Research on Safety Risk Evaluation of Road Bridge Construction Based on Network Analysis Method

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Abstract: as for construction technology and management characteristics of road and bridge construction, this paper constructs evaluation index system on safety risk of road and bridge construction, this system mainly includes 2 levels such as risk element level and risk factor, effect of each factor presents network structure. On this base, this paper applies network analysis method theory to establish risk evaluation model and method on road and bridge construction safety, it also applies fuzzy comprehensive judgment method and combines with Xinhua viaduct construction case of Guangqing expressway reconstruction and expansion project to illustrate application of this method and calculate construction safety risk grade, which can provide base for risk management, the obtained conclusion conforms to objective reality of project.

1. Introduction

Road bridge engineering has characteristics such as multiple bridge structures, complicated construction technology, severe and changeable construction environment, vast participated units and personnel, meanwhile bridge construction will mutually affect with present road, water transport. Therefore, it has plenty of safety risks in the process of road bridge construction, which will cause frequent safety accidents as well as casualties and economic losses. So it is necessary to develop research on safety risk evaluation of road bridge construction, understand existing safety risk factors in construction process and internal relations make quantitative analysis and confirm safety risk grade, so we can adopt corresponding measures to reduce risks.

2. Safety risk evaluation index system on road bridge construction based on network analysis method

According to principle of network analysis method and combine with characteristic of road bridge engineering, this paper establishes safety risk evaluation index system (see table 1) of road bridge construction based on ANP. This index system is divided into target layer, element layer and factor layer. In the target layer, safety risk is not only target but also the unique evaluation standard. In the factor layer, it considers regarding 6 kinds of risks such as design risk, construction technology risk, personnel material and mechanic risk, organization management risk, environment condition risk and transportation risk etc as risk elements, these 6 kinds of risk elements are mutually affected and related. For example, through bridge structure confirmed by survey design will affect its construction plan and complication of construction technology so it will further cause construction risk, meanwhile it will affect transportation organization, construction personnel arrangement, building material choice, mechanic equipment allocation and construction organization, management etc in construction. Therefore, mutual relations of the above-mentioned risk elements present network structure.

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Table 1 Safety risk effect factors

target layer	element layer	factor layer
road bridge construction safety risk R	survey and design risk R1	Insufficient survey, wrong prediction R1.1
		design file quality disaccord with requirement R1.2
		design deviates from construction R1.3
		Immature design theory R1.4
		Problems caused by design alteration R1.5
	construction technology risk R2	immature construction processR2.1
		Unqualified construction quality control R2.2
		Unreasonable construction plan R2.3
		Violate construction standard R2.4
	personnel material and mechanic risk R3	Quality of worker and administrator R3.1
		Unqualified building material quality R3.2
		Usage problem of special material R3.3
		Mechanic equipment is imperfect R3.4
		fault in mechanic and power R3.5
		error in mechanic

target layer	element factor	factor layer
road bridge construction safety risk R	personnel, material and mechanic equipment R3	unstable mechanic performanceR3.8
		cooperation of human-machine R3.9
	organization management risk R4	Imperfect safety organization R4.1
		Inharmoniousness in each department R4.2
		Imperfect safety prevention measure R4.3
		Imperfect emergency measures R4.4
		Imperfect ire prevention and disaster prevention equipment R4.5
		Safety education has not been implemented R4.6
	environment condition risk R5	Bad geological condition R5.1
		Bad climate condition R5.2
		Unfavorable geographic and geomorphic conditions R5.3
		Complicated bridge feature R5.4
		Unstable water and power supply R5.5
		Conditions of nearby buildings and houses R5.6
	transportation risk R6	Road transportation conditions R6.1

		installation commissioning R3.6			
		Improper mechanic maintenance R3.7			Transportation condition of site engineering cars R6.2。

3. Safety risk evaluation method on road bridge construction based on network analysis method

A. Mutual effect matrix construction on safety risk factor of road bridge construction is based on network analysis method, mutual effect of the above-mentioned 6 kinds of bridge construction safety risk elements can be indicated by matrix. The scale of effect is between 0 and 1, 0 represents the former has no effect on the latter, 1 represents all the effect of the former on the latter.

$$W = \begin{bmatrix} W_{11} & W_{12} & W_{13} & W_{14} & W_{15} & W_{16} \\ W_{21} & W_{22} & W_{23} & W_{24} & W_{25} & W_{26} \\ W_{31} & W_{32} & W_{33} & W_{34} & W_{35} & W_{36} \\ W_{41} & W_{42} & W_{43} & W_{44} & W_{45} & W_{46} \\ W_{51} & W_{52} & W_{53} & W_{54} & W_{55} & W_{56} \\ W_{61} & W_{62} & W_{63} & W_{64} & W_{65} & W_{66} \end{bmatrix}$$

In the mutual-effect matrix, it totally has 6×6 sub matrix, each matrix all represents effect relations of corresponding 2 kinds of safety risk factors, for example, W_{12} represents effect if survey design risk（R_1）on construction technology risk, while W21 represents reaction of construction technology risk（R_2）on survey design risk（R_1）. Sub matrix W_{12} has 4 column vectors, they are respectivelyη_1, η_2, η_3, η_4, the first column η_1 represents all risk factors of survey design in sub matrix W_{12},（$R_{1.1}$，$R_{1.2}$，$R_{1.3}$，$R_{1.4}$，$R_{1.5}$）is the weight sequence on effect degree of imperfect construction process as for construction technology risk, the rest of 3 columns η_2， η_3， η_4 also indicate corresponding weight sequence. Each weight sequence vector （η_1， η_2， η_3， η_4）establishes comparison judgment matrix to calculate, on making comparative judgment, we invite risk analysis expert and combine with real condition of project to make grading. For example, in the calculation of η_1, it uses risk factor R2.1 of construction technology as sub standard to compare with effect degree of any 2 factors on $R_{2.1}$ of survey design, it uses 1-9 scale method to assign points and further establishes comparative matrix A_1， and then calculates normalized eigenvector of matrix A_1, this vector isη_1.

Table 2 Comparative judgment matrix A_1

[2.1immature construction process R2.1]→1group	1.1insurfficientsurvey, predict error	1.2 design file quality disaccord with requirement	1.3design deviates from construction	1.4immature design theory
1.1 insufficient survey, predict error 1.2 design file quality disaccord with requirement 1.3 design deviates from construction 1.4 immature design theory 1.5 problems caused by design alteration				

B. Risk factor weight sequence on safety risk factor of road bridge construction can calculate weight sequence on safety risk factor of road bridge construction according to mutual effect matrix W, the steps are as follows:

(1) It makes weight on mutual effect matrix W, every sub matrix of mutual effect W is normalized, but its influence is not normalized, in order to calculate, it needs to make weight. Make comparative judgment on mutual effect among 6 risk factors and get 6 comparative judgment matrixes, it calculates normalized characteristic vector and combine with one weight matrix D.

$$D = \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} & d_{15} & d_{16} \\ d_{21} & d_{22} & d_{23} & d_{24} & d_{25} & d_{26} \\ d_{31} & d_{32} & d_{33} & d_{34} & d_{35} & d_{36} \\ d_{41} & d_{42} & d_{43} & d_{44} & d_{45} & d_{46} \\ d_{51} & d_{52} & d_{53} & d_{54} & d_{55} & d_{56} \\ d_{61} & d_{62} & d_{63} & d_{64} & d_{65} & d_{66} \end{bmatrix}$$

It uses weight matrix D to weight on effect matrix, and it gets weight effect matrix $\overline{W}$.

$$\overline{W} = (d_{ij}W_{ij}) =$$

$$\begin{bmatrix} d_{11}W_{11} & d_{12}W_{12} & d_{13}W_{13} & d_{14}W_{14} & d_{15}W_{15} & d_{16}W_{16} \\ d_{21}W_{21} & d_{22}W_{22} & d_{23}W_{23} & d_{24}W_{24} & d_{25}W_{25} & d_{26}W_{26} \\ d_{31}W_{31} & d_{32}W_{32} & d_{33}W_{33} & d_{34}W_{34} & d_{35}W_{35} & d_{36}W_{36} \\ d_{41}W_{41} & d_{42}W_{42} & d_{43}W_{43} & d_{44}W_{44} & d_{45}W_{45} & d_{46}W_{46} \\ d_{51}W_{51} & d_{52}W_{52} & d_{53}W_{53} & d_{54}W_{54} & d_{55}W_{55} & d_{56}W_{56} \\ d_{61}W_{61} & d_{62}W_{62} & d_{63}W_{63} & d_{64}W_{64} & d_{65}W_{65} & d_{66}W_{66} \end{bmatrix}$$

(2) Calculate weight sequence, column vector of weight effect matrix W represents initial weight sequence of safety risk factor, it set as $Z^{(0)}$, make limit operation on it.

$$Z^{\infty} = \overline{W}^{\infty} Z^{(0)} = \lim_{k \to \infty} \overline{W}^{k} Z^{(0)}$$

The meaning of formula (2) means making square of k times on weight effect matrix $\overline{W}$, when limit $\lim_{k \to \infty} \overline{W}^{k}$ exists, multiply this limit with $^{(0)}$, and then it gets the final weight sequence Z^{∞} of safety risk factor.

3 Strategic methods on safety risk control in road bridge construction

At present, the usual safety risk control strategies in the field of civil engineering are as follows: risk aversion, risk transfer, risk mitigation and risk retention etc, in addition, there are various of combination strategies. As for the same engineering construction project, it can make many kinds of safety risk coping strategies, safety risk problems of the same kind appears in the different engineering construction projects, so the adopted risk coping strategy may be different. Therefore, we need to comprehensively consider characteristics of engineering project, detailed condition of safety risk, fund state, experience level of risk administrators etc to determine to use which kind of risk coping strategy. According to experience analysis on road bridge construction process in the past, as for some important safety risk factors, table 3 lists some control strategies and detailed measures used by construction units in the road bridge construction process. In the following it makes brief introduction to the usual safety risk coping strategy in the present engineering construction.

1． Risk aversion

(1) Connotation of risk aversion

Risk aversion means fundamentally eliminating risk hidden danger by changing the original design plan or construction plan of road bridge, or guarantee safety target of road bridge construction affected by risk factors. Risk aversion belongs to method of fundamentally and directly eliminating safety risk.

Table 3 Usual safety risk control strategy and detailed measures in road bridge construction

safety risk factor category		control strategy of safety risk	detailed measures
environment condition risk	bad geological condition	risk transfer	buy insurance
	abnormal climate condition	risk transfer	buy insurance
	unstable water and power supply, bad place	risk aversion	strengthen management
Survey design risk	Insufficient survey , predict error	risk retention	claim for compensation
	design file quality disaccord with requirement	risk retention	claim for compensation
personnel material and mechanic risk	quality of worker and administrator	risk aversion	strengthen management
	unqualified building material	risk aversion	Strengthen control and management of purchasing process
	construction mechanic and power failure	risk retention	claim for compensation
construction technology risk	Unqualified construction quality	risk aversion	strengthen control and management in construction process
	violate construction standard	risk aversion	strengthen control and management in construction process

There are 2 main implementation ways for risk aversion: 1. avoid the possibility of safety risk accidents. 2. Avoid the possible loss caused by safety risk accidents.

(2) Risk aversion methods. In the safety risk management of road bridge construction, the detailed methods of avoiding risks are as follows: termination method, engineering method, procedure method etc, please see reference literatures.

2． Risk transfer

(1) Connotation of risk transfer. It means seeking the third party by any means and makes the third party together undertake consequence caused by safety risk of road bridge construction, but it dose not really eliminate risk. In the project of road bridge engineering, there are many kinds of transfer

ways, for example, many enterprises compose bidding unions and purchase engineering insurance, choose contract evaluation way favorable for its own party, sub-contract partial engineering. The aim of these risk transfer is to make the overall construction contractor have less risk loss.

(2) The usual ways of safety risk transfer in road bridge construction are divided into insurance and non-insurance.1) engineering project insurance. Engineering insurance of road bridge means construction contractor pay insurance fees to insurance company, once there is insured risk accidents and causes loss, insurance company will provide economic compensation. Seeing from risk management, insurance actually belongs to measures of risk transfer, overall construction contractor buys engineering insurance and transfers risk responsibility should be undertaken by its own to insurance company.

2) Risk transfer of non-insurance, it has many ways: ① it uses means of engineering guarantee to transfer risk. ② Subcontract part construction engineering undertaken by it to the other units so as to transfer risks. ⑧ Adopt contract pricing way which is favorable to its own to transfer risk. ④ Apply contract condition to transfer risk.

3． Risk mitigation

(1) Connotation of risk mitigation. It means using every kind of channel to reduce the possibility of safety risk occurrence in road bridge construction or the unfavorable consequence to the acceptable degree. Risk mitigation can not eliminate risk, it just relieves risk influence. How to make target of risk mitigation (reduce risk to what kind of degree), which needs to make comprehensive consideration according to real condition of road bridge construction and enterprise ability. As for the confirmed risks, risk administrators can effectively control them, as for the unclear risks, risk administrators firstly need to investigate probability of incidents and possible unfavorable influence, and then make measures of mitigating this risk.

4 Conclusions

This paper constructs risk evaluation index system and evaluation model focuses on road bridge construction safety according to principle of network analysis method, and it applies this model into Xinhua viaduct engineering case and calculates weight sequence of its safety risk factor, and then it applies fuzzy comprehensive judgment method to confirm its safety risk grade. Engineering case demonstrates that network analysis method more reflects mutual relations among road bridge construction safety risk factors than analytic hierarchy process, which is more perfect, more scientific and reasonable in real application.

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