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Procedia Engineering 43 (2012) 369 – 373

Procedia Engineering

www.elsevier.com/locate/procedia

International Symposium on Safety Science and Engineering in China, 2012 (ISSSE-2012)

Study on Safety Assessment of Fire Hazard for the Construction Site

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Abstract

In order to better prevent fire accidents of construction site, a index system of safety assessment was established for fire hazard of construction combined with related specifications site, first level indexes of which were composed by fire safety management, general floor plan, building fire, thermal insulation material and temporary fire control facility, the weight of the safety assessment indexes was determined by AHP, and five single factor and the overall of index system of safety assessment for fire hazard of the construction site were evaluated respectively by fuzzy mathematical methods, and the safety situation of each single factor in the system was understudied, at the same time, the overall fire safety conditions of the system was grasped.

Keywords: Construction site, Fire hazard, Index system, Fuzzy mathematics, Safety assessment

1. Introduction

With the socio-economic development and the strengthening of urbanization, the number of civil and industrial construction projects increasing, the construction project fire frequently occur in recent years, some of which have greater impact, August 14, 2007, the Shanghai World Financial Center Fire accident; July 27, 2008, Jinan Olympic Sports Center Gymnasium fire accident, February 9, 2009, CCTV North Side Building fire accident; November 15, 2010, 728 Jiaozhou Road, Jingan District, Shanghai, a 28-story floor facade wall construction of high-rise residential fire accidents, which have a lot of fire accidents relation with thermal insulation materials [1], which brought about huge casualties and property losses. In such conditions, the state attaches great importance to fire accidents of the construction field, and promulgated " Technical code for fire safety of construction Site "(GB50720-2011); in the same time, safety assessment of the construction fire is necessary, at present, the literature of construction hazard research [2-4] and safety assessment of building fire hazard research [5-6] were more, but the literature of safety assessment for fire hazard of the construction site research are nothing, in order to prevent fire accidents of construction, in this article AHP and fuzzy mathematics method were used to analyze the impact of various factors on the construction system, which explore its occurrence.

2. Safety assessment of fire hazard for the construction site

2.1. Safety assessment index system for fire hazard of the construction site

Safety assessment index system for fire hazard of the construction site was determined with " Technical code for fire safety of construction Site "(GB50720-2011) [7], see Table 1.

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doi:10.1016/j.proeng.2012.08.064

2.2. Fuzzy synthesis assessment model

2.2.1 Establish factors set and assessment set for fuzzy synthesis assessment

The assessment project is divided into q assessment unit（q=1，2，…，t）, assume the indices set is $U=\{U_1, U_2,\cdots, U_m\}$; the assessment set is $V=\{V_1, V_2,\cdots, V_n\}$.

2.2.2 Establishment of the weight set

The weight of the safety assessment indexes was determined by AHP, The steps are as follows:

Table 1. Safety assessment index system for fire hazard of the construction site

Fire safety management	General floor plan	Building fire	Thermal insulation material	Temporary fire control facility
Fire safety education and training system	Fire prevention space	Temporary construction fire	Material type	Fire extinguisher
Flammable and inflammable and explosive dangerous goods management system	Fire road	Under construction fire	Fire performance	Temporary fire water supply system
Fire, electricity, gas management system		Safety evacuation		Emergency lighting
Fire safety inspection system				
Emergency plan drill system				

(1)Establishment of hierarchy Structure model

It was shown in Table 1

(2)Establishment of judge matrix

Judgment matrix $A=(a_{ij})$ was established, which a_{ij} indicates the assignment of the relative importance degree ratio of an assessment index. Whose elements are met:

$$A\begin{cases} a_{ij} \rangle 0(i,j=1,2,\cdots,n) \\ a_{ij}=1(i=1,2,\cdots,n) \\ a_{ij}=1/a_{ij}\ (i,j=1,2,\cdots,n) \end{cases}$$

, the assignment is available to nine values judge method (Table 2) [8].

Table 2. The scale sheet of nine values judge

Scale	Signification
1	Both A_i and A_j are equally important
3	A_i is little important than A_j
5	A_i is obvious important than A_j
7	A_i is strongly important than A_j
9	A_i is extreme important than A_j
2，4，6，8	The importance degree between the two adjacent judgment scale

(3)Matrix consistency test

When the ratio CR of value of average random consistency index RI (Table 3) and the consistency index CI [CI= (λmax-n) / (n-1)] meet the CR=CI/RI<0.10, the judgment matrix is in line with consistency test conditions; otherwise, the initial judgment matrix established is not satisfactory, which need to re-assignment, amend carefully, until the consistency test by far.

Table 3. Value of average random consistency index RI

N	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54

(4) Determination of the indexes weights

After judgment matrix A of consistency test, the largest Eigen value λ_{max} corresponding eigenvectors was normalized, which get the weight vector of the various indexes $W=(\omega_1,\omega_2,\cdots,\omega_n)^T$

2.2.3 Fuzzy assessment for single factor

Firstly assess single factors U_i $(i=1,2,\cdots,m)$ of U set, and then determine subordination r_{ij} of V_j $(j=1,2,\cdots,m)$ for the factors U_i, which obtain assessment vector $r_i=(r_{i1},r_{i2},\cdots,r_{in})$ of single factors for No. i factor U_i, it is fuzzy subset of assessment set. Then get the assessment matrix of single factor:

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{3}$$

2.3.4 Fuzzy comprehensive assessment

When determine fuzzy matrix R and fuzzy vector A, carry on fuzzy synthesis assessment by fuzzy transform,

$$B=A\cdot R=(b_1,b_2,\cdots,b_n) \tag{4}$$

Two hierarchy fuzzy comprehensive assessment:

$$B=(A_1,A_2,\cdots A_t)\cdot(B_1,B_2,\cdots B_t) \tag{5}$$

Finally

$$S=\sum_{i=1}^{n} b_i c_i \tag{6}$$

3. Study on application of the model

To a construction site in Jilin Province, for example, with a total construction area of 27,491 square meters, construction engineering level 2, the design life of 50 years, building layers and building height of 3-6 layers, 22.75 meters; fire design of building classification and fire rating of class 2, 2; Roofing grade level Ⅱ.

3.1. Hierarchical structure, weight and assessment set of safety assessment index for fire hazard of the construction site

3.1.1 Hierarchical Structure of safety assessment index for fire hazard of the construction site

Hierarchy factors set can be obtained by safety assessment index system for fire hazard of the construction site in Table 1 as follows:

The first hierarchy factor set is: $U=\{U_1,U_2,U_3,U_4,U_5\}$

The second hierarchy factor set is: $U_1=\{u_{11},u_{12},u_{13},u_{14},u_{15}\}$; $U_2=\{u_{21},u_{22}\}$; $U_3=\{u_{31},u_{32},u_{33}\}$; $U_4=\{u_{41},u_{42}\}$; $U_5=\{u_{51},u_{52},u_{53}\}$

3.1.2 The calculation of the of indexes weights

The weight was determined by AHP, weight specific calculation need calculation data of the MATLAB programming. The data obtained below were the results calculated and normalized through computer programming.

3.1.2.1 Calculation results of first level indexes weights

Judgment matrix A was established by first level indexes U_1,U_2,U_3,U_4,U_5 of fire hazard of the construction site, the calculation results were shown in Table 4.

Table 4. Calculation results of first level indexes weights

Matrix A	U_1	U_2	U_3	U_4	U_5	Weight ω
U_1	1	4	3	4	3	0.44
U_2	1/4	1	1/2	2	1/2	0.11
U_3	1/3	2	1	3	1	0.19
U_4	1/4	1/2	1/3	1	1/3	0.07
U_5	1/3	2	1	3	1	0.19
			$\lambda_{max}=5.09$	$C_R=0.02<0.10$		

3.1.2.2 Calculation results of second level indexes weights

Table 5. Calculation results of second level indexes weights

Fire safety management ω_1	General floor plan ω_2	Building fire ω_3	Thermal insulation material ω_4	Temporary fire control facility ω_5
0.17	0.86	0.32	0.14	0.77
0.26	0.14	0.56	0.86	0.16
0.39		0.12		0.07
0.11				
0.07				
$\lambda_{max}=5.13$ $C_R=0.03<0.10$	$\lambda_{max}=2.00$ $C_R=0<0.10$	$\lambda_{max}=3.02$ $C_R=0.02<0.10$	$\lambda_{max}=2.00$ $C_R=0<0.10$	$\lambda_{max}=3.05$ $C_R=0.05<0.10$

With first level indexes weights calculation, calculation results of second level indexes weights were shown in Table 5.

3.1.3 Assessment factors set

Assessment factors set of fire hazard system of the construction site was determined by Delphi, expert group of 10-member safety experts was drawn from safety expert database of the construction site fire, respectively, the single factors of 24 under the index 1 were assessed by the system assessment set respectively, which obtain judgment matrix R1, R2, R3, R4, R5,.

$$R_1 = \begin{pmatrix} 0.00 & 0.50 & 0.40 & 0.10 & 0.00 \\ 0.20 & 0.40 & 0.40 & 0.00 & 0.00 \\ 0.10 & 0.60 & 0.30 & 0.00 & 0.00 \\ 0.10 & 0.50 & 0.40 & 0.00 & 0.00 \\ 0.30 & 0.50 & 0.20 & 0.00 & 0.00 \end{pmatrix} \quad R_2 = \begin{pmatrix} 0.20 & 0.10 & 0.10 & 0.60 & 0.00 \\ 0.40 & 0.30 & 0.20 & 0.10 & 0.00 \end{pmatrix} \quad R_3 = \begin{pmatrix} 0.20 & 0.30 & 0.20 & 0.20 & 0.10 \\ 0.40 & 0.40 & 0.10 & 0.10 & 0.00 \\ 0.50 & 0.30 & 0.10 & 0.10 & 0.00 \end{pmatrix}$$

$$R_4 = \begin{pmatrix} 0.40 & 0.30 & 0.20 & 0.10 & 0.00 \\ 0.30 & 0.40 & 0.20 & 0.10 & 0.00 \end{pmatrix} \quad R_5 = \begin{pmatrix} 0.50 & 0.20 & 0.00 & 0.30 & 0.00 \\ 0.40 & 0.30 & 0.20 & 0.00 & 0.10 \\ 0.20 & 0.40 & 0.20 & 0.20 & 0.00 \end{pmatrix}$$

3.2. Assessment set

There into, $5A$ as "very safety"; $4A$ as " safety "; $3A$ as "medium"; $2A$ as "danger"; A as "very danger".

The assessment results is determined by the fuzzy maximum subordination principle, there will be some uncertainty, in order to get the assessment results, the results rank adopt the percentage system, safety rank standard of fire hazard of the construction site [9] in table 6.

Table 6. Safety rank standard for fire hazard of the construction site

Safety rank	$5A$ （very safety）	$4A$ （safety）	$3A$ （medium）	$2A$ （danger）	A （very danger）
Composite score S	90～100	80～90	70～80	60～70	0～60

3.3. One hierarchy fuzzy comprehensive assessment

In the fire hazard system of the construction site, fire safety education and training system, flammable and inflammable and explosive dangerous goods management system, fire, electricity, gas management system, fire safety inspection system, emergency plan drill system of the single factor were assessed respectively, first of all, the fuzzy assessment to fire safety management factors of the construction site:

Index weight matrix of fire safety management factor known is: $A_1 = \{A_{11}, A_{12}, A_{13}, A_{14}, A_{15}\} = (0.17, 0.26, 0.39, 0.11, 0.07)$

$$B_1 = A_1 \cdot R_1 = (0.17,0.26,0.39,0.11,0.07) \cdot \begin{pmatrix} 0.00 & 0.50 & 0.40 & 0.10 & 0.00 \\ 0.20 & 0.40 & 0.40 & 0.00 & 0.00 \\ 0.10 & 0.60 & 0.30 & 0.00 & 0.00 \\ 0.10 & 0.50 & 0.40 & 0.00 & 0.00 \\ 0.30 & 0.50 & 0.20 & 0.00 & 0.00 \end{pmatrix} = (0.123,0.513,0.347,0.017,0.000)$$

So toward one hierarchy assessment， first, assessment result was determined in accordance with maximum subordination principle, and which may obtain that the safety state of the fire hazard system of the construction site is "safety"; because this assessment set of the results is fuzzy, various ranks of the system are divided into five intervals with the percentage system in Table 6. Assume the tier vector of the grade parameters in choice assessment set is: $C = (c_1, c_2, c_3, c_4, c_5) = (95,85,75,65,30)$

$S_1 = B_1 \cdot C^T = 0.123 \times 95 + 0.513 \times 85 + 0.347 \times 75 + 0.017 \times 65 = 82.42$, the assessment result is "safety".

The same theory,

$B_2 = (0.228,0.128,0.114,0.530,0.000)$， S_2 =75.54， the assessment result is "medium";

$B_3 = (0.348,0.356,0.132,0.132,0.032)$， S_3 =82.76， the assessment result is "safety";

$B_4 = (0.314,0.386,0.200,0.100,0.000)$， S_4 =84.14， the assessment result is "safety";

$B_5 = (0.463,0.230,0.046,0.245,0.016)$， S_5 =83.39， the assessment result is "safety".

Above calculation results, assessment results of the single factor were above "safety" or "medium".

Assessment matrix R is as follows:

$$R = (B_1, B_2, B_3, B_4, B_5)^T = \begin{pmatrix} 0.123 & 0.513 & 0.347 & 0.017 & 0.000 \\ 0.228 & 0.128 & 0.114 & 0.530 & 0.000 \\ 0.348 & 0.356 & 0.132 & 0.132 & 0.032 \\ 0.314 & 0.386 & 0.200 & 0.100 & 0.000 \\ 0.463 & 0.230 & 0.046 & 0.245 & 0.016 \end{pmatrix}$$

3.4. Two hierarchy fuzzy synthesis assessment

$A = \{A_1, A_2, A_3, A_4, A_5\} = (0.44, 0.11, 0.19, 0.07, 0.19)$ was known, consider R as the assessment matrix of $U = \{U_1, U_2, U_3, U_4\}$, so

$$B = A \cdot R = (0.44, 0.11, 0.19, 0.07, 0.19) \cdot \begin{pmatrix} 0.123 & 0.513 & 0.347 & 0.017 & 0.000 \\ 0.228 & 0.128 & 0.114 & 0.530 & 0.000 \\ 0.348 & 0.356 & 0.132 & 0.132 & 0.032 \\ 0.314 & 0.386 & 0.200 & 0.100 & 0.000 \\ 0.463 & 0.230 & 0.046 & 0.245 & 0.016 \end{pmatrix} = (0.255, 0.378, 0.213, 0.144, 0.010)$$

Assessment result was determined in accordance with maximum subordination principle, which was that safety state of the highway tunnel construction system is "safety".

According to this formula $S = B \cdot C^T = 0.255 \times 95 + 0.378 \times 85 + 0.213 \times 75 + 0.144 \times 65 + 0.010 \times 30 = 81.99$

The final score of fire hazard system of the construction site is 81.99, the safety rank standard for fire hazard of the construction site is "safety" by table 6.

4. Conclusions

(1) Fire hazard system of the construction site was more salient, the insulation material fire was pay attention to gradually in recent years, which need the government introduce a certain degree of support policies to support the research work of the fire performance of insulation materials;

(2) Index system of safety assessment for fire hazard of the construction site was determined by " technical code for fire safety of construction Site ", which is divided into ire safety management, general floor plan, building fire, thermal insulation material and temporary fire control facility of five parts, which was able to reflect on site fire safety conditions of the overall construction;

(3) The weight of the safety assessment indexes were determined by AHP, which combined with expert opinion and the calculation data of MATLAB program,

(4) The multi-level synthesis assessment of fuzzy comprehensive assessment on the various factors for fire hazard of the construction site, which able to get the qualitative and quantitative results of the assessment, the results of quantitative assessment was divided into different safety rank standard, and can be more correct to reflect its actual fire hazard.

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