other two kinds of boards, indicating that the fire resistance of glass magnesium boards is better, calcium silicate boards is second, gypsum boards is the worst.

Table 3

The fire resistance of specimens with different kinds of cladding boards

Layer numbers of cladding plates b1+b2（layer）	Fire resistance（min）		
	FRGB	GMB	CSB
1+1	257	313	261
2+1	335	367	282

In general, the fire resistance of composite walls can be effectively and economically improved by selecting high-quality cladding plates, appropriate layer numbers, and thickness of cladding plates.

3.4.7. Axial compression ratio

The relationship between the axial compression ratio and the fire resistance is shown in Fig. 12. With the axial compression ratio increases, the fire resistance of composite walls decreases. When the number of layers of gypsum boards on the fire surface and the backfire surface respectively is 1 layer and the axial compression ratio is 0.3 and 0.8, the fire resistance of specimens is 283min and 207min respectively, falling about 36%. When the numbers of layers of gypsum boards on the fire surface and the backfire surface respectively is 2 layers and 1 layer, the other situations are the same, the fire resistance of specimens is 347min and 307min respectively, falling about 13%. It can be seen that the axial compression ratio has a great influence on the fire resistance of walls, and the influence of the axial compression ratio on the fire resistance limit is weakened when layer numbers of gypsum boards increase. Therefore, in designing the fire resistance, the influence of the axial compression ratio can be reduced by increasing layer numbers of gypsum boards.

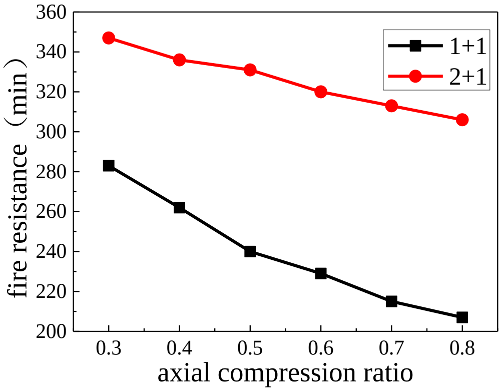


Fig. 10 Relationship between axial compression ratio and fire resistance

3.4.8. Depth-thickness ratio

The relationship between the depth-thickness ratio and the fire resistance of composite walls is shown in Fig. 11. When the depth-thickness ratio is less than 400, the fire resistance increases with the increase of depth-thickness ratio. When the depth-thickness ratio is more than 400, the fire resistance decreases with the increase of depth-thickness ratio. When the number of L-type stiffeners is 4, the influence is more obvious. It can be seen that the fire resistance can be improved by optimizing the design for the structure.

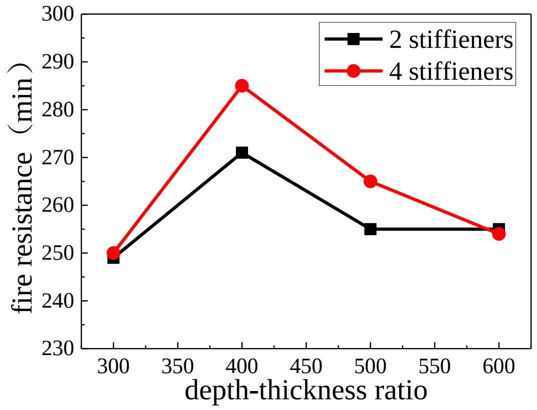


Fig. 11 Relationship between depth-thickness ratio and fire resistance

3.5. Summary analysis

As a basic specimen, its parameters are: rock wool thickness of 100mm, keel distance of 600mm, fire surface gypsum board layer number for a layer, backfire surface gypsum board layer number for a layer, thickness of 10mm, deep ratio of 375, fire resistance for 256min. The simulated value of parameter analysis was compared with the calculated value of the basic specimen to analyze the influence of different parameters on the fire resistance of the specimen, as shown in Fig. 12.

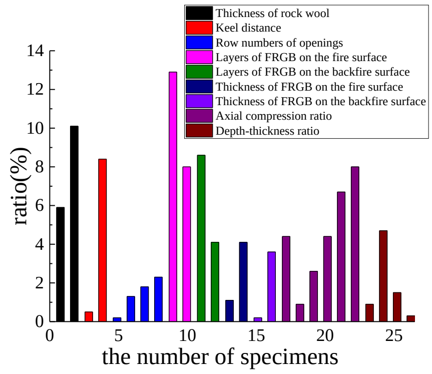


Fig. 12 The influence degree of different parameters on fire resistance

It can be seen from Fig. 12 that the thickness of rock wool, the number and thickness of plasterboard layers, and the axial compression ratio have a greater impact on the fire resistance, and the keel distance also has a certain impact. However, considering the use of building space, the number and thickness of plasterboard layers are mainly considered in the design of fire resistance, and the thickness of rock wool can be considered as appropriate.

4. Design method of fire-resistant structure

4.1. Design formula for fire resistance

The analytical result of the fire resistance of composite walls is shown in table 7. The fire-resistance design formula was proposed. According to the fire-resistance simulation values of different specimens, the fire-resistance regression equation was obtained by polynomial superposition regression analysis, as follows:

$$T_e = 113.95 + 0.92 \times h - 121.72 \times n - 0.02 \times \lambda + 65.89 \times b_1 + 39.89 \times b_2 \qquad (1)$$

which h is the thickness of rock wool, n is the axial compression ratio, λ is the depth-thickness ratio, b1 is layer numbers of gypsum boards on the fire surface, b2 is layer numbers of gypsum boards on the backfire surface; the thickness of rock wool ranges from 50mm to150mm, the axial compression ratio ranges from 0.3 to 0.8, and the depth-thickness ratio ranges from 300 to 600.

Table 7
The analytical results of the fire resistance of composite walls

Specimen number	Thickness of rock wool (mm)	Layer numbers of FRGB b1+b2 (layer)	Axial compresion ratio	Depth-thickness ratio	Fire resistance（min）		
					Simulated value	Test value	Deviation
1	50	1+1	0.3	400	222	219.66	-1.1%
2	100	1+1	0.3	400	285	265.66	4.8%
3	150	1+1	0.3	400	314	311.66	-0.7%
4	100	1+2	0.3	400	309	305.55	-1.1%
5	100	2+1	0.3	400	335	331.55	-1.0%
6	100	2+2	0.3	400	368	371.45	0.9%
7	100	1+1	0.5	400	240	241.32	0.5%
8	100	1+1	0.6	400	229	229.15	0.1%
9	100	1+1	0.7	400	215	216.98	0.9%
10	100	1+1	0.8	400	207	204.80	-1.1%
11	100	1+1	0.3	300	250	268.05	6.7%
12	100	1+1	0.3	500	265	263.28	-0.7%
13	100	1+1	0.3	600	251	260.89	2.6%

The formula is used to recalculate the fire resistance of the wall to verify the correctness. The calculated values are shown in Table 7, and the deviation is shown in Table 7 when compared with the finite element simulation values. This comparison shows that the calculated value agrees well with the simulated value, because the maximum deviation is only 6.7%. Therefore, the formula can be used to predict the fire resistance of composite walls well.

4.2. Design method for fire resistance

According to the “Code For Fire Protection Design Of Building”(The 2018 Edition) (GB 50016-2014) [12], when the fire-resistance rating is 3, the fire resistance of composite walls is not less than 120min; when the fire-resistance rating is 1, the fire resistance is not less than 180min. Therefore, in this section, based on the analytical result of the finite element, the structural design method of fire resistant is proposed, which meets the fire resistance requirement of 120min and 180min.

4.2.1. The fire resistance is 120min

Firstly, according to the “Technical Specification For Concrete Structures Of Tall Building” (JGJ 3-2010) [11], the axial compression ratio of walls in the reinforced bottom zone is 0.5, and that in other zone is 0.3, the choice of depth-thickness ratio and stiffeners must meet the serviceability limit state. Hence, 4 L-shaped stiffener ribs are selected, and the depth-thickness ratio is 400. The gypsum board is used as the wall cladding board, and the fire surface and backfire surfaces are covered with a cladding board with a thickness of 10mm. With the rock wool as the filling material, the thickness of that is 50mm. Through the above measures, the fire resistance requirement of 120min can be met. When the axial compression ratio is 0.5, the fire resistance limit calculated by formula (1) is 195min, meeting the requirement of fire resistance limit of 120min. In addition, the keel distance and row numbers of openings have little effect on the fire resistance, which can be determined according to the actual requirements.

4.2.2. The fire resistance is 180min

According to the fire-resistant structure design idea proposed in this paper, the concrete form and construction measures of fire-resistant 180min composite wall are refined. The load level, depth ratio and reinforcement design are the same as those of fire-resistant 120min.

In the design of the thickness of the cladding board, the gypsum board is used as the cladding board of the wall, and the fire surface and the backfire surface are covered with a layer of cladding board with a thickness of 10mm.With the rock wool as the filling material, its thickness is 50mm. Through the above measures, it can meet the fire resistance requirement of 180 min. When the axial compression ratio is 0.5, through increasing the layer numbers of gypsum boards on the fire surface, or using glass magnesium plates as cladding plates, it can also meet the requirements of fire resistance with 180min.

5. Conclusions

In this paper, the fire resistance structure of box-type assembled composite walls is designed and its fire resistance is analyzed by the finite element method. The effects of parameters on fire resistance were studied, such as the thickness of rock wool, the keel distance and rows of openings, the layer number and thickness of gypsum boards, types of cladding plates, the depth-thickness ratio and the axial compression ratio. The conclusions are as follows:

(1)According to the finite element analysis, among the factors affecting the fire performance, the thickness of rock wool, the number and thickness of gypsum board, and the axial compression ratio have a greater impact on the fire performance; the keel distance also has a certain influence. However, considering the use of building space, the thickness of rock wool can also be considered as appropriate when designing fire resistance. Increasing the thickness of gypsum board on fire surface can effectively improve the fire resistance limit of wall; and changing the type of covering plate is also an economic and effective measure.

(2) In this paper, the fire resistance design method of composite wall is summarized, and the formula of fire resistance calculation of wall is put forward according to the result of finite element analysis. Through the verification, the proposed formula can be used for practical engineering.

References

[1] Men J.J., He Q.Q., Lan T., Guo C.L., Jiang Z.Q., “Shaking table model test design for box-type steel structure residence”, Industrial Architecture, 2018, 48(09), 9-14+82.
[2] Lan T., Guo C.L., Men J.J., He Q.Q., Zhao T., Wang L.Y., “Shake table model test of prefabricated box-type steel structure house”, Industrial Architecture, 2018, 48(09), 1-8.
[3] Lan T., Song Z., Men J.J., Zhao T.Z., Zhao T., Wang L.Y., “Experimental study on seismic performance of box-type steel structure modules reinforced with reinforced corners”, Industrial architecture, 2018, 48 (09), 15-21.
[4] GB 50011-2010, Code of seismic design for buildings 2016, Ministry of Housing and Urban-Rural Development of the People's Republic of China, Beijing, China, 2016.
[5] Zhao T.T., “Study on seismic performance of wall in bottom reinforced area of box-plate steel structure residence”, Xi’an University of Architecture & Technology, 2018.
[6] Li G.Q., Han L.H., Lou G.B., Jiang S.C., Fire resistance design of steel structure and steel-concrete composite structure, China, 2006.
[7] Li G.Q.et al, Steel structure resistance calculation and design, China, 1999.
[8] T. T. Lie, M. Chabot, “Method to predict the fire resistance of circular concrete filled hollow steel columns”, Journal of Fire Engineering, 1990, 2(4), 111-126.
[9] GB/T 9978-2008, Fire-resistance tests-elements of building, Ministry of Housing and Urban-Rural Development of the People's Republic of China, Beijing, China, 2008.
[10] Chen W., “Fire resistance test and theoretical research of cold-formed steel bearing composite wall”, Southeast University, 2014.
[11] JGJ 3-2010, Technical specification for concrete structures of tall building, Ministry of Housing and Urban-Rural Development of the People's Republic of China, Beijing, China,2010.
[12] GB 50016-2014, Code for Fire Protection Design of Building 2018, Ministry of Housing and Urban-Rural Development of the People's Republic of China, Beijing, China, 2018.