A Preliminary Study on the Comprehensive Evaluation of the Disaster Prevention System of Large Urban Underground Space

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Abstract. The original urban planning can never meet the requirements of the rapid development and the increasing population in big cities in China. The best way to solve this problem is to develop the underground space (including tunnels). With the exhaustion and saturation of the shallow underground space, the development of urban area is more and more relying on the excavation of deep underground space. Nowadays, the advanced technology of high strength concrete, excavation method in soft soil and ground deformation control make it possible to build underground space with a larger scale, span length and depth. The common disasters and hazards that large urban underground space faces are the same as that of ordinary underground space, but considering the damage and the rescue difficulties, more attention should be paid to the influence of disasters on large underground space. The study and research on the evaluation of the disaster prevention system of underground space still have not raised enough attention yet. The Comprehensive Evaluation of the disaster prevention system is set up based on the study of the characteristics of large underground space itself and disaster effects. The evaluation of the prevention of fire, flood, earthquake and attack are discussed. This is a preliminary study of the future disaster management and emergency rescue of urban underground space.

Keywords. underground space, disaster characteristics, disaster prevention, comprehensive Evaluation

1. Introduction

Urban underground space has been explored and used as basement, passageway, metro tunnel and parking garage for a long time. The development of relatively shallow underground space is the primary stage, during which the mentioned underground structures are relatively small in scale, span length and depth. People usually go into these places only for passing by, they don’t like to stay in this kind of underground space.

Nowadays, the advanced technology makes it possible to build underground structures with a larger size and more comfortable environment such as ventilation and lighting. Generally, large urban underground space should meet the index shown in table 1. They are now used as restaurant, theatre and shopping center. People can stay in these places for a period and really enjoy the time. Just as each coin has two side, disasters in these large underground space will then course even larger loss and danger in human lives. It is very important to evaluate the disaster prevention design of each large underground structure.

Table 1 The index of large urban underground space

<table>
<thead>
<tr>
<th>Index</th>
<th>Clear height</th>
<th>Span length</th>
<th>Building area</th>
<th>Area of a single room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>&gt;5m</td>
<td>&gt;12m</td>
<td>&gt;15000m²</td>
<td>Larger than the maximum area of a fire compartment</td>
</tr>
</tbody>
</table>
2. Characteristics of disasters in large underground space

Common disasters in large underground space are fire, flood, earthquake and attack, similar to those in ordinary underground space, but the characteristics of these disasters are definitely different.

2.1. Fire in large underground space

Fire can spread very fast because of the large span length and adequate air (Prochazka et al, 2011). High temperature will also make the flue gas spread full of the space. It is more difficult for fire fighters to reach the fire origin in large underground space, shown in Figure 1. The usual evacuation mode of people is attempt, failure and attempt. It is relative easier for people to find the right way out in ordinary underground space. Group effect is harder to predict in large and deep underground space. Since there is a long way to go from the center to the exit, it is rather difficult to discriminate the right direction under the fire situation and the flue gas. Most victims are killed by toxic gas in fire, so there is more risk in human lives and property when fire breaks out in large underground space. Last but not least, stampede casualties may be caused during evacuation.

2.2. Flood in large underground space

Flood may cause water accumulation at the bottom layer of the underground structure (Ishikawa et al, 2002). For ordinary underground space, the water level is shallower and usually will not bring about huge losses. For large underground space which has 5~6 layers, water from all directions and upper layers will accumulate at the bottom layer and the water level may exceed the height of an adult. Thus, it is danger for people and equipment at the bottom part of the underground structure. The difficulty of drainage in deep underground space is also higher.

2.3. Earthquake in large underground space

The seismic performance of underground structure is much better than structure above ground, owing to the consistency of the structure. This does not simply mean that underground structure will not be destructed in earthquake. Severe damage could happen because the inconsistency of large underground space (Hu et al, 2005). Compared with fire and flood, it is more difficult to repair the large underground structure after earthquake destruction.

2.4. Attack in large underground space

Ordinary underground basement usually is not the attacking target during war or in terrorist attack because of the large quantity, small scale and less people in it. Large urban underground space such like underground shopping mall and theatre usually accommodate a great number of people. These places are more possible to be chosen as the attacking target because the consequences and social influence are greater (Shen et al, 2013). The air defense structure or shelter affiliated to large underground space should has solidity and be detected regularly.

3. Current research and key problem

Current scientific research and study usually focus on one theme of underground disaster. Fire, flood and earthquake are separately studied and prevented in different design document or scientific report (Vetter et al, 2012). However, disaster prevention is definitely a comprehensive project and these disasters should be studied together. A preliminary study on the comprehensive evaluation of the disaster prevention system is established in this paper to
set up a standard rudiment for the evaluation of the disaster prevention design of large underground spaces. Considering the length of this paper, the frame structure of the evaluation system is introduced with several typical detailed rules. The majority of the detailed rules and the evaluation process are not presented here.

4. Comprehensive Evaluation of the disaster prevention system

Fuzzy evaluation method, multivariate statistical evaluation method, and analytic hierarchy process method are the most common methods in the evaluation of a comprehensive system (Yang et al., 2012; Vieira et al., 2012; Ennaceur et al., 2014). For the disaster prevention of large urban underground space, analytic hierarchy process method is more suitable according to the frame structure of the system. The process of analytic hierarchy process method is shown in table 2.

With analytic hierarchy process method, the first order of the evaluation system is shown in Figure 2.

Table.2 Steps of analytic hierarchy process method

<table>
<thead>
<tr>
<th>Step</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Set up the analysis model and its hierarchy</td>
</tr>
<tr>
<td>2</td>
<td>Determination of weight vector</td>
</tr>
<tr>
<td>3</td>
<td>Analyze each hierarchy</td>
</tr>
</tbody>
</table>

The evaluation degree of the disaster prevention system is calculated with the degree and score of the four parts,

$$M = \sum_{i=1}^{4} \alpha_i K_i$$  \hspace{1cm} (1)

Where, $M$ is the final score of the comprehensive disaster prevention system. $K_i$ is the score of fire prevention, flood prevention, earthquake prevention and attack prevention, $i = 1,2,3,4$. $\alpha_i$ is the weight vector of the four parts. The maximum score of each part is 100, and the qualified score is 60. The evaluation is stopped if any of the four parts is unqualified. Corresponding prevention design should be revised immediately. Function (1) is calculated if all the four parts are qualified and the final degree of the comprehensive disaster prevention system is shown in table 3.

Table 3. Final degree of the comprehensive disaster prevention system

<table>
<thead>
<tr>
<th>Degree</th>
<th>Score</th>
<th>Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>85-95</td>
<td>No need</td>
</tr>
<tr>
<td>B</td>
<td>75-85</td>
<td>Probably</td>
</tr>
<tr>
<td>C</td>
<td>60-75</td>
<td>Need</td>
</tr>
</tbody>
</table>

Each part is evaluated according to the sub-items as follows.

4.1. Evaluation of fire prevention

Fire prevention is the most important part of the first order. The second evaluation order in this part is shown in table 4, where $K_{ij}$ is the score of each sub-item, thus

$$K_i = \sum_{j=1}^{8} \alpha_{ij} K_{ij}$$  \hspace{1cm} (2)

Where, $\alpha_{ij}$ is the weight vector of the sub-items, $i = 1,2,...,8$.  

![Figure 2. First order of disaster prevention system](image)
Architecture of large underground space is the key influence factor to the spread of the fire. The evaluation content of architecture includes the inside layout, fire resistance rating and structure of the underground building. The detailed rules of the evaluation content are collected from current standards, papers and researches. $K_{1j}$ is decided by how much percent the disaster prevention design meet the detailed rules.

Signals are critical in the evacuation when fire breaks out (Jung et al, 2010). Flue gas usually spread along the ceiling of the room and staircase, so the signals should be placed at the lower part of the wall. Considering the chaos in fire, voice prompt is needed at key positions and the volume should be high and clear enough for people to hear.

The development of computer science has made it possible to set up a 3d model of the underground space before construction (Nguyen et al, 2013). With the building information modeling, fire and evacuation simulation can be carried out to check the rationality of the design, see Figures 3 and 4. The score of $K_{15}$ can be evaluated with the simulation results.

Fire risk assessment is also an important component of the evaluation, because the consequences and property losses are calculated. Some additional score can be added if there are some new material and techniques used in fire control.

### 4.2. Evaluation of flood prevention

The second evaluation order in flood prevention is shown in table 5. Natural condition refers to the location of the entrance of the underground building. Sometimes people’s fondness is prior to terrain rationality in the location of the entrance. Low-lying entrance makes it easy for rain and ground water to poured into the underground space. Waterproof means the function in ground water and soil water resistance, so the entrance and the seepage performance of the main structure are the emphasis of evaluation. On the other hand, a well designed water culvert under the main structure can reduce the water quantity at the entrance and prevent the bottom part from soaking (Figure 5).

<table>
<thead>
<tr>
<th>Natural condition</th>
<th>Waterproof</th>
<th>Drainage</th>
<th>Rescue and evacuation</th>
<th>Risk assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood prevention</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Evacuation simulation of large urban underground space

Figure 5. Water culvert under the main structure
4.3. Evaluation of earthquake prevention

The second evaluation order in earthquake prevention is shown in table 6. Natural condition here refers to the seismic zone of the underground structure. Considering fire and flood prevention, electric cables and water pipe should not be embedded in the weak part where is easy to be broken when earthquake occurs. Thus, the secondary disasters such as leakage and fire can be avoided.

<table>
<thead>
<tr>
<th>Earthquake prevention</th>
<th>Natural condition</th>
<th>Seismic reliability</th>
<th>Rescue and evacuation</th>
<th>Risk assessment</th>
</tr>
</thead>
</table>

4.4. Evaluation of attack prevention

Usually air defense structure and shelters are divided into some independent protective unit. The main evaluation aspects are the strength, rigidity and durability of the structure of each unit.

5. Different between road tunnel and typical large underground space

Underground shopping center is a typical kind of large urban underground space which usually compose 2–3 floors of commercial shops and 2–3 floors of parking garage. The scale of an underground shopping center is limited no matter it is a polygon or a round area. The former evaluation system can be applied to it directly. Road tunnel is quite different from underground shopping center, the length of a road tunnel is extremely larger than the diameter. The evaluation system also should be modified when applied to a road tunnel (Kazaras et al, 2014).

5.1. Difference in fire prevention

Most of the fires in road tunnels are initiated by traffic accident. The flow mode of flue gas and escape route of road tunnels are totally different from that of typical underground buildings. If the two directions are separately designed in two tunnels, connecting channel should be set every 300–400m, shown in Figure 6. Otherwise, fans should start work as soon as possible and the direction of the wind should be opposite to the escape direction.

5.2. Difference in flood prevention

Flood in road tunnel can make vehicles flameout and is sometimes danger to human lives. Flood control of road tunnel includes two aspects of work. One is to retain water from the entrance and soil, another is drainage within the tunnel. In contrast to the water culvert of typical underground building which is like a reservoir, water culvert in road tunnel is more like a pipe under the tunnel.

5.3. Visibility in road tunnel

Since most of the fires in road tunnels are initiated by traffic accident, it is important to reduce the accidents. Particulate matter, Carbon monoxide and Nitrogen oxides not only influence the visibility, but also delay the response capability of drivers, so it is important to keep the air quality better than that specified in relative standard (Tunnels study centre of France, 2010). This is not necessary in typical underground buildings.

6. Conclusion

The characteristics of large urban underground space and possible disasters are different from that of ordinary underground structures. Comprehensive evaluation of the disaster prevention system of urban architecture is a trend
to protect the safety of structure and human lives. A prototype of the comprehensive evaluation standard is established here for large urban underground space. The general frame structure, orders and ratings principle are described, with which the comprehensive disaster prevention degree can be calculated. For underground space rank B and C, corrective measures should be taken according to the detailed rules which are not fulfilled.

References


