CrossFire
Advanced Structural Fire Engineering at Intersections Among Disciplines
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Structural Fire Design Methods of Steel-plate Composite Walls (SC Wall)

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1. Introduction

- Steel-plate composite walls (**SC walls**), consisting of steel tubes filled with concrete, have been increasingly adopted in international design practices due to their superior structural performance.
- Design provisions and guidelines for SC walls have not yet been established in South Korea, so international standards such as AISC must be referenced.
- Especially, fire resistance design is essential, but international standards have many parameters and result in conservative design.
- To support efficient design in practice, this study proposes a practical structural fire design method based on temperature-dependent strength evaluation.

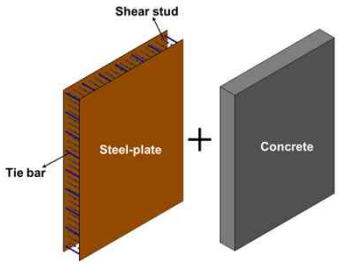


Figure 1. Composition of SC Wall

$$R = [-18.5(\frac{P_u}{P_n})^{\left(0.24-\frac{L/t_{sc}}{230}\right)} + 15](\frac{1.9t_{sc}}{200} - 1)$$

Figure 2. AISC fire resistance prediction equation

Figure 3. AISC design provisions and guideline

2. Research Overview

Research Object

Proposal of temperature-based structural fire design method

Design Method ①	Design Method ②
Temperature profile	Temperature prediction equation
Heat transfer analysis using FEA	Steady-state thermal resistance model

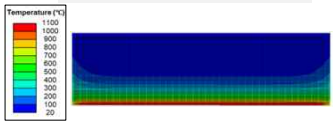


Figure 4. Finite element method using ABAQUS

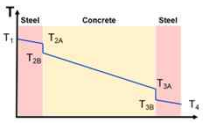
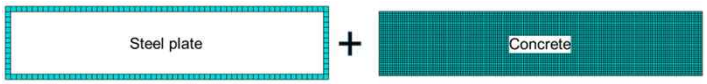
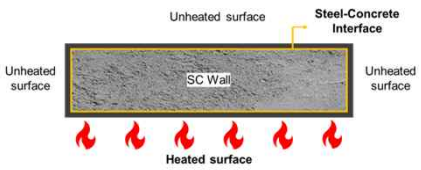


Figure 5. Steady-state thermal resistance model

3. FE Model and Validation



(a) FE model



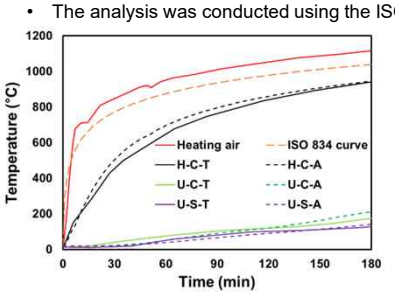
(b) Fire exposure condition

(c) Thermal parameters

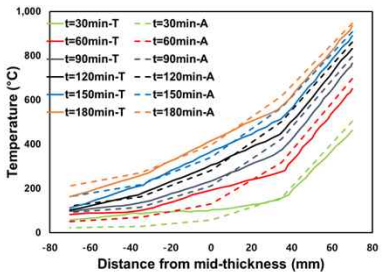
Convection heat transfer coefficient (W/m²K)	Heated surface	25
	Unheated surface	4
Thermal contact conductance (W/m²K)	250	
Emissivity of steel	0.7	

Figure 6. FE modeling of SC Wall

- The thermal properties of the materials were applied with reference to the Eurocode.
- The analysis was conducted using the ISO 834 standard fire curve.



(a) Comparison of time-temperature curve



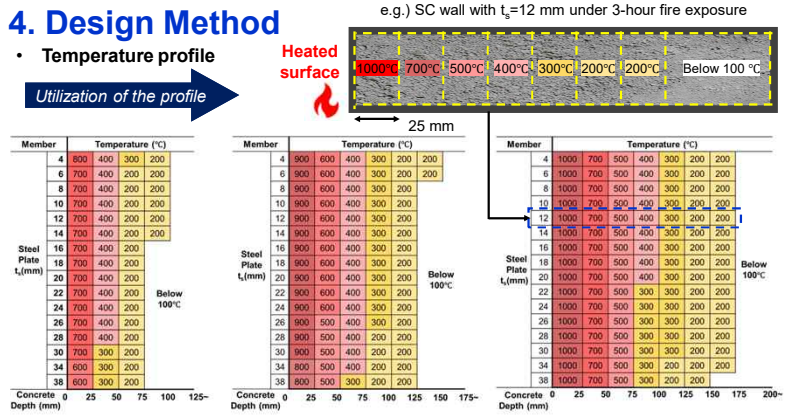
(b) Comparison of temperature distribution

Figure 7. FE model validation by comparing FEA and test results

4. Design Method

- **Temperature profile**

Utilization of the profile



(a) 1-hour fire exposure **(b)** 2-hour fire exposure **(c)** 3-hour fire exposure

Figure 8. Temperature profile

- **Temperature prediction equation**

$$T(x) = \frac{1}{1-\alpha}(T_c - \alpha T_{iso}) + \Delta T_g$$

$$\alpha = \frac{R_c}{{}^1/_{h_o} + R_s + {}^1/_{h_\alpha} + R_c}$$

$$\Delta T_g = \dot{q}(0.2x - 0.5x^2)$$

x = Concrete depth, m
$T(x)$ = Concrete temperature at x, ℃
T_c = Concrete temperature at steel-concrete interface, ℃
T_{iso} = Temperature according to ISO 834 standard fire curve, ℃
ΔT_g = Temperature rise due to heat generation, ℃
$\dot{q}$ = Heat generation per unit volume of concrete, W/m³
R_c = Concrete thermal resistance for conduction, W/m²℃
R_s = Steel thermal resistance for conduction, W/m²℃
h_o = Convection coefficient at the heated surface, W/m²℃
h_α = Thermal resistance at steel-concrete interface, W/m²℃

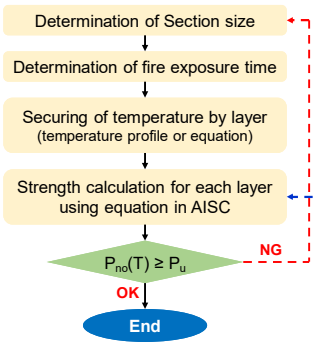


Figure 10. Design process

$$P_{no}(T) = A_s F_y(T) + \sum_{i=layer} 0.85 A_c f_{ck}(T_i)$$

Figure 9. Equation in AISC

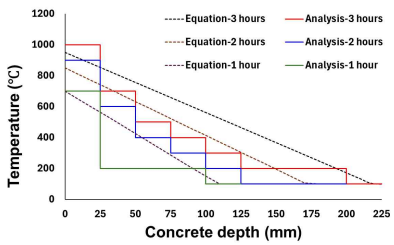


Figure 11. Comparison between the profile and equation

5. Design Example

Table 1. Information of SC wall

Steel-plate thickness	Concrete thickness	Yield stress (steel-plate)	Compressive strength (Concrete)	Fire exposure time
12 mm	300 mm	355 MPa	30 MPa	2-hour

Table 2. Example of strength calculation using AISC equation (Figure. 9)

(a) Temperature profile

List	Layers of material							
	Steel		Concrete					
Depth(mm)	-		0~25	25~50	50~75	75~100	100~125	Over 125
Temperature (℃)	1000	100	900	600	400	300	200	100
P_{no} per layer (N/mm)	170.4	4,260	60	112.5	562.5	637.5	712.5	5250
P_{no} (N/mm)	10856.4							

(b) Temperature prediction equation

List	Layers of material								
	Steel		Concrete						
Depth (mm)	-		0~25	25~50	50~75	75~100	100~125	125~150	150~175	Over 175
Temperature (℃)	1000	100	900	800	700	600	500	400	200	100
P_{no} per layer (N/mm)	170.4	4,260	60	112.5	225	337.5	450	562.5	712.5	3,750
P_{no} (N/mm)	9708.9									

6. Conclusion

- This study proposes a temperature-based structural fire design method for efficient design of SC walls by domestic structural engineers.
- Heat transfer analysis was conducted to obtain the temperature profile of SC wall, and a steady-state thermal resistance model was applied to derive a simplified internal temperature prediction equation.
- Using both two method, strength of fire-exposed SC walls was evaluated and compared, verifying the practical applicability.