Safety risk prediction of cantilever construction of sanduizi super large bridge on Jinshajiang River Based on basic Bayes model

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Abstract. In order to better control the safety risk of bridge construction, this paper takes the cantilever construction of sanduizi super large bridge on Jinshajiang River as an example, and establishes the safety risk prediction model by using Bayes principle. Firstly, it constructs the Bayes relationship model of construction environmental factors and cantilever construction key process risk factors and events, and then uses Bayes theory to analyze the probability of risk events in various cases. Finally, the overall safety risk of cantilever construction, the influence degree of various influencing factors on the overall safety risk and the most unfavorable risk combination are studied. Through the application of examples, the results show that on the basis of theoretical research, targeted safety control measures are taken, and the safety risk is effectively controlled.

1. Introduction
The main bridge of sanduizi bridge on Jinshajiang River is a three span prestressed concrete continuous rigid frame super large bridge of 90.5m + 200m + 105.8m. The upper structure is a single box double chamber box section. The width of the top plate of the box girder is 19.5m, and the height of the box girder changes from 12.5m to 4.2m according to the parabola. The cantilever hanging basket is used for construction. The maximum cantilever section of the whole bridge has 27 sections. The north bridge site is located in the subtropical River Valley. The climate is not clear in four seasons, the temperature changes greatly, the rainfall is concentrated, and the climate conditions are complex. The main span of the bridge crosses the main stream of Jinsha River, and the side spans cross provincial highway 310 and dujin highway respectively, resulting in great traffic interference. The cantilever construction of the superstructure of the bridge lasts for a whole year. During the construction period, the most unfavorable seasons, such as gale, rainstorm and high temperature, are experienced. Moreover, there are many uncertain factors in the external environment of the construction, which makes the construction difficult and risky. According to the Code for safety evaluation of highway projects and Guide for Construction Safety Risk Assessment of highway bridges and tunnels, the safety risk assessment of the bridge is grade III (high risk), and the risk assessment of the cantilever construction of the superstructure is more than grade III. Therefore, the safety risk prediction method is adopted to establish the Bayes model for the safety risk of the cantilever construction of the bridge, and the analysis and research are carried out to further study and judge the prediction risk, so as to provide the basis for the safety prevention and control of the construction sequence, and effectively reduce the probability of accidents. It is proved that the
safety risk of the bridge can be controlled by adding safety measures in the later stage based on the Bayes prediction model.

2. Bayes safety risk prediction model

The occurrence of safety accidents cannot be simply evaluated by "certain occurrence" or "no occurrence". There are certain rules to follow and certain probability of occurrence can be met at the same time. As the occurrence of safety accidents, there are not only the external environment factors, but also the unsafe factors of people and things, and there are many uncertain factors. If we can make inferences and decisions based on uncertain information, we can predict the probability of accidents under various circumstances. The basic principle of Bayes model can well infer the conditional probability of safety accidents. The application of Bayes principle to the prediction of safety risk in cantilever construction of upper structure of sanduizi bridge shows that Bayes model can well reveal the relationship between the uncertainty factors of safety accidents and the probability of safety risk.

The whole probability and Bayes principle are fully used to build the risk prediction model of superstructure construction safety risk prediction. The main influencing factors of superstructure construction risk are divided, as shown in Figure 1. Suppose that the risk space of the superstructure construction risk factor event a is Ω, and the climate impact factor events in a year are B1, B2, ..., Bn, and is a partition of Ω, and P(Bi)>0 (i=1, 2, ..., n), P(A)=ΣP(A|Bi)P(Bi)(i=1,2,…,n ). At the same time, according to the construction process, each cantilever construction section is divided into C1, C2, ..., Cn, and is a partition of Ω, and P(Ci)>0 (i=1,2,…,n), Then P(A)=ΣP(A|Ci)P(Ci) (i=1,2,…,n).

Figure 1 Bayesian model of safety risk in cantilever construction of superstructure

Risk space is divided into two parts, namely B and C. Through the statistics of the national safety risk of the same type of bridge construction and the occurrence rate of climate influencing factors during...
the construction period, \( P(B), P(C), P(A \mid B), P(A \mid C) \) are the prophetic conditions. According to the full probability formula \( P(A) = P(B) \times P(A \mid B) + P(C) \times P(A \mid C) \), the cantilever construction safety risk probability can be predicted.

In order to effectively predict the risk probability of safety accident in each process of cantilever construction section Ci, the Bayes model is used to carry out the inverse deduction, assuming that the risk space of cantilever construction risk event a is \( \Omega \), \( C_1, C_2, \ldots, C_n \) is a partition of \( \Omega \), and \( P(A)>0, P(C_i)>0 \) (\( i=1,2,\ldots,n \)), so \( P(C_i \mid A) = \frac{P(A \mid C_i)P(C_i)}{\sum_{j=1}^{n} P(A \mid C_j)P(C_j)} \) can predict the safety risk, and then take corresponding measures to reduce the probability of accidents.

3. Safety risk prediction of cantilever construction

According to the principle of Bayes model, the risk factors of cantilever construction are collected, and the risk factors that may lead to accidents are analyzed from the aspects of human, machine, material, method and environment through the investigation of relevant personnel and the discussion of evaluation group. The accident possibility level is divided into four levels, as shown in Table 1.

| Probability interval | Center value | Probability level description |
|----------------------|-------------|-----------------------------|
| >0.3                 | 0.8         | probable                    |
| 0.03-0.3             | 0.1         | probably                    |
| 0.003-0.03           | 0.01        | accidental                  |
| <0.003               | 0.001       | Not likely                  |

According to the probability of Bi occurrence, we use the average days of climate influence / 360 days incidence rate as the risk probability through the statistics of the weather data of the first three years. The average days of gale, rainfall, high temperature and low temperature were 21 days, 93 days, 34 days and 62 days, so the \( P(B_i) \) were 0.0583, 0.2583, 0.0944 and 0.1722 respectively.

The probability of accident in construction process Ci is large, because of randomness and many unknown factors. According to the calculation method of risk factor probability based on Bayes inference principle, the prior probability distribution is calculated through investigation and statistics, and then the likelihood probability distribution is determined by regarding the event Ci as a stable and independent Bernoulli process. Finally, the posterior distribution density is obtained by using Bayes formula, and the occurrence probability of the event is deduced. The probability of birth.

For example, in the case of Ci, the risk probability \( p(C_1) \) of hanging basket walking is calculated. First, a preliminary survey result is obtained by questionnaire survey on experts with relevant professional experience, and experts' opinions are divided. After calculation, the prior probability distribution is obtained, as shown in Table 2.

| Risk factors and names | Risk occurrence probability classification | Survey results | Prior probability distribution |
|------------------------|------------------------------------------|----------------|--------------------------------|
| Hanging basket walking | Not likely 0.001                          | 27             | 0.5870                         |
|                        | accidental 0.01                           | 11             | 0.2391                         |
|                        | probably 0.1                             | 7              | 0.1522                         |
|                        | probable 0.8                             | 1              | 0.0217                         |
|                        | total                                    | 46             | 1                              |

Then determine the likelihood probability distribution. For the likelihood that one failure is found in the four routine inspections of "hanging basket walking" process by team, field technician, safety administrator and safety director, it is assumed that the likelihood probability of risk factors of "hanging basket walking" is as follows.
The probability distribution of "hanging basket walking" risk is calculated by Posterior probability distribution=Prior probability distribution X, Likelihood probability distribution/sum (Likelihood probability distribution), and the probability correction of risk factors is shown in Table 3.

**Table 3. Probability correction table of risk factors**

| Risk factors and names | Risk occurrence probability classification | Prior probability distribution | Likelihood probability distribution | Prior probability distribution x likelihood probability distribution | Posterior probability distribution |
|------------------------|--------------------------------------------|-------------------------------|------------------------------------|---------------------------------------------------------------|-----------------------------------|
| Not likely 0.001        | 0.5870                                     | 0.0040                        | 0.0023                             | 0.0373                                                        |
| accidental 0.01         | 0.2391                                     | 0.0388                        | 0.0093                             | 0.1510                                                        |
| probably 0.1            | 0.1522                                     | 0.2916                        | 0.0444                             | 0.7208                                                        |
| probable 0.8            | 0.0217                                     | 0.0256                        | 0.0056                             | 0.0909                                                        |
| **Σ**                   | **1.0000**                                 | **0.3600**                    | **0.0616**                         | **1**                                                         |

Then P(Hanging basket walking C1)=0.001×0.0373+0.01×0.1510+0.1×0.7208+0.8×0.0909=0.1463, which is the probability of occurrence of "hanging basket walking C1" risk factors. With this method, we can calculate P(C2)=0.2104, P(C3)=0.1072, P(C4)=0.1762, P(C5)=0.1104.

Considering the environmental factors in the cantilever safety risk of the superstructure and the safety risk in the key construction process, the method of full probability P(A)=ΣP(Bi)×P(A|Bi)+ΣP(Ci)×P(A|Ci) calculates the construction safety risk. After obtaining the existence or occurrence probability of risk factors, based on common sense judgment, statistical data and consultation with personnel with relevant work experience, the conditional probability P(A|Bi) and P(A|Ci) between nodes are obtained, and the occurrence probability of each risk event is calculated, as shown in Table 4.

**Table 4. Calculation table of occurrence probability of risk events and contribution degree of risk factors**

| Name of risk event | Risk factors affecting the event | Probability of risk factors conditional probability | Probability of occurrence x conditional probability | Probability of occurrence of this risk event | Contribution of risk factors |
|--------------------|---------------------------------|-----------------------------------------------------|-----------------------------------------------------|---------------------------------------------|------------------------------|
| Environmental risk  | Gale effect                     | 0.0583                                              | 0.8                                                 | 0.0466                                       | 0.4655                       |
|                     | High temperature effect         | 0.0944                                              | 0.12                                                | 0.0113                                       | 0.1129                       |
|                     | Rainstorm impact                | 0.2583                                              | 0.1                                                 | 0.0258                                       | 0.2577                       |
|                     | Effect of low temperature       | 0.1722                                              | 0.1                                                 | 0.0172                                       | 0.1718                       |
| Key construction procedures | Hanging basket walking         | 0.1463                                              | 0.85                                                | 0.1244                                       | 0.6261                       |
|                     | templates installing            | 0.2104                                              | 0.1                                                 | 0.0210                                       | 0.1057                       |
|                     | Reinforcement fabrication and installation | 0.1072 | 0.11 | 0.0118 | 0.1987 | 0.0594 |
|                     | Concrete pouring                | 0.1762                                              | 0.11                                                | 0.0194                                       | 0.0976                       |
|                     | Prestressing tension            | 0.1104                                              | 0.2                                                 | 0.0221                                       | 0.1112                       |
It can be seen from the above that the cantilever safety risk prediction $P(A)=0.1001+0.1987=0.2988$. According to the accident possibility level in Table 1, the accident probability is possible and the risk level is above level III. According to Bayes principle, the probability of each factor is the contribution of risk factors, as shown in Figure 2.

![Figure 2. Bayesian model of safety risk in cantilever construction of superstructure](image)

As can be seen from Figure 3, gale weather and hanging basket walking factors are the main factors of cantilever construction safety risk. Therefore, in view of these two unfavorable factors, hanging basket walking operation in gale weather should be avoided as far as possible. At the same time, a series of perfect safety control measures should be formulated to reduce the risk of accidents.

4. Conclusion
Through the application of Bayes model in the cantilever construction safety risk prediction of sanduizi super large bridge on Jinshajiang River, it plays an important role in the construction safety control of the bridge. In the cantilever section construction, the adverse weather such as strong wind and the occurrence rate of hanging basket walking operation are relatively high. Due to the scientific research based on Bayes principle, the necessary safety measures are taken in advance. The closure of the main bridge has been successfully completed without safety risk.

By using Bayes principle, the safety risk prediction model of cantilever construction of bridge superstructure is established, and the safety risk prediction index is quantified, which not only meets the basic principle of mathematical statistics, but also studies from the perspective of the probability of safety risk events. This method has several advantages: Firstly, the probability of $P(A)$ can be fully quantified, so that the probability of unsafe factors in environment and key construction processes can be predicted. In addition, it can reflect the probability of various influencing factors on the safety risk of the whole event. At the same time, it reflects the influence degree of the most unfavorable factors from various influencing factors, so as to provide a scientific theoretical analysis basis for construction safety measures. However, the disadvantage of the whole prediction research is that the prior probability and part of the conditional probability events mainly rely on the known safety risk events of the same type of bridge and expert evaluation, and the data sample size is too small, which depends on the knowledge level and ability of experts, but the Bayes principle is an improvement on the traditional safety risk evaluation system, with the development of information technology, the establishment of big data of bridge safety risk will provide a more accurate data basis for bridge construction safety risk prediction, and the research of basic Bayes model bridge safety risk prediction will have a better development space.

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