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Research on two-dimensional heat transfer characteristic of enclosure structure

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Abstract. The heat transfer characteristic of typical thermal bridge is tested, and numerical simulation is carried out by ANSYS finite element analysis software. The accuracy of two-dimensional heat transfer numerical simulation method is verified through comparative analysis. It can be seen that the temperature simulated values of each measuring point are consistent with the variation trend of the measured values, and the temperature deviations are not more than 10%. This shows that the finite element numerical simulation method can accurately analyze the two-dimensional heat transfer characteristics of the thermal bridge.

1. Introduction

The thermal bridge refers to the part of the wall with high heat flux density, which has higher inner surface temperature in summer and lower inner surface temperature in winter. The area of wall structure affected by thermal bridge accounts for 20%-50% of the total area of wall structure [1]. The thermal bridge of window in frame structure is studied, and the influence of thermal bridge on energy consumption of wall structure is analyzed [2-4]. The calculation method of the thermal bridge is studied, and the accuracy of the two-dimensional heat transfer calculation of the thermal bridge is verified [5-7]. In this paper, the heat transfer characteristic of typical thermal bridge is tested, and numerical simulation is carried out by ANSYS finite element analysis software. The accuracy of two-dimensional heat transfer numerical simulation method is verified through comparative analysis.

2. Two-dimensional heat transfer test

2.1. Test principle

The power of heat transfer is temperature difference. The heat transfer of wall structure goes through three processes: surface heat absorption, wall structure heat transfer and surface heat release. The heat transfer of the specimen was measured by protective hot box method. The principle of protective hot box method is to first establish specific temperature and radiation conditions on both sides of the specimen, and then measure the surface temperature and other parameters on both sides of the specimen. The protective hot box test device consists of a cold box, a metering box, a protective box, a mobile frame, an electric refrigeration system, an electric heating system and a monitoring system. The temperature of protective box and metering box controlled by the monitoring system is basically the same, which can reduce the heat loss of the test system.

The heat flux Q is equal to the difference between the total heat flux of the metering box Q_p and the heat loss of the test system. The heat loss of the test system includes the heat loss through the metering



box Q_1 and the heat loss through the edge of the specimen Q_2 . The heat flux of the specimen Q is expressed as:

$$Q = Q_p - Q_1 - Q_2 \quad (1)$$

Ideally, the temperature inside the metering box is uniform and consistent with that inside the protective box, and the heat transfer coefficient on the surface of the specimen is uniform and consistent. The heat loss through the edge of the specimen Q_2 can be neglected. The heat flux of the specimen Q is expressed as:

$$Q = Q_p - Q_1 \quad (2)$$

2.2. Test design

The design of the specimen and the arrangement of temperature measuring points are shown in Figure 1. The middle of the enclosure structure is reinforced concrete wall, and aerated concrete walls are on both sides. The spacing of measuring points 1-13 in horizontal direction is 50mm, and that of measuring points 7 and 14 in vertical direction is 50mm.

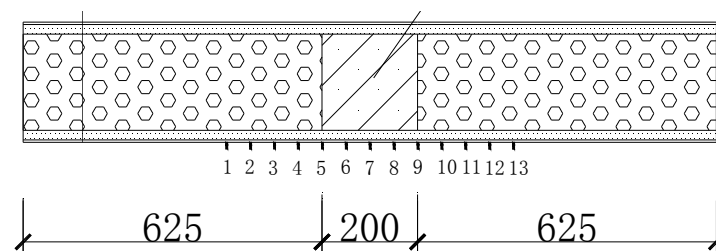


Figure 1. Specimen Design and Temperature Measuring Point Arrangement

2.3. Test results and analysis

During the test, the temperature of the hot chamber is set to 30°C, and the temperature of the cold chamber is set to -10°C. The temperature of each measuring point is recorded every hour. When the temperature of each measuring point tends to be stable, the test ends. The measured values of the surface temperature at the hot side of each measuring point are shown in Table 1.

Table 1. Surface temperature measured at hot side of each measuring point

Measuring point	1	2	3	4	5	6	7
$T_{is}(^{\circ}\text{C})$	22.94	22.92	22.87	22.46	22.05	21.68	21.63
Measuring point	8	9	10	11	12	13	14
$T_{is}(^{\circ}\text{C})$	21.67	22.07	22.44	22.88	22.91	22.93	21.63

From point 1-13, it can be seen that the thermal bridge has a certain influence on the heat transfer in its vicinity in the horizontal direction, while from point 14, the thermal bridge has no influence on the heat transfer in its vicinity in the vertical direction, which verifies that the heat transfer of the thermal bridge can be treated according to two-dimensional heat transfer.

3. Finite element simulation of two-dimensional heat transfer

3.1. Principle of finite element simulation

According to Fourier's law and the first law of heat, the differential equation of heat conduction is established. The differential equation of heat conduction is expressed as equation (3).

$$\rho c \frac{\partial t}{\partial \tau} = \frac{\partial}{\partial x} \left(\lambda \frac{dt}{dx} \right) + \frac{\partial}{\partial y} \left(\lambda \frac{dt}{dy} \right) + \frac{\partial}{\partial z} \left(\lambda \frac{dt}{dz} \right) \quad (3)$$

In the formula, ρ -density (kg/m^3); c -specific heat capacity (kJ/(kgK)); λ -thermal conductivity (W/(mK)); t -temperature variable (K); τ -time variable (s); x, y, z -space variable (m). Specific heat capacity characterizes the heat flux required to absorb or emit when the temperature increases or decreases by 1K.

The heat conduction differential equation is based on the premise that the heat transfer is isotropic and there is no internal heat source. After simplification, the differential equation of heat conduction is expressed as equation (4).

$$\frac{\rho c}{\lambda} \frac{\partial t}{\partial \tau} = \frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2} \quad (4)$$

In steady state heat transfer, the equation is expressed as shown in equation (5).

$$\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2} = 0 \quad (5)$$

When the height of the heat transfer object is greater than 10 times the thickness, the temperature field in the direction of the height of the heat transfer object is constant, and the differential equation of heat conduction is shown in equation (6).

$$\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} = 0 \quad (6)$$

The common boundary conditions are divided into three categories: the first is the temperature of the known heat transfer object surface; the second is the heat flux of the known heat transfer object surface; the third is the temperature around the known heat transfer object and the heat transfer coefficient between the heat transfer object and the surface of the heat transfer object. The boundary conditions in this paper are the third kind of boundary conditions. The boundary conditions of the heat transfer object are shown in expressions (7) and (8).

$$-\lambda \frac{\partial t}{\partial y} \Big|_{y=d} = \alpha_i (t_{f1} - t_1) \quad (7)$$

$$-\lambda \frac{\partial t}{\partial y} \Big|_{y=0} = \alpha_e (t_2 - t_{f2}) \quad (8)$$

In the formula, t -temperature variable (K), y -space variable (m), t_{i1} -indoor ambient temperature (K), t_{i2} -outdoor ambient temperature (K), t_1 -internal surface temperature (K), t_2 -external surface temperature (K), α_i -internal surface heat transfer coefficient (W/(m²K)), α_e -external surface heat transfer coefficient (W/(m²K)), λ -thermal conductivity (W/(mK)), d -thickness (m). Surface heat transfer coefficient characterizes the heat flux through 1m² when the temperature difference between the surface of the heat transfer object and the air nearby is 1K.

3.2. Parameter of finite element simulation

ANSYS is used to model the specimen. The size of the model is the same as that of the specimen. The size of the finite element mesh is 0.02m. The thermal conductivity of aerated concrete block wall, reinforced concrete and cement mortar are 0.24W/(mK), 1.74W/(mK) and 0.93W/(mK), respectively.

3.3. Results and analysis of finite element simulation

The model is simulated by ANSYS. The simulated values of the surface temperature at the hot side of each measuring point are shown in Table 2.

Table 2. Surface temperature simulated at hot side of each measuring point

Measuring point	1	2	3	4	5	6	7
T_{im} (°C)	24.05	24.05	24.01	23.59	23.18	22.83	22.78
Measuring point	8	9	10	11	12	13	14
T_{im} (°C)	22.83	23.18	23.59	24.01	24.05	24.05	22.78

From Table 2, it can be seen that the temperature simulated values of each measuring point are consistent with the variation trend of the measured values, and the temperature deviations are not more than 10%. This shows that the finite element numerical simulation method can accurately analyze the two-dimensional heat transfer characteristics of the thermal bridge. The simulated value of temperature is slightly larger than the measured value, because the thermal conductivity in the simulation is the ideal thermal conductivity. The thermal conductivity of the material in the test is slightly increased due to water absorption and other reasons.

4. Conclusion

The temperature simulated values of each measuring point are consistent with the variation trend of the measured values, and the temperature deviations are not more than 10%. The heat transfer of thermal bridge can be analyzed in terms of two-dimensional heat transfer. The finite element numerical simulation method can accurately analyze the two-dimensional heat transfer characteristics of the thermal bridge.

Acknowledgments

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