Spatial model and safety evaluation for water supply and drainage system and fire fighting system of football field

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Abstract

With the host of World Cup in Brazil, football becomes popular again and more audiences watching games in football field. To guarantee audiences' personal safety, the water supply and drainage system and fire fighting system of football field are significant. In order to provide a reasonable water supply and drainage system and the standard for evaluating the fire fighting system of football field, the necessity of the design of water supply and drainage system was analyzed and the design plan and layout map of the drainage system were obtained. Afterwards, the analytic hierarchy process (AHP) model was constructed for analyzing the safety evaluation standard for the fire fighting system of football field. In consideration of the influencing factors including personal safety, property safety, construction safety and environment safety, the proportions of each factor that influences the standard for evaluating the fire fighting system were acquired by analyzing. The analysis of the proportions of the factors such as safe evacuation facilities, fire protection, and smoke exhaust and alarm system indicated that there were slight differences among the proportions of these factors; and the safe evacuation facilities factor accounted for a largest proportion. All these illustrated that the safety evaluation of fire fighting system of football field had to be performed based on the standard that whether there were safe evacuation facilities, fire protection, and smoke exhaust and alarm system, and apply the personal safety protection as its main objective.

Keywords: Drainage system, Safety Evaluation for fire fighting system, Analytical hierarchy process

1 Introduction

With the rapid development of the society, sports competition and other entertainments develop fast in China as well. Since the reform and opening-up, the physical quality of Chinese people has increased continuously with the rapid increase of national economy, and favorable performance has been achieved in successive Olympic Games. China has been a sports power [1]. Furthermore, the successful host of 2008 Olympic Games in Beijing shows that a qualitative leap has made in the economy, physical education and technology of China.

To ensure the normal use, there are strict requirements for water supply and drainage system in sports ground (especially outdoor ground). In addition, major accidents including fire caused by multiple factors have taken place in many fields and brought about large casualty and property losses [2-3]. Therefore, the safety evaluation for the fire fighting system of sports fields, which is the major facility for protecting people's live security, is of great significance [4]. To guarantee the entire outdoor fields can be used normally after heavy rain and successfully protect personal safety in the fields, the tube arrangement of water supply and drainage system and the standard for the safety evaluation of the fire fighting system were investigated by taking the football field as an example.

2 Model establishments

2.1 SPATIAL MODEL OF DRAINAGE SYSTEM OF FOOTBALL FIELD

The drainage system of football field mainly consists of two parts, the surface runoff drainage system and underground one [5]. Although the time of rainwater drainage is not explicitly stipulated, to reduce the influence of water on real-time competition, the water has to be drained as quickly as possible. Aimed at this, a round of sewer is arranged at the edge of the football field and there is slope on the ground to lead the water in the sewer. Additionally, blind drains are set under the football field. In the drainage, water flows from ground to drainage blanket and blind drains and sewers afterwards and finally drained out through drain-pipe. Figure 1 illustrates the general map layout of the drainage system of the football field.

As the safety evaluation of fire fighting measures in football field relates to personal safety, the authors pay lots attention on it [6-7]. The evaluation points of fire fighting system are analyzed by establishing model.

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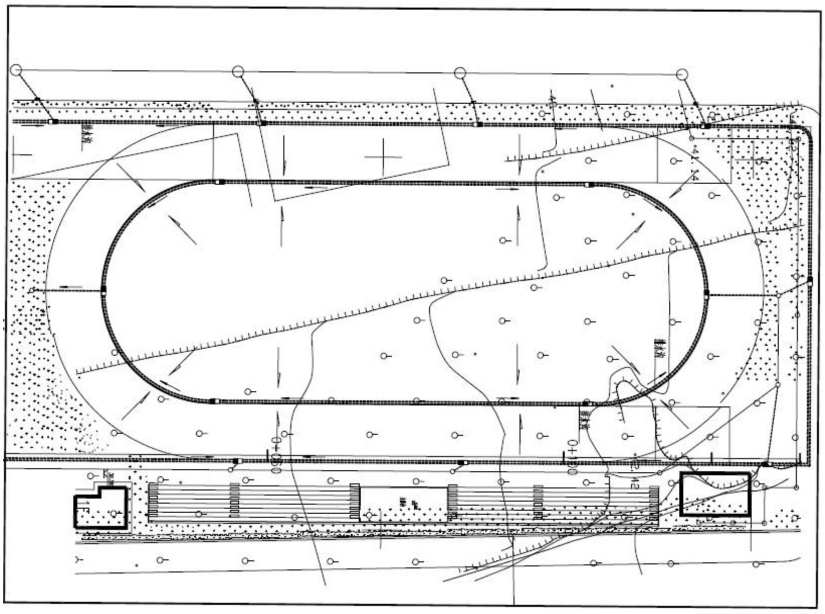

FIGURE 1 Layout of drainage facilities in the football field

2.2 CONSTRUCTION OF ORDER INCREASED HIERARCHY STRUCTURE

To obtain the specific standard for safety evaluation of fire fighting system of the football field, the factors that greatly influence the evaluation of fire fighting system were found out. In other words, the major factors that influence the evaluation indexes of the fire fighting system were found out. Then, based on AHP, the standards for safety evaluation of fire fighting system were quantized [8]. The relations of objective layer, criterion layer and schematic layer were established afterwards.

Objective layer is the safety evaluation standards for fire fighting system of football field.

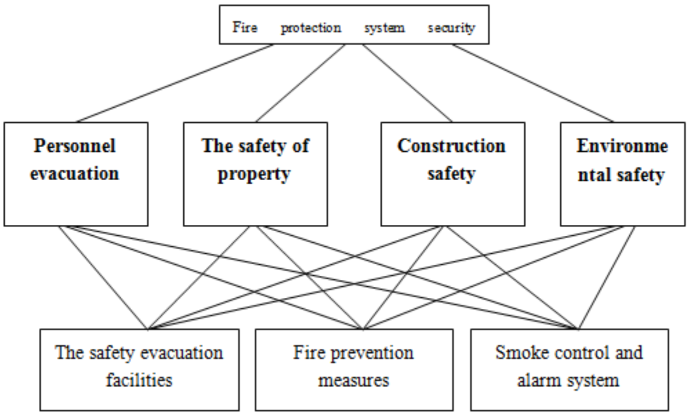

FIGURE 2 Order increased hierarchy structure

Criterion layer contains the influencing factors of the schemes.[9] Y_1, Y_2, Y_3 and Y_4stand for personnel evacuation, property security, construction security and environment protection respectively. In schematic layer,V_1 is safe evacuation facilities factor, V_2 is fire protection measures, and V_3 is smoke exhaust and alarm system.[10] Then the order increased hierarchy structure was obtained, as demonstrated in Figure 2.

2.3 BUILD OF JUDGMENT MATRIX

Suppose that α_{ij} is the ratio of the influence of β_i on G to that of β_j on G, and a judgment matrix A is obtained. Assume that the judgment matrix between the second layer and the first layer is A_1, the element is α_{ij}, the divisor are α_i , α_j,and the factor is A_1. Then the below judgment matrix A_1 is obtained.

$$A_1 = \begin{bmatrix} A_1 & \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 \\ \alpha_1 & a_{11} & a_{12} & a_{13} & a_{14} \\ \alpha_2 & a_{21} & a_{22} & a_{23} & a_{24} \\ \alpha_3 & a_{31} & a_{32} & a_{33} & a_{34} \\ \alpha_4 & a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}. \quad (1)$$

Table 1 shows the meanings and relations of elements in the quantized judgment matrix.

TABLE 1 Meanings of elements in the quantized judgment matrix

Variable	Description
a_{12},	The significance of elements 1 and 2
a_{13}	The significance of elements 1 and 3
a_{23}	The significance of elements 2 and 3
a_{ii}	The superiority degree of element i itself, and is supposed to be 1
a_{ji}	The significance and a_{ij} are reciprocal

To determine the value of α_{ij} in Table 1, the proportion scales ranging from 1 to 9 are assigned to different influence degrees, as displayed in Table 2.

TABLE 2 Proportion scales range from 1 to 9

Scale	Meaning
1	For two elements, they have same significance
3	For two elements, the former is significant than the later
5	For two elements, the former is apparently significant than the later
7	For two elements, the former is intensively significant than the later
9	For two elements, the former is extremely significant than the later
2.4.6.8	Scale values correspond to the intermediate states of the above judgments

Based on this, the judgment matrices G_2, G_3, G_4, G_5 of the four groups of two-factor $Y_i \sim Y_j, V_i \sim V_j$, of factors A_2, A_3, A_4, A_5 are acquired. In which, elements are represented by a_{ij}, b_{ij}, as shown in formulae (1) and (2)

$$G_2 = \begin{bmatrix} A_2 & Y_1 & Y_2 & Y_3 \\ Y_1 & a_{11} & a_{12} & a_{13} \\ Y_2 & a_{21} & a_{22} & a_{23} \\ Y_3 & a_{31} & a_{32} & a_{33} \end{bmatrix}, \quad (2)$$

$$G_3 = \begin{bmatrix} A_3 & V_1 & V_2 \\ V_1 & b_{11} & b_{12} \\ V_2 & b_{21} & b_{22} \end{bmatrix}. \quad (3)$$

According to lots experts' experience, mass of literatures and the scale set of 1~9, the pairwise comparison matrix, that is, the comparison matrix was obtained, as demonstrated in Table 3.

TABLE 3 Comparison matrix

G	Y_1	Y_2	Y_3	Y_4
Y_1	1	3	4	5
Y_2	1/3	1	2	3
Y_3	1/4	1/2	1	2
Y_4	1/5	1/3	2	1

TABLE 4 Comparison matrix

Y_1	V_1	V_2	V_3
V_1	1	3	2
V_2	1/3	1	1/2
V_3	1/2	2	1

TABLE 5 Comparison matrix

Y_2	V_1	V_2	V_3
V_1	1	1/3	1/2
V_2	3	1	3
V_3	2	1/3	1

TABLE 6 Comparison matrix

Y_3	V_1	V_2	V_3
V_1	1	1/4	1/3
V_2	4	1	1
V_3	3	1	1

TABLE 7 Comparison matrix

Y_4	V_1	V_2	V_3
V_1	1	1/4	1/5
V_2	4	1	1/3
V_3	5	3	1

2.4 CONSISTENCY CHECK

The check formula of consistency index is $CI = \frac{\lambda_{\max} - n}{n-1}$. Where $\lambda_{\max}$ is the maximum characteristic value of the comparison matrix, and n is the order of the comparison matrix [11]. It is observed that the comparison matrix is inversely proportional to the value of CI.

$$C=\begin{Bmatrix}1 & 3 & 4 & 5\\ 1/3 & 1 & 2 & 3\\ 1/4 & 1/2 & 1 & 2\\ 1/5 & 1/3 & 2 & 1\end{Bmatrix}\xrightarrow{\textit{Column vector normalization}}$$

$$\begin{Bmatrix}0.562 & 0.621 & 0.444 & 0.455\\ 0.185 & 0.207 & 0.222 & 0.273\\ 0.140 & 0.104 & 0.111 & 0.182\\ 0.112 & 0.068 & 0.222 & 0.091\end{Bmatrix}$$

$$\xrightarrow[\textit{According to the row sum}]{\textit{Column vector normalization,}}\begin{Bmatrix}0.521\\ 0.221\\ 0.134\\ 0.124\end{Bmatrix}=W^{(0)}$$

$$CW^{(0)}=\begin{Bmatrix}1 & 3 & 4 & 5\\ 1/3 & 1 & 2 & 3\\ 1/4 & 1/2 & 1 & 2\\ 1/5 & 1/3 & 2 & 1\end{Bmatrix}\begin{Bmatrix}0.521\\ 0.221\\ 0.134\\ 0.124\end{Bmatrix}=\begin{Bmatrix}5.211\\ 2.213\\ 1.340\\ 1.242\end{Bmatrix}$$

$$\lambda_{\max}^{(0)}=\frac{1}{4}\left(\frac{5.211}{0.521}+\frac{2.213}{0.221}+\frac{1.340}{0.134}+\frac{1.242}{0.124}\right)=4.06$$

$$w^{(0)}=\begin{pmatrix}0.521\\ 0.221\\ 0.134\\ 0.124\end{pmatrix}$$

The judgment matrix is

$$C_1=\begin{Bmatrix}1 & 3 & 2\\ 1/3 & 1 & 1/2\\ 1/2 & 2 & 1\end{Bmatrix},C_2=\begin{Bmatrix}1 & 1/3 & 1/2\\ 3 & 1 & 3\\ 2 & 1/3 & 1\end{Bmatrix},$$

$$C_3=\begin{Bmatrix}1 & 1/4 & 1/3\\ 4 & 1 & 1\\ 3 & 1 & 1\end{Bmatrix},C_4=\begin{Bmatrix}1 & 1/4 & 1/5\\ 4 & 1 & 1/3\\ 5 & 3 & 1\end{Bmatrix}$$

The corresponding maximum characteristic value and vector are

$$\lambda^{(1)}{}_{\max}=3.62,w^{(1)}{}_1=\begin{Bmatrix}0.332\\ 0.332\\ 0.452\end{Bmatrix}$$

$$\lambda^{(2)}{}_{\max}=4.53,w^{(1)}{}_2=\begin{Bmatrix}0.523\\ 0.246\\ 0.083\end{Bmatrix}$$

$$\lambda^{(3)}{}_{\max}=3.43,w^{(1)}{}_3=\begin{Bmatrix}0.634\\ 0.234\\ 0.143\end{Bmatrix}$$

$$\lambda^{(4)}{}_{\max}=3.54,w^{(1)}{}_4=\begin{Bmatrix}0.645\\ 0.256\\ 0.135\end{Bmatrix}$$

Based on $CI=\frac{\lambda_{\max}-n}{n-1}$, the *RI* value is calculated, as illustrated in Table 7.

TABLE 7 RI values

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

For the judgment matrix *C*, $\lambda^{(0)}{}_{\max}=4.53, RI=0.99$

$$RI=\frac{4.53-4}{4-1}=0.096, \quad (4)$$

$$CR=\frac{CI}{RI}=\frac{0.096}{0.99}=0.097<0.1. \quad (5)$$

It represents that the inconsistent degree of *C* is within tolerance range; in the condition, the weight vector can be replaced by the characteristic vector of *C*. Similarly, judgment matrices C_1, C_2, C_3,and C_4 pass the consistency check by using the above principle. The calculation results from objective layer to schematic layer are demonstrated in Figure 3.

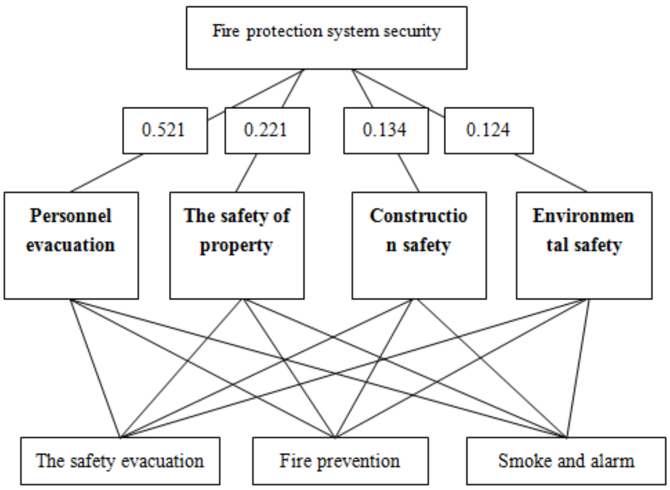

FIGURE 3 Calculation results from objective layer to schematic layer

$$\begin{Bmatrix} 0.332 \\ 0.332 \\ 0.452 \end{Bmatrix}, \begin{Bmatrix} 0.523 \\ 0.246 \\ 0.083 \end{Bmatrix}, \begin{Bmatrix} 0.634 \\ 0.234 \\ 0.143 \end{Bmatrix}, \begin{Bmatrix} 0.645 \\ 0.256 \\ 0.135 \end{Bmatrix}$$

The calculation results are as follows:

$$w^{(1)} = (w_1^{(1)}, w_2^{(1)}, w_3^{(1)}, w_3^{(1)}) = \begin{Bmatrix} 0.332 & 0.523 & 0.634 & 0.645 \\ 0.332 & 0.246 & 0.234 & 0.256 \\ 0.452 & 0.083 & 0.143 & 0.135 \end{Bmatrix}$$

$$w = w^{(1)} w^{(0)}$$

$$= \begin{Bmatrix} 0.332 & 0.523 & 0.634 & 0.645 \\ 0.332 & 0.246 & 0.234 & 0.256 \\ 0.452 & 0.083 & 0.143 & 0.135 \end{Bmatrix} \begin{Bmatrix} 0.521 \\ 0.221 \\ 0.134 \\ 0.124 \end{Bmatrix} = \begin{Bmatrix} 0.354 \\ 0.304 \\ 0.342 \end{Bmatrix}$$

The aforementioned AHP analysis indicates that when considering the influencing factors including personal, property, construction and environment security, the proportions of factors that influence the standards of fire fighting system of the football field are calculated. The proportions of safe evacuation facilities, fire protection, and smoke exhaust and alarm system are 0.354, 0.304 and 0.342, respectively. Obviously, there are slight differences among these proportions, and the safe evacuation facilities accounts for a largest proportion [12]. All these explain that the safety evaluation of the fire fighting system of football field had to be performed based on the standard that whether there were safe evacuation facilities, fire protection, and smoke exhaust and alarm system, and apply the personal safety protection as its main objective.

3 Conclusion

The necessity of the design of water supply and drainage system was analyzed and the design plan and layout map of the drainage system were provided firstly. Afterwards, the analytic hierarchy model was constructed for analyzing the safety evaluation standards for the fire fighting system of football field. In consideration of the influencing factors including personal safety, property safety, construction safety and environment safety, the proportions of each factor that influences the standard for evaluating the fire fighting system were acquired in analysis. The proportions of safety disperse facilities, fire protection, and smoke exhaust and alarm system are 0.354, 0.304 and 0.342, respectively. It indicated that there were slight differences among the proportions of these factors; and the safe evacuation facilities factor accounted for a largest proportion. All these explained that the safety evaluation of the fire fighting system of football field had to be performed based on the standard whether there were safe evacuation facilities, fire protection, and smoke exhaust and alarm system, and apply the personal safety protection as its main objective.

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