Research on Evaluation Method of Joint Prevention Operation Safety Risk in Railway-highway Bridge

Qiang Li [1,a], Haifeng Li [2,3,b,*]

[1] Jiangsu BaiSheng Safety Science and Technology Limited Company, Jiangsu, 21000, PRC;

[2] Department of Transportation Engineering, Tongji Zhejiang College, Zhejiang, 314051, PRC;

[3] Key Laboratory of Road and Traffic Engineering of the Ministry of Education, Tongji University, Shanghai, 201804, PRC.

[a]275086552@qq.com, [b,*]haifengli@tongji.edu.cn

Abstract. To build railway-highway bridge has become a common view to highly utilize transport corridor across river. Based on the operation risk research analysis of bridge in the world, joint prevention risk of railway-highway bridge is identified, a quantitative evaluation method of risk rating is put forward, and some related parameters are recommended. Combined design solution of Changtai Yangtze River Bridge, a dataset of joint prevention risk during operation to Changtai Yangtze River Bridge is provided and joint prevention risk rating is calculated according to the previous risk evaluation method and criteria, as a reference for scientific evaluation and effective control of joint prevention risk during operation to Changtai Yangtze River Bridge.

Keywords: railway-highway bridge; safety; joint prevention risk; operation; evaluation method; Changtai Yangtze River Bridge.

1. Introduction

With the rapid development of economy in China, the amount and scale of the ways by bridge across Yangtze river increases quickly, to build railway-highway bridge has also been a trend[1]. As a more complicated transportation corridor, railway-highway bridge faces a challenge on its operation and safety management, which arises the public widely focus and emphasis, and some researchers and practioners have make some achievement on it

Literatures investigation shows that, dozens of railway-highway bridges have been built, such as Qiantang River Bridge, Nanjing Yangtze River Bridge, Wufengshan Yangtze River Bridge etc. in China, and Seto-naikai Bridge in Japan, Fehmarn Belt Bridge in Danmark etc. But, due to the significant difference in design and operation and maintenance between railway-highway bridge and single-track corridor bridge (i.e., railway bridge or highway bridge), the operation safety risk management mode of single-track corridor cannot meet the new requirements of the railway-highway bridge.

The safety management is one of the most key technologies to the manager of the railway-highway bridge, it needs to solve not only the theory and key technology of operation safety risk evaluation, but also the system of safety management. By the analysis and evaluation of various safety risk in the operation of the railway-highway bridge, it is a meaningful work to bulid the safety risk evaluation system for double-track bridge, improve the risk prevention scenario, and reduce the lost caused by risk.

Based on the identification and evaluation theory and method of railway-highway bridge, taking Changtai Yangtze River Bridge with triple-track corridor (railway, expressway, highway) as a example, this paper will make some analysis on the railway-highway bridge operation safety risk identification and quantifiable evaluation.

2. Concept of Joint Prevention Risk in Railway-highway Bridge Operation

The safety risk in railway-highway bridge operation comes from not only the common components of bridge (such as main structure, pier and foundation etc.), but also the passing vehicle

and the across object (such as river etc.). At the same time, if railway corridor and highway corridor are laid in the same layer, there may be some risk in one of the corridors, which may cause more serious damage to the other corridor. So, the design mode and layout of the corridors play an important role in the management and control of the operation safety risk for the railway-highway bridge.

Literature's analysis shows that, the typical risk of railway-highway bridge mainly is caused by the deterioration of bridge structure performance, environmental conditions (such as overload and collision of vehicle, train derailment, earthquake etc.) and mutual action of different corridors in same layer (such as train glare etc.). As for the previous two types of risk, lots of research works have done[2-5], but as for the third one, few research works are reported[6].

In order to evaluate scientifically the operation safety risk of railway-highway bridge, the concept of joint prevention safety risk is introduced in this paper.

To differ from the safety risk from the common bridge with single-track corridor (i.e., Main Risk), in the management and control of the operation safety risk in railway-highway bridge, it needs to consider not only the main risk, but also the associated risk, which is caused by the above main risk. Thus, in the safety risk management, main risk and associated risk must be managed at the same time, and so, joint prevention safety risk is put forward here.

3. Evaluation of Joint Prevention Risk in Railway-highway Bridge Operation

3.1 Evaluation Method

There are three steps in evaluating grade of joint prevention risk. First, to determine the grade of the main risk according to its type, happening possibility and order of severity. Second, to analyze the grade of the associated risk caused by the above main risk. And finally, to sum the quantifiable risk grade and determine the grade of the joint prevention risk according to the unified standard of the risk grade evaluation. This method is name as "Quantifiable Evaluation Method of Joint Prevention Risk".

The calculation is based on the following formulas (1) or (2),

To independent risk (with one main risk and one/some associated risk)

$$R_i = \omega_i \times P_i \times C_i + \sum_{j=1}^{n} \omega_{ij} \times P_{ij} \times C_{ij} \quad (1)$$

To coexisting risk (with no main risk and all associated risk)

$$R_i = \sum_{j=1}^{n} \omega_{ij} \times P_{ij} \times C_{ij} \quad (2)$$

Where,

i is the serial number of Joint Prevention Risk;

R_i is the grade of the ith Joint Prevention Risk;

ω_i is the weight of the main risk of the ith Joint Prevention Risk;

P_i is the possibility of the main risk of the ith Joint Prevention Risk;

C_i is the lost severity of the main risk of the ith Joint Prevention Risk;

j is the serial number of the associated risk of the ith Joint Prevention Risk;

ω_{ij} is the weight of the jth associated risk of the ith Joint Prevention Risk;

P_{ij} is the possibility of the jth associated risk of the ith Joint Prevention Risk;

C_{ij} is the consequence of the jth associated risk of the ith Joint Prevention Risk;

To be normal, the greater of R_i , the larger of the risk grade.

3.2 Evaluation Parameters

There are four types of evaluation parameters in "Quantifiable Evaluation Method of Joint Prevention Risk", i.e., the possibility, consequence, weight and risk rating. The above parameters are recommended in Table 1 to Table 4.

Table 1 Possibility of Risk Rating

Serial No.	Likelihood	Referece data
1	Very likely	(9-10]
2	likely	(6-9]
3	About as likely as not	(3-6]
4	Unlikely	(1-3]
5	Very unlikely	(0-1]

Table 2 Consequence of Risk Rating

Serial No.	Consequence level	Referece data
1	Severe	10
2	Major	5
3	Moderate	2
4	Minor	1

Table 3 Risk Rating

Serial No.	Risk Rating	Referece data
1	Very high	(55,100]
2	High	(20,55]
3	Medium	(5,20]
4	Low	(0,5)

Table 4 Weight of Risk Rating

Risk Happening Position / Risk Associated Object	Triple-track corridor、twin-layer (ONLY Expressway in above layer, Highway and railway in bottom layer)			Double-track corridor,twin-layer (Highway in above layer, railway in bottom layer)	
	Expressway	Railway	Highway	Highway	Railway
Expressway	0.5	0.2	0.2	/	/
Highway	0.25	0.3	0.5	0.75	0.25
Railway	0.25	0.5	0.3	0.25	0.75

4. Typical Joint Prevention Risk Evaluation Practice

4.1 Changtai Yangtze River Bridge Design Solution

Changtai Yangtze River Bridge is built between Changzhou and Taizhou, Jiangsu province, China and its total length is 10.03km. This bridge is a railway-highway bridge with triple-track corridor, Expressway in the upper-layer, highway and railway in the same bottom-layer. The design speed of expressway is 100km/h, the design speed of highway is 80km/h and the design speed of railway is 200km/h.

4.2 Joint Prevention Risk Grade Evaluation

Based on the design characteristics and risk identification dataset of Changtai Yangtze River Bridge, and according to the above method, the grade of the Joint Prevention Risk of Changtai Yangtze River Bridge is calculated, and is illustrated in Table 5.

Table 5. Grade of the Joint Prevention Risk of Changtai Yangtze River Bridge

No.	Risk Type	Risk Source		Risk Positon	Associate Object	Risk rating
1	Bridge subsidiary	Bridge	Damage or falling	Expressway	Highway	Medium

	facilities	structure			Railway	
2	Bridge maintence work	Bridge structure	Improper work	Expressway	Highway Railway	Medium
3	Failure of equipment	Bridge structure	Signal etc.	Expressway	Highway Railway	Medium
4	Vehicle collision	Corridor passing	Damage of vehicle collision	Expressway	Highway Railway	High
5	hazardous chemicals leakage	Corridor passing	hazardous chemicals leakage	Expressway	Highway Railway	Very high
6	Fire	Corridor passing	Vehicle fire	Expressway	Highway Railway	Very high
7	Bridge subsidiary facilities	Bridge structure	Damage or falling	Highway	Expressway Railway	Medium
8	Bridge maintence work	Bridge structure	Improper work	Highway	Expressway Railway	Medium
9	Vehicle collision	Corridor passing	Damage of vehicle collision	Highway	Expressway Railway	High
10	hazardous chemicals leakage	Corridor passing	hazardous chemicals leakage	Highway	Expressway Railway	Very high
11	Fire	Corridor passing	Vehicle fire	Highway	Expressway Railway	Very high
12	Overload of vehicle	Corridor passing	Overload etc.	Highway	Expressway Railway	High
13	Bridge subsidiary facilities	Bridge structure	Damage or falling	Railway	Expressway Highway	Medium
14	Bridge maintence work	Bridge structure	Improper work	Railway	Expressway Highway	Medium
15	Train derail	Corridor passing	Train derail	Railway	Expressway Highway	Very high
16	Train glare	Corridor passing	Train glare	Railway	Expressway Highway	Medium
17	Object invasion	Corridor passing	Object invasion	Railway	Expressway Highway	Very high

18	fire	Corridor passing	Train fire etc.	Railway	Expressway Highway	Very high
19	Damage of bridge	Bridge structure	Main structure,pier,foudation damage	/	Expressway Highway Railway	High
20	Ship collision	Corridor passing	Ship collision on pier	/	Expressway Highway Railway	Very high
21	thunder	Natural environment	thunder	/	Expressway Highway Railway	High
22	Heavy fog	Natural environment	Heavy fog	/	Expressway Highway Railway	Very high
23	earthquare	Natural environment	earthquare	/	Expressway Highway Railway	Very high
24	attack of terrorism	others	attack of terrorism	/	Expressway Highway Railway	Very high

Table 5 shows that, the number of the Joint Prevention Risk of Changtai Yangtze River Bridge is 24, in which, the number of the very high risk is 11, the high risk is 5, the medium risk is 8.

5. Summary

1) Based on the design characteristics of railway-highway bridge and its risk management requirements, concept of Joint Prevention Risk is put forward.
2) A method on evaluation of Joint Prevention Risk is put forward and the value of its related parameters are recommended at the same time.
3) The risk evaluation practice based on Changtai Yangtze River Bridge shows that the method is easy to use to aid make counter-measurements on risk management in railway-highway bridge.

6. Acknowledge

The above research works are supported by the project of the Jiaxing Science and Technology Plan (Grant No.2021AZ30001) and the Key Laboratory of Road and Traffic Engineering of the Ministry of Education, Tongji University, PRC.

References

[1]. Junqing Lei. Zuwei Huang. Chengzhong Gui. etc. Analysis of the Current Status and Continous Development Trend of railway-highway bridge. Steel Bridge. 2016. 31(11):1-4+37

[2]. Rongfeng Zhang. Xingjun Nai. Review on Operation Risk Evaluation of Bridge. China Water Transport. 2020. 20(10):123-125

[3]. Kamaitis Z. Risk of Accidents Due to Vehicle Bridge Collision[C]//International conference on safety, rick and reliability - trends in engineering. 2001, 753~758

[4]. Das P, Gibbs M. Vehicle collision loading criteria for bridge piers and parapets[C]//International conference on safety, rick and reliability - trends in engineering. 2001, 249~254

[5]. Xin Ruan. Research on Bridge Engineering Risk Evaluation System and Key Problems. Tongji University. 2006

[6]. Donghui Shan. Xiao Niu. Zhongbin Luo. etc. Research on Operation Risk Safeguard Mechanism of Railway-highway Corridor. Journal of China and Foreign Highway. 2021. 41(2):215-219