Construction Safety Evaluation for Prefabricated Concrete-Constructions based on Attribute Mathematics

CHANG Chunguang[1, a], YANG Shuang[1,b], and LUO Jingyu[2,c]

[1]School of Management, Shenyang Jianzhu University, Shenyang 110168, China

[2]School of Information and Control Engineering, Shenyang Jianzhu University, Shenyang 110168, China

[a]chang_chunguang@163.com, [b]ccg777@sohu.com, [c]ccg7788@sohu.com

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Abstract. This paper applies the attribute mathematics theory to prefabricated building construction safety evaluation, establishes the attribute mathematics model of prefabricated building construction safety evaluation. Based on the analysis of main causes of prefabricated building construction safety, personnel quality, technology and equipment, safety management, environment are chosen as the Level I indexes, and four Level I indexes divide into several Level II indexes.Calculating the single indexes attribute measure by establishing attribute measure functions. To calculate the comprehensive attribute measure, the weight of the evaluation index is determined by using the analytic hierarchy process (AHP). Finally, the safety of the target project ares recognized by the confidence criterion.Take a concrete project as an example to explain how to use the model to evaluate prefabricated building construction safety.

Introduction

The prefabricated building is a building constructed by assembling, jointing the prefabricated parts in the factory and partially casting in the with the traditional building,the prefabricated building saves energy and resources, makes the construction process more environmentally friendly, improves the technology content of the construction industry, is in accordance with the development strategy of green architecture and architectural indusrtialiaztion, and meets the requirements of sustainable development of construction industry. The prefabricated building is in the developing stage, and the construction safety management must be solved to develop prefabricated building. Establishing prefabricated building construction safety evaluation system is only one part of the safety management work, only by establishing scientific and accurate prefabricated building construction safety evaluation system to make accurate judgment of safety degree of prefabricated building construction. However, current research on prefabricated building construction safety evaluation is still at the initial stage,there are problems such as the evaluation indexes system is not comprehensive enough ,evaluation method is not scientific,etc. Therefore, it is necessary to study prefabricated building construction safety evaluation, propose a scientific and accurate evaluation system and evaluation methods.

Although the study of prefabricated building construction safety is less, but some achievements were made in the traditional building evaluation, and proposed a series of evaluation methods,such as analytic hierarchy process (AHP)[1], gualitative risk analysis[2], grey relation model[3], task demands assessment(TDA)[4]. But the large and small operations of the fuzzy sets in the fuzzy comprehensive evaluation result in the loss of some intermediate information.Lead to the phenomenon of unclear level division and evaluation of the structure is irrational[5]. This paper establishes the safety evaluation indexes system for prefabricated building construction, determines the weights of indexes by using the analytic hierarchy process,evaluates the safety of the prefabricated building construction by using attribute mathematics evaluation method.

Establish prefabricated building construction safety evaluation

Establish evaluation indexes system. According to the construction features of prefabricated building and the regulations of prefabricated building safety established in various provinces and cities,by surveying and analysing the prefabricated building safety situation,the safety evaluation system as shown in table 1.

Table 1 Prefabricated building safety evaluation indexes system

Level Iindexes	Level IIindexes
Personnel quality	Quality level of employee culture
	Technical level of employees
	Safety education and training situation
	Enterprise qualification and qualification of employees
Technology and equipment	Large equipment installation and safety control
	Maintenance of construction equipment
	Safety protection facilities
	Security sign setting
	Construction technology maturity degree
Safety management	Safety production rules and regulations
	Organization for safety production management
	Safety supervision and inspection
	Risk source and component stacking management
	Accident prevention and emergency management
Environment	The natural environment
	The working environment
	The surrounding environment

The division of evaluation level. The safety of prefabricated building is divided into 5 evaluation levels:Excellent C_1, Good C_2, General C_3,Poor C_4, FailureC_5.The 5 evaluation levels constitute the level set U= (C_1 ,C_2 ,C_3 ,C_4,C_5), the standard of each indexes of evaluation scores of concrete as shown in table 2.The specific standard to classify the level of indexes are shown in Table 2.

Table 2 Evaluation standard and classification standard

Evaluation Level				
Excellent	Good	General	Poor	Failure
100-90	90-80	80-70	70-60	60-0

Prefabricated building construction safety evaluation method

References Let *X* be a collection of objects to be evaluated. Each element in *X* has the characteristic m indexes (I_1,I_2 ,…,I_m).The elements in X set(C_1,C_2,…,C_K).Cn as the evaluation grade[7].The extent of the evaluation object to level k expressed by attribute measure μ_k. μ_{jk} denotes the extent belonging to level *k* of index *j* by attribute measure.

Single index attribute measure. We use the number μ $(x \in A)$ or $\mu(A)$ to quantitatively describe the extent of the "x having attribute A".Because of convenience, the attribute measure is

between [0,1].Different attribute sets can give the corresponding attribute measure.But the attribute measure must subject to

$$\mu_k \geq 0, \sum_{k=1}^{K} \mu_k = 1 \tag{1}$$

$$\mu_{jk} \geq 0, \sum_{k=1}^{K} \mu_{jk} = 1 \tag{2}$$

The evaluation grades for each index are usually represented by a number.The evaluation standards are expressed in the form of table 3, which is actually a single indexes grade partition .

Table 3 Single index classification table

Level Index	C_1	C_2	...	C_K
I_1	a_{10}-a_{11}	a_{11}-a_{12}	...	a_{1K-1}-a_{1K}
I_2	a_{20}-a_{21}	a_{21}-a_{22}	...	a_{2K-1}-a_{2K}
......				
I_m	a_{m0}-a_{m1}	a_{m1}-a_{m2}	...	a_{mK-1}-a_{mK}

Single indexes attribute measure function $\mu_{jk}(t)$ was established by table 3.In table 3,a_{jk} subjects to $a_{j0} < a_{j1} < \cdots < a_{jK}$ or $a_{j0} > a_{j1} > \cdots > a_{jK}$.

$$b_{jk} = \frac{a_{jk-1} + a_{jk}}{2}, k = 1,2,\ldots,K \tag{3}$$

$$d_{jk} = \min\left(|b_{jk} - a_{jk}|, |b_{jk+1} - a_{jk}|\right), k = 1,2,\cdots,K-1 \tag{4}$$

The single evaluation indexes attribute measure function is as follows:

$$\mu_{j1}(t) = \begin{cases} 1, & t < a_{j1} - d_{j1} \\ \dfrac{|t - a_{j1} - d_{j1}|}{2d_{j1}}, & a_{j1} - d_{j1} \leq t \leq a_{j1} + d_{j1} \\ 0, & a_{j1} - d_{j1} < t \end{cases} \tag{5}$$

$$\mu_{jK}(t) = \begin{cases} 1, & a_{jK-1} + d_{jK-1} < t \\ \dfrac{|t - a_{jK-1} + d_{jK-1}|}{2d_{jK-1}}, & a_{jK-1} - d_{jK-1} \leq t \leq a_{jK-1} + d_{jK-1} \\ 0, & t < a_{jK-1} - d_{jK-1} \end{cases} \tag{6}$$

$$\mu_{jk}(t) = \begin{cases} 0, & t < a_{ji-1} - d_{ji-1} \\ \dfrac{|t - a_{jk-1} + d_{jk-1}|}{2d_{jk-1}}, & a_{jk-1} - d_{jk-1} \leq t \leq a_{jk-1} + d_{jk-1} \\ 1, & a_{jk-1} + d_{jk-1} < t < a_{jk} - d_{jk} \\ \dfrac{|t - a_{jk} + d_{jk}|}{2d_{jk}}, & a_{jk} - d_{jk} \leq t \leq a_{jk} + d_{jk} \\ 0, & a_{jk} + d_{jk} < t \end{cases} \tag{7}$$

Where, $j = 1,2,\cdots,m; k = 2,3,\cdots K-1$. From the above formula can be known any t, $\mu_{jk}(t)$ subjects to formula1.

Multi-indexes attribute measure. If it is known each single indexes I_j ($1 \leq i \leq m$) of sample x and each single indexes attribute measure $\mu_{jk} = \mu$ $(x_j \in C_k)$ of sample x.The weight of the j indexes is ω_j , ω_j comply with:

$$\omega_j \geq 0, \sum_{j=1}^{m} \omega_j = 1 \tag{8}$$

By weighted sum, multi-indexes attribute $\mu_k = \sum_{j=i}^{m} \omega_j \mu_{jk}$ can be obtained by indexes weights ω_j and single index attribute measure μ_{xjk} .

Attribute recognition analysis. After the attribute measure $\mu_k = \mu \ (x \in C_k), 1 \le k \le K$ of sample x is obtained, two common recognition standards are used to determine the level of the X, and the two standards are the minimum price criterion and the confidence criterion.For orderly evaluation set $(C_1, C_2, \cdots, C_K)$ adopt confidence criterion to identify the level of sample x.In prefabricated building construction safety evaluation, the evaluation set $(C_1, C_2, \cdots, C_K)$ is set as an ordered set.For example, in prefabricated building construction safety evaluation,the evaluation set is C_1={very safe},C_2={safe},C_3= {unsafe}. Generally consider "very safe" better or stronger than "safe" ,record as $C_1 > C_2$.In the same way,$C_2 > C_3$.If set C_1 = {unsafe},C_2={safe},C_3={very safe},then $C_1 < C_2 < C_3$.Set the evaluation set for the ordered set,assume $C_1 > C_2 >, \cdots, > C_x$, confidence is λ , $0.5 < \lambda \le 1$.If $k_0 = \min \left\{ k \left| \sum_{i=1}^{k} \mu_{il} \ge \lambda, 1 \le k \le K \right. \right\}$, it is considered that μ belongs to level C_{k_0} .

The above standard require "strong" class or level of a considerable proportion.In application, the confidence level λ generally takes between 0.6 and 0.7.

Application Example

Single indexes attribute measure function. In application, according to the relationship between the safety indexes of the construction safety indexes, the construction safety evaluation standard of the prefabricated building construction is shown in Table 1.According to the above formula, single indexes attribute measure functions are as follows:

$$\mu_{11}(t) = \begin{cases} 1 & 95 < t \\ \dfrac{t-85}{10} & 85 \le t \le 95 \\ 0 & t < 85 \end{cases} ; \quad \mu_{12}(t) = \begin{cases} 0 & 95 < t \\ \dfrac{95-t}{10} & 85 \le t \le 95 \\ \dfrac{t-75}{10} & 75 \le t \le 85 \\ 0 & t < 75 \end{cases} ; \quad \mu_{13}(t) = \begin{cases} 0 & 85 < t \\ \dfrac{85-t}{10} & 75 \le t \le 85 \\ \dfrac{t-65}{10} & 65 \le t \le 75 \\ 0 & t < 75 \end{cases} ;$$

$$\mu_{14}(t) = \begin{cases} 0 & 75 < t \\ \dfrac{75-t}{10} & 65 \le t \le 75 \\ \dfrac{t-55}{10} & 55 \le t \le 65 \\ 0 & t < 55 \end{cases} ; \quad \mu_{15}(t) = \begin{cases} 0 & 65 < t \\ \dfrac{65-t}{10} & 55 \le t \le 65 \\ 1 & t < 55 \end{cases} .$$

The single indexes attribute measure functions of $II_2 \sim II_{17}$ are the same as II_1.

Weights of indexes. In this paper, the weights of II level indexes correspond to the I level indexes are determined by using analytic hierarchy process, as shown in Table 4.

Table 4 Safety evaluation indexes weights

Level I indexes	Weights	Level II indexes	Weights
Personnel quality	0.242	Quality level of employee culture	0.213
		Technical level of employees	0.276
		Safety education and training situation	0.258
		Enterprise qualification and qualification of employees	0.253
Technology and equipment	0.261	Large equipment installation and safety control	0.216
		Maintenance of construction equipment	0.225
		Safety protection facilities	0.213
		Security sign setting	0.178
		Construction technology maturity degree	0.168
Safety management	0.266	Safety production rules and regulations	0.187
		Organization for safety production management	0.179
		Safety supervision and inspection	0.216
		Risk source and component stacking management	0.207
		Accident prevention and emergency management	0.211
Environment	0.231	The natural environment	0.36
		The working environment	0.34
		The surrounding environment	0.3

Case Study. Comprehensive evaluation of prefabricated building construction safety projects.Randomly selected 40 experts and engineers to fill in project safety questionnaire.The score of each evaluation indexes as shown in table 5 after statistical analysis software processing data.

Table 5 Weights and scores of indexes

Level II indexes	Weights of Level II indexes	scores
Quality level of employee culture	0.213	87
Technical level of employees	0.276	82
Safety education and training situation	0.258	79
Enterprise qualification and qualification of employees	0.253	83
Large equipment installation and safety control	0.216	89
Maintenance of construction equipment	0.225	91
Safety protection facilities	0.213	85
Security sign setting	0.178	79
Construction technology maturity degree	0.168	84
Safety production rules and regulations	0.187	81
Organization for safety production management	0.179	85
Safety supervision and inspection	0.216	87
Risk source and component stacking management	0.207	89
Accident prevention and emergency management	0.211	81
The natural environment	0.36	87
The working environment	0.34	82
The surrounding environment	0.3	84

The attribute measure of prefabricated building construction safety evaluation index is calculated according to the measure function of individual index attribute.The results are II_1=(0.2,0.8,0,0,0) II_2=(0,0.7,0.3,0,0) ; II_3=(0,0.4,0.6,0,0); II_4=(0,0.8,0.2,0,0) ; II_5=(0.4,0.6,0,0,0); II_6=(0.6,0.4,0,0,0) II_7=(0,1,0,0,0) ; II_8=(0,0.4,0.6,0,0); II_9=(0,0.9,0.1,0,0) ; II_{10}=(0,0.6,0.4,0,0) ; II_{11}=(0,1,0,0,0) II_{12}=(0.2,0.8,0,0,0) ; II_{13}=(0.4,0.6,0,0,0); II_{14}=(0,0.6,0.4,0,0) ; II_{15}=(0.2,0.8,0,0,0); II_{16}=(0,0.7,0.3,0,0); II_{17}=(0,0.9,0.1,0,0). Then calculate the comprehensive attribute measure $(\mu_{x1}, \mu_{x2}, \mu_{x3}, \mu_{x4})$=(0.118242,0.70692,0.17484,0,0). According to comprehensive attribute measure, the reliability of the project belongs to excellent is 0.118242.The reliability of belongs to good is 0.118242+0.70692=0.82516.Even taking the high confidence level of 0.8, the project safe level is still good.Generally the confidence to take between 0.6 and 0.7, the result of the prefabricated building construction safety evaluation is determined as good.

Conclusion

In Based on the theory of attribute mathematics, the model of prefabricated building construction safety evaluation is established. Providing an idea of prefabricated building construction safety evaluation.Quantitative methods to evaluate prefabricated building construction safety , making the evaluation results more accurate and reliable.Prefabricated building construction safety is evaluated by using the attribute mathematical model established in this paper.Can be seen from the calculation results, the method of attribute mathematics can be used to evaluate prefabricated building construction safety.

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