Performance-based fire protection design of ruins protection pavilion based on air-supported membrane structure

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Abstract

At present, air-supported membrane structure is widely applied in the large span space buildings. The stability of air-supported membrane structure and main function of building lead to fire protection design of buildings becomes special and difficult. In this paper, an air-supported membrane structure ruins protection pavilion in Chinese is taken for representative example to analyse the feasibility of fire protection design and propose corresponding solutions of performance-based fire protection. By means of combustion experiment and numerical simulation, carry out fire risk analysis of air-supported membrane structure, smoke spread process and safe evacuation analysis in fire scenes. The results show that, personnel safe evacuation can achieve before the dangerous coming time. It verifies that on the premise of enhancing effective protection of fire protection systems and equipment, the ruins protection pavilion can reach the same safe level that required by the code. That is to say, existing fire protection design is feasible. Both performance-based fire protection design and membrane architecture are more widely applied to the special building, as a result, lots of problems needed to be solved. For this purpose, we hope to provide some reference for related engineering and technical personnel.

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Keywords: Performance-based fire protection design; Ruins protection pavilion; Air-supported membrane structure; Combustion characteristics experiment; Numerical simulation

1. Introduction

1.1. Project overview

A ruins protection pavilion with single layer, whose height is 25.50 m, and building area is 9772.13 m². The main function of the building is protecting ruins and exhibiting. The foundation of the shed use reinforced concrete structure, and the upper adopt air-supported membrane structure, while its fire resistance rating is Two. The fire protection systems and equipment installed in the ruins protection pavilion contains outdoor fire hydrant system and fire extinguisher, except for indoor fire hydrant system, automatic fire extinguishing system, smoke control and smoke exhaust system, and automatic fire alarm system.

The ancient cultural ruins were dug within the ruins protectorate. Around it, there is a passageway whose width is 7.00 m for visitors to walk, 10 emergency exits (M1 to M10) whose respective width is 1.30 m for evacuation. Figure 1 shows the planar graph of the ruins protection pavilion.

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1.2. Air-supported membrane introduction

In order to protect the ruins to the greatest extent, the ruins protection pavilion is formed by air-supported membrane structure.

![Fig. 1. Planar graph of the ruins protection pavilion](image)

Air-supported membrane structure is a new kind of spatial structure that was researched and developed rapidly since the 1970s. It has better mechanical performance and certain rigidity because of bearing tension only. Besides, it has advantages of light weight, various stable shape, short construction period, convenient maintenance, low cost, even being prone to fit nature. As a consequence, it has been named ‘the 21st century architecture’ in the international architects.

Air-supported membrane structure is a kind of modern building structure that attracts more attention [1]. Good fabric is used as its material. Membrane surface is supported by intramembrane air pressure or tightens with flexible steel wire rope and rigid support structure through the transfer of force on bending inner face. Therefore, structure system with certain stiffness and tension that fit for cover large span space forms.

2. The problems needed to be demonstrated

2.1. Fire risk of air-supported membrane structure

Air-supported membrane structure is a kind of modern building structure that has many advantages, however, fire risk analysis is one of the key technologies to the structure.

- Membrane material combustion characteristics: By the membrane material combustion characteristics experiment, observe dynamic phenomena of material combustion and obtain performance parameters and the critical burning temperature. Figure 2 are phenomena of membrane material combustion characteristics experiment. This kind of material belongs to flame retardant material, but its surface shrinks and tightens and it becomes thinner after being heated. The heated samples will melt at certain temperature. Membrane material will burn and generate a mass of heat smoke when exceeding the critical burning temperature, which endanger the whole structure stability and the safety of evacuation [2].

- Fire risk of whole structure: Although project adopts air-supported membrane structure, and chooses membrane material #8028 as retaining structure, related information about air-supported membrane usage in domestic ruins protection pavilion and experiment data on a large scale is scarce. When encountering fire attack, the internal gas between surfaces will leak via holes so that surfaces will cling each other. Since fire in the bottom may lead to a vertical spread, the
temperature near to the vertical material is still high. For this reason, the vertical retaining structure has a bigger danger than the top one.

Fig. 2. Phenomena of membrane material combustion characteristics experiment.

2.2. Difficulties of fire design

And the main fire design problem in this project include:

- Fire resistance rating of building: The ruins protection pavilion belongs to a class of important public buildings, whose required fire resistance rating is Two. While, codes and standards present are lacking in fire protection measures and strategies on air-supported membrane structure. In consideration of that, whether fire resistance rating of this class building reaches Two or not is worthy of discussing and studing.

- The area of fire compartment: As an exhibition hall without automatic fire extinguishing system and automatic fire alarm system, ruins protection pavilion’s maximum allowable area of one fire compartment is defined 2500.00 m\(^2\) according as article 5.3.1 and 5.3.4 of *Code for fire protection design of building* (GB 50016-2014) [3]. Now the fire compartment is divided only one with 9772.13 m\(^2\) so that it can’t conform to the requirement of code. But in view of unique form of architecture, single function, ventilation and fire load of the air-supported membrane ruins protection pavilion, rationality and feasibility of current fire compartment is worthy of discussing and studing.

3. Feasibility analysis and solution of fire protection design

3.1. Feasibility analysis and solution of applying air-supported membrane structure

- Application of air-supported membrane structure: Air-supported membrane structure is a kind of modern building structure that has a wide range of applications in large span structure, such as stadiums, shopping malls, exhibition centers, etc [4]. In recent years, The Beijing National Aquatics Center (or known as the Water Cube) is obviously a specialized application deepened from air-supported membrane structure in Olympic Stadium, see Figure 3.

Fig. 3. The Beijing National Aquatics Center (or known as the Water Cube)

- Basic information of the membrane material: The material chosen to applied to the ruins protection pavilion is membrane material #8028, with an appearance of white plate products and a thickness of 0.8mm. Its internal material is warp knitted polyester fiber base cloth. Surface coating uses PVC material with plasticizer, vinyl fluorine-containing polymer,
folpet and flame retardant, etc. Flame resistance meets California fire marshal requirements, UL214, NFPA 701 and ASTM D6413-2 second flameout, ASTM E84-flame spread index<25, smoke development rating<450, ASCE 17-96. B. Tested by National Center for Quality Supervision and Testing of Fire Building Materials, the toxicity of its smoke is grade ZA1 and the combustion performance reaches grade B of Classification for burning behavior of building materials and products (GB 8624-2006) [5], equal to grade B1 of Classification for burning behavior of building materials and products (GB 8624-2012) [6]. Currently, this material has been successfully applied to many projects such as large coal storage shed and service center.

- Air-supported membrane material combustion characteristics experiment: We finish ignition experiment about membrane material #8028 to inspect samples’ spread ability of flame in actual fire, and the trend of melting and dropping phenomenon after heated. After ignition, following experimental phenomena will be obtained:
  1) The heated samples will melt at 260°C, burn at the critical temperature 395.5 to 407.6°C conservatively.
  2) With approaching melting temperature, softening and pyrolysis of the material occurs by thermal effect of the flame, and burning holes appear on the surface. To some extent, burning holes will be ventilation holes.
  3) As this membrane material is thin and light, more scattered fragments will be taken away by hot smoke rather than fall on the ground.
  4) The material will burn away if in continuous fire effect. While the ignited membrane material doesn’t continue to burn and spread, but self-extinguish after leaving the fire. Combustion products exist in certain viscous state, not entirely in combustion state of thermosetting material.
  5) No obvious melting and dropping phenomenon appears in the experimental process, but thick black smoke emerges in 600s.

Figure 4 are results of membrane material combustion characteristics experiment.

(a) long limb before the experiment  (b) short limb before the experiment  (c) long limb after the experiment  (d) short limb after the experiment

Fig. 4. Results of membrane material combustion characteristics experiment.

- Safety analysis of Structural fire protection: The basis of safety analysis of Structural fire protection in this building is: the vertical retaining structure will not burn and spread. According to results of above experiment, molten melt drops are generated none by the heated membrane material in the experimental process. Even if generated, drops from upper membrane structure will cool soon on their way down. Therefore, result manifests that material will not propagate flame and spread fire in the whole structure, which is relatively safe.

- The effectiveness of smoke storage in air-supported membrane structure: air-supported membrane material applied in this building is theoretically feasible in terms of building function and volume. Besides, the fluence of ceiling effect on smoke flow conditions, heat smoke effect on structure stability and integrity, as well as other unforeseen circumstances is considerable. So we will set fire scenes to analyse the fluence of material effect on structural instability time (SIT) in fire, so as to verify the effectiveness of smoke storage in this air-supported membrane structure, to ensure the feasibility of applying air-supported membrane material in whole pavilion finally.

3.2. Feasibility analysis and solution of enlarging the area of fire compartment

Enlarging the area of fire compartment will exert an effect on the required safe evacuation time (RSET) by changing the number of evacuees and evacuation distance. Consequently, comparing the result of the required safe evacuation time (RSET) and the available safe evacuation time (ASET) by simulation of software FDS and Pathfinder, judge the feasibility
of enlarging the area of fire compartment.

Finally, availability and rationality of fire control strategy of the ruins protection pavilion using air-supported membrane structure can be demonstrated via contrasting ASET, SIT and RSET.

4. Safety objectives and analysis method

Obviously, overall objectives of fire protection design should be safety objectives. Based on the building function, regional effect and crowd of the building, the subdivision of such basic objectives may result in underlying particular objectives:
- satisfying personal life safety (as the chief objective) and ensuring safe personal evacuation to outdoors upon fire occurrence;
- protecting ruins.

In performance-based fire protection design, by availing principles and methods in fire protection safety engineering and in accordance with particular conditions in a building’s structure, functional purposes and its internal flammables, numerical simulation is used in quantitative analysis and evaluation of fire risk in a building, in order to obtain an optimum fire design plan and thereby provide the most reasonable fire protection for the building. In the end, the performance-based fire protection design method is required to argue whether the proposed fire protection design can come true the above-mentioned objectives or reach the same safe level that required by the code[7-8]. Furthermore, perhaps it needs making some necessary modifications or adjustments and proposing corresponding suggestions.

5. Design fire scenes

5.1. The analysis of the fire hazard source and heat release rate

The building belongs to public gathering places, so a dense crowd is fail to evacuate possibly when it is open. However, less flammable materials are in the ruins protection pavilion. The main fire load is the solid combustibles carried by visitors, and the heat release rate can be set 2.00 MW. Heat release rate of car fire in the garage can be set 5.00 MW. Meanwhile, the building belongs to large space buildings, so the fire in the inner space could develop rapidly, seen as a fuel control fire.

5.2. The setting of the fire source locations and fire scenes

In order to design fire scenes, setting fire source locations by the spatial geometry character and fire risk of the building firstly. Mainly investigating the fire scale, smoke storage effectiveness of the air-supported membrane building, distribution of evacuation passageway and exit, as well as the most disadvantage influence of fire applied to safe evacuation, five representative fire source locations are set in the following typical positions in this paper, as shown in Figure 5 [9].

![Fig. 5. Schematic diagram of fire source locations](image)
Design a respective fire scene for each fire source location in the air-support membrane ruins protection pavilion. Total fire locations and fire scenes are showed in Table 1.

Table 1. Total fire locations and fire scenes

<table>
<thead>
<tr>
<th>Fire scene</th>
<th>Fire source location</th>
<th>Fire area</th>
<th>Fire position</th>
<th>Fire type</th>
<th>Heat release rate (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>ruins protectorate</td>
<td>center of ruins protectorate</td>
<td>solid combustibles fire</td>
<td>2.00</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>surrounding</td>
<td>passageway between M4 and M5</td>
<td>solid combustibles fire</td>
<td>2.00</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>passageway</td>
<td>passageway between M6 and M7</td>
<td>solid combustibles fire</td>
<td>2.00</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>garage</td>
<td>western passageway of M10</td>
<td>solid combustibles fire</td>
<td>2.00</td>
</tr>
<tr>
<td>5</td>
<td>E</td>
<td>garage (near M1)</td>
<td></td>
<td>car fire</td>
<td>5.00</td>
</tr>
</tbody>
</table>

6. Prediction of smoke spread process

6.1. Criteria of personnel safety

- Building structure is a direct restriction to the personnel safety. Only if building structure keep stability and integrity in the fire, people can evacuate safely and orderly. Expounded in air-supported membrane material combustion characteristic experiment, the melting temperature for heated membrane material is 260°C, and the critical burning temperature is 395.5 to 407.6°C conservatively. In order to ensure that air-supported membrane material doesn’t destroyed by heat smoke, we identify the performance criterion of simulation of structural instability time (SIT) managed by $T_{SIT}$, is: the highest temperature of smoke in space (e.g., ceiling) is lower than the melting temperature of air-supported membrane material (260°C).

- When fire occurring, the personnel’s safety effected by resilient fire environment measured by a series of performance parameters, including heat transfer, toxicity, visibility, etc. As long as there is a parameter can’t accord with quantitative judgment standard, the environment is harm to personnel’s safety. The following performance parameters are determined as the personnel safety criteria with reference to the data from SFPE Handbook of Fire Protection Engineering and Fire Protection Engineers Guide (Australia), etc [10-13]. Considering of the safe margin, adopted value in this paper are listed in Table 2.

<table>
<thead>
<tr>
<th>Performance parameter</th>
<th>Limiting value</th>
<th>Adopted value in this paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of smoke layer above ground (m)</td>
<td>&gt;1.5</td>
<td>≥2.1</td>
</tr>
<tr>
<td>Temperature of air layer below the height 2.1m (°C)</td>
<td>&lt;65</td>
<td>≤60</td>
</tr>
<tr>
<td>Carbon monoxide concentration of air layer below the height 2.1m (ppm)</td>
<td>&lt;1000</td>
<td>≤500</td>
</tr>
<tr>
<td>Visibility of air layer below the height 2.1m (m)</td>
<td>&gt;10</td>
<td>≥10</td>
</tr>
</tbody>
</table>

6.2. Physical model and Parameter design

The simulation software FDS is utilized to research fire and smoke spread of the air-supported membrane ruins protection pavilion. Because only rectangular model can be built in FDS, we use line instead of arc to approximately solve the circular arc model (e.g., arc wall) in this building. Full-scale fire field model of air-support membrane ruins protection pavilion is built in software FDS, effect diagram of model is showed in Figure 6.

Fig. 6. Effect diagram of model
Following assumptions are taken for simulative calculation of a smoke flow by availing FDS:

- Building model: modeling based on the building actual size;
- Environmental conditions: initial temperature is 20 °C, initial wind velocity is 0 m/s;
- Fire source locations: set fire source locations A to E corresponding to Fire scene 1 to 5;
- Fire sizes: solid combustibles fire is 2.00 MW; car fire is 5.00 MW;
- Simulated time: 1200 s (This paper holds that the firefighters begin to control fire in 1200 s).

### 6.3. Simulation results of available safe evacuation time (TASET) and structural instability time (TSIT)

Using FDS, a version of field model software, to simulate smoke spread process in different fire scenes. The result shows that the highest temperature of smoke in space (e.g., ceiling) is lower than the melting temperature of air-supported membrane material (260°C) in 1200s. So it is ensured that air-supported membrane material doesn’t destroyed by heat smoke, and building structure can keep stability and integrity in the fire. Even if air-supported membrane structure collapse accidently, roof will fall off slowly, and the time of falling off to height 2.1m above the ground exceeds 30min. In order to ensure safe evacuation, by considering of the safe margin, we set $T_{SIT} \leq 20$min.

In addition to the highest temperature of range which is away from M10 in Fire scene 4 and M1 in Fire scene 5, the highest temperature of other ranges in other fire scenes is lower than setting danger temperature 60°C. In every fire scene, the time of each performance parameter reaching adopted limiting value at clear height around safety exits, and the simulation results of available safe evacuation time ($T_{ASET}$) are listed in Table 3.

<table>
<thead>
<tr>
<th>Fire scene</th>
<th>Fire source location</th>
<th>The time of temperature reaching 60°C (s)</th>
<th>The time of carbon monoxide concentration reaching 500ppm (s)</th>
<th>The time of visibility reaching 10m (s)</th>
<th>$T_{ASET}$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>1057</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>1057</td>
</tr>
<tr>
<td>5</td>
<td>E</td>
<td>697</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>697</td>
</tr>
</tbody>
</table>

### 7. Analysis of safe evacuation

#### 7.1. Purpose and criteria of analysis of safe evacuation

The purpose of analysis of safe evacuation is to judge the safety of process of evacuation through simulating the required safe evacuation time ($T_{RSET}$), the available safe evacuation time ($T_{ASET}$), the structural instability time ($T_{SIT}$) and contrasting them. To achieve functional goals of safe evacuation, evacuation design should meet the following criteria simultaneously: 1) $T_{ASET} > T_{RSET}$; 2) $T_{SIT} > T_{RSET}$ [2].

#### 7.2. The setting of the parameters and evacuation scenes

According to the main function of the ruins protection pavement and the data provided by the project, visitors will not be allowed to enter into the inner beyond 1000 in the meantime. Considering the working staffs, the number of crowd is 1100. Due to the difference of the ruins protection pavement and other public gathering places, we increase personnel proportion of the old and children. In this paper, we has summarized the personnel evacuation speed systematically: finding the data of Human dimensions of Chinese and adding them to evacuation simulation software.

Combined with the fire scenes in this paper, evacuation scenes are designed as shown in Table 4.

<table>
<thead>
<tr>
<th>Evacuation scene</th>
<th>Fire source location</th>
<th>Fire area</th>
<th>Fire position</th>
<th>Fault points of evacuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>ruins protectorate</td>
<td>center of ruins protectorate</td>
<td>surrounding passageway is available</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>surrounding</td>
<td>passageway between M4 and M5</td>
<td>passageway between M4 and M5 fails</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>passageway</td>
<td>passageway between M6 and M7</td>
<td>passageway between M6 and M7 fails</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>western passageway of M10</td>
<td>western passageway and M10 fails</td>
<td></td>
</tr>
</tbody>
</table>
7.3. Calculation of required safe evacuation time ($T_{RSET}$)

Due to the uncertain factors which are against the evacuation when evacuating practically it is necessary to consider a safe margin to the evacuating time. Factor 1.5 is selected in this article. The calculation formula of required safe evacuation time ($T_{RSET}$) for all people can be expressed as Formula (1).

$$T_{RSET} = T_A + T_R + 1.5 \times T_M$$

Where, $T_{RSET}$ is required safe evacuation time (s); $T_A$ is alarm time (s); $T_R$ is response time (s); $T_M$ is move time (s).

Because the space are spacious and vision is open, people can find fire immediately, we set $T_A$ as 60s, $T_R$ as 120s, set $T_M$ by forecast and analysis from evacuation simulation software Pathfinder. Adding personnel characteristics and evacuation behavior to importing FDS model, we can get different $T_M$ corresponding to five fire scenes.

Evacuation model of the ruins protection pavilion set by software Pathfinder is as shown in Figure 7, and the evacuation process of Fire scene 5 ($T=0$), for example, is showed in Figure 8.

![Evacuation model of the ruins protection pavilion set by software Pathfinder](image1)

Fig. 7. Evacuation model of the ruins protection pavilion set by software Pathfinder

![Evacuation process diagram of Fire scene 5 ($T=0$)](image2)

Fig. 8. Evacuation process diagram of Fire scene 5 ($T=0$)

7.4. Results of evacuation analysis

After required safe evacuation time is compared with available safe evacuation time and structural instability time, we can get the judgement of evacuation safety in different fire scenes. The judgement results can be shown in Table 5.

<table>
<thead>
<tr>
<th>Fire scene</th>
<th>Fire source location</th>
<th>Fire area</th>
<th>Fire position</th>
<th>$T_{ASET}$ (s)</th>
<th>$T_{SIT}$ (s)</th>
<th>$T_{RSET}$ (s)</th>
<th>Evacuation safety judgment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>ruins protectorate</td>
<td>center of ruins protectorate</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>268</td>
<td>Safe</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>surrounding</td>
<td>passageway between M4 and M5</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>268</td>
<td>Safe</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>passageway</td>
<td>passageway between M6 and M7</td>
<td>&gt;1200</td>
<td>&gt;1200</td>
<td>292</td>
<td>Safe</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>western passageway of M10</td>
<td>1057</td>
<td>&gt;1200</td>
<td>300</td>
<td>Safe</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>E</td>
<td>garage</td>
<td>garage (near M1)</td>
<td>697</td>
<td>&gt;1200</td>
<td>291</td>
<td>Safe</td>
</tr>
</tbody>
</table>
According to the result of evacuation simulation and calculation, it can be seen that the required safe evacuation time of the air-supported membrane ruins protection pavilion is 300 s, and is shorter than both the available safe evacuation time and the structural instability time. It is believed that existing evacuation design can meet the requirements of safe evacuation.

Nevertheless, smaller safe allowance and bigger fire hazard can be found in Fire scene 4 and 5 than any other contemplated fire scene by means of comparing the delta-T respectively. It can be speculated that M10 and M1 are most unfavorable and important sites, which are prone to cause serious accidents. In consequence, we need to pay more attention during the daily safety check for eliminating fire hazard and prevent fire from happening\cite{14}.

8. Conclusion

Through the above analysis, including fire risk analysis of air-supported membrane structure, smoke spread process and safe evacuation analysis in fire scenes, conclusion can be made by the engineering applications of air-supported membrane ruins protection pavilion, as well as computer simulation:

- From the membrane material combustion characteristics experiment, temperature for the heated membrane material to melt at 260°C. It is presumed that once the surface temperature of membrane structure exceeds 260°C, holes will appear on the surface, and the structure loses stability. Later, material burns at the critical temperature 395.5 to 407.6°C. While the ignited membrane material doesn’t continue to burn and spread, but self-extinguish after leaving the fire. Moreover, no obvious melting and dropping phenomenon appears in the experimental process, but thick black smoke emerges in 600s. Even if molten melt drops are generated, drops from upper membrane structure will cool soon on their way down. Upon the feasibility analysis of applying air-supported membrane material in whole pavilion, we also set fire scenes to verify the effectiveness of smoke storage and structural stability in this air-supported membrane structure, concluding that its safety can achieve equivalent fire protection safety level required by codes.
- Safe evacuation analysis of air-supported membrane ruins protection pavilion manifests that, the required safe evacuation time is shorter than both the available safe evacuation time and the structural instability time, and it is believed that existing design can meet the requirements of safe evacuation. In other words, enlarging fire compartment area will not affect personal safety evacuation.
- It can be speculated that M10 and M1 are most unfavorable and important sites, which are prone to cause serious accidents. In consequence, we need to pay more attention during the daily safety check for eliminating fire hazard and prevent fire from happening. In conclusion, on the premise of enhancing effective protection of fire protection systems and equipment, the ruins protection pavilion can reach the same safe level that required by the code. That is to say, existing fire protection design is feasible.
- As time goes by, performance-based fire protection design is more widely applied to the special building. Through scientific measurement and reasonable analysis to verify building fire protection design, reduce the effects of fire, ensure personal and property safety, and enhance economic and social benefits, which is extremely important.

References

[5] Classification for burning behavior of building materials and products (GB 8624-2006)
[6] Classification for burning behavior of building materials and products (GB 8624-2012)