Design and Practical Application of the Solar Radiation Simulator

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Abstract: Solar radiation simulator is widely used in many fields such aviation, aerospace, armament, agriculture, auto industry and material. Meanwhile, a lot of analysis and experiments are conducted by many scholars which base on sectional temperature distribution of concrete filled steel tube (CFST) under actual solar radiation effect. Considered that complex analysis results are different from physical conditions and there are many operational difficulties in the complex experiments, a solar radiation simulator of which features can meet the 2-class requirements of solar simulator general specification is designed, and 4 CFST specimens are conducted under unilateral radiation test. The conclusion is that the sectional temperature distribution is well agreed with the analysis results of such simple progress, therefore in order to make up for the shortcomings of complex numerical analysis reliability and experimental operability in the actual situation, the secondary development and design achievements could be conducted basing on it.

Keywords: Solar radiation simulator, Concrete filled steel tube (CFST), Temperature field, Design, Application.

1. Introduction

Solar radiation simulator is widely used in many fields such aviation, aerospace, armament, agriculture, auto industry and material [1-2]. Large solar simulator are built in many foreign countries such as JPLSS15B and GSFC SES in America [3-4], ESTEC in Europe [5], NASA in Japan [6], IABG in German [7], INTESPACE in France [8], BK600/300 in Russia and LSSC in India [9]. At the same time, the operating principal and system design of solar radiation simulator are research by domestic scholars, and simulation and experimental validation on such base are conducted. In view of the difference of thermal performance parameters between two materials of CFST, the actual CFST arch bridge will lead to an irregular temperature distribution by solar radiation effect, and then which work together with other loads will affect its performance. A lot of analysis and experiments are conducted by many domestic scholars which base on sectional temperature distribution and temperature effects of CFST under actual solar radiation effect.

However complex numerical analysis result can be convergent only by a great many of assumptions, which has some difference from the actual situation and can’t reflect actual situation properly, at same time, the analysis results are wanted to guide the experiment and verify analysis results by experiment test, while the sectional sunshine temperature field
testing of CFST is also affected by climatic conditions, and then there are many difficulties in experiment’s maneuverability when considering many factors (solar radiation effect, load, creep and shrinkage of concrete, expansion of concrete) interact together. In this paper, in order to make up for the shortcomings of complex numerical analysis reliability and experimental operability in the actual situation, the secondary development and design achievements could be conducted basing on it. A solar radiation simulator is designed based on the foundation of ref. [10-14], which is not only can meet the requirement of specification [2], but also carry out solar radiation environmental simulation experiment. 4 CFST specimens are conducted by unilateral radiation test, and the feasibility and expansibility can be verified by comparing the analysis results of such simple progress with measured values.

2. Design of Solar Simulator

2.1. Design Scheme

Combining the formulas of solar radiation intensity calculation in ref. [19] with considering the most disadvantage conditions, the radiation intensity of controlled surface is 1120±10 %W/m². Moreover, the choice of light source and design of system is the key to the fabrication of solar radiation simulator, the metal halide lamp is chosen for such test system whose spectrum is close to the sunlight, and the final design of solar radiation simulator in this test is assembled by 20 metal halide lamps (power is 150 W and lampshade is 26×20 cm) with 5 rows and 4 columns according to the design scheme of ref. [14], considering the quantity and arrangement of light source, distance between each lamp, proportion of effective radiation surface, longitudinal cross section size of CFST specimen, power of metal halide lamp in market, shape and size of lampshade. The preliminary design is shown in Fig. 1.

The radiation intensity of measured points under different setting conditions are tested multiple times by changing the radiation distance (L) and vertical distance (S) between lights (in Fig. 2). The intensity test equipment of solar radiation is CMP3 shortwave radiation sensor, and data acquisition equipment is Solrad (METEON 3) hand-held radiation data measuring instrument. At last, the radiation intensity of 10 points in Fig. 1 could be guaranteed in the range between 1008 and 1232 W/m² when the S is 0 mm and L is 20 cm. Therefore, the radiation intensity of representative points within the scope of longitudinal section CFST specimens are completely investigated and tested after ensuring the arrangement and radiation distance of light source of solar radiation simulator(in Fig. 3 and Fig. 4), measured values of 23 points are all in the range between 1008 and 1232 (W/m²). Due to the limit of space, the radiation intensity –time diagram of some points are only listed, which is shown in Fig. 5, while the radiation intensity of the symmetrical points are not the same because the fixed position of the lampshade are not absolutely consistent and the light source is not absolutely parallel to the radiation surface.
2.2. Performance Parameters Measurement

The metal halide lamp will take some time to stable work, so the early period of work should not be used as a reference basis, each measuring point will take 30 min from lamp beginning to end, then, the interval (10~30 min) is only took to examine the unevenness and instability. The maximum value and minimum value of radiation intensity between 23 measured points are 1221 and 1010 W/m² respectively during the interval (10~30 min), according to the specification [2], the unevenness (9.56 %) is less than 10 %, which meets requirements of C-class, at the same time, the instability of the representative points such as 1, 8 and 19 points are 0.7 %, 1 % and 1.2 % respectively, which are less than 2 % and meet requirements of B-class.

3. Practical Application of Solar Simulator

3.1. Experimental Program

4 CFST specimens (Φ219×6×657mm) are fabricated with the expansive agent dosage of 10 %, the arrangement of temperature sensor (PT-100 platinum thermometric resistance) is shown in Fig. 6, and the unilateral radiation test is conducted after 28 days’ standard curing, the temperature data of concrete are tested to ensure its hydration heat release completely during the standard curing. The radiation distance between light source of solar radiation simulator and specimens are adjusted to 20 cm, and a partition is placed between them, the partition is removed after 1 hour that the radiation intensity of solar radiation simulator guarantees currency stability, then the specimen begin to achieve unilateral radiation effect. Effect time takes 8 hours (the maximum temperature difference of CFST section becomes stable), temperature data are automatic gathered by CH301C -16 road recorder controller, the unilateral radiation effect process of 4 CFST specimens is shown in Fig. 7
3.2. Measured Temperature Field Analysis

3.2.1. Measured Value Analysis

Through the continuous observation to temperature data, the temperature variations of 4 specimens are shown in Fig. 8.

The temperature difference between day-side and night-side of 4 specimens vary very small after 300 min effect, and they are 19 °C ± 1 °C; the 5 measured points’ temperature variations of 4 specimens all show an upward trend under unilateral radiation effect, but the magnitude of rising are not the same, from the temperature difference – time curves, the temperature of each point continue to rise under unilateral radiation effect, the maximum negative temperature difference between measured points B and A of each specimen are reached when the effect affects for 100 min, that is, the temperature of B point reaches the minimum temperature at this time, then, the temperature of each point continues to increase with the increase of effect time, the temperature of B point is equal to its of A point when the effect affects for 250 min, at last, the positive temperature difference between measured points B and A of each specimen continues to increase with the increase of effect time.

3.2.2. Comparison Analysis Between Theoretical and Measured Value

The testing process is analyzed by the finite element analysis method of heat conduction through literature [18], where $q_e$ is 1120 W/m², and the comparison diagram between analysis results and measured average results is shown in Fig. 9.

Fig. 7. Experiment set-up.

(a) T-t and $\Delta t$-t of No.1 specimen.

(b) T-t and $\Delta t$-t of No.2 specimen.

(c) T-t and $\Delta t$-t of No.3 specimen.

(d) T-t and $\Delta t$-t of No.4 specimen.

Fig. 8. T-t and $\Delta t$-t variation diagram of four specimens.
change rate of E curve has the decreasing tendency, which does not affect the all analysis.

4. Conclusion

This paper is based on the design, fabrication, test and examination of the solar radiation simulator, which is also adopted in the unilateral radiation test of 4 CFST specimens. The following conclusions are drawn based on the work described in this paper:

1) The radiation intensity of solar simulator within the effective radiation scope is in the range of 1008 and 1232 (W/m²) when the radiation distance is 20 cm, and the unevenness and instability meet the C-class and B-class of General specification for solar simulator respectively, even basing on the above reference, the simulator which meet many actual requirements can be designed by changing the radiation distance and effective radiation scope.

2) The temperature change of CFST section under unilateral radiation effect is well agreed with numerical analysis results, which illustrates the feasibility and reliability of such design scheme, at the same time, in order to make up for the shortcomings of complex numerical analysis reliability and experimental operability in the actual situation, the secondary development and design achievements (which could achieve the environmental simulation of phenomenon that the sun rises in the east and sets in the west) could be conducted basing on it.

Acknowledgments

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References

[8]. Toulouse Laboratory. Description Notice of SIMLES Space Simulation Chamber, SOPEMEA, 1979, pp. 4-7.


