Scheme comparison for bridge reinforcement or reconstruction based on practical effects

Fu-Jun Xie
Central South University, Changsha, 410075, China
Transport Bureau of Hengyang City, Hengyang, 421001, China

Abstract. It is an important part of scheme comparison for dangerous bridges reinforcement or reconstruction. Through systematic compared dangerous bridge reinforcement with its reconstruction based on the practical effect, a comprehensive evaluation method can be made. With the method, the scheme comparison analysis of dangerous bridges in Hengyang city is carried out. Finally, the program of dangerous bridge to be reinforced or reconstructed is obtained. This method can provide practical guidance for decisions of dangerous bridges scheme comparison.

1. Introduction
The highway transportation’s role and status in the national economy is increasing with a continuous development of the national economy. It has been get more and more attention. In recent years, a great upsurge of highway construction is coming in our country, meanwhile, the construction scale continues to rise and the highway mileage continues to grow. By the end of 2015, the highway mileage has been reached 4577300 kilometers which density is 0.4768 kilometers per square kilometer. The number of highway bridges is 779000 that is 45927700 meters. Among the highway bridges, the number of greatest long span bridges is 3894 that is 6904200 meters, the number of great long span bridges is 79512 that is 20608500 meters. (among a world's top ten greatest long span suspension bridges, 5 in China; among a world's top ten greatest long span cable stayed bridges, 7 in China; among a world's top ten greatest long span arch bridges, 6 in China). So, China has become the second largest bridge country after the United States.

Highway bridge is a throat for open highway which bearing and traffic capacity is a key to highway traffic system. It is affects the economic benefits and social benefits of highway transportation directly. Highway bridge construction have made an great achievement in our country from 2001 to 2010. In terms of quantity and scale, our country has became a largest bridge country in the world. However, many problems of bridge maintenance management have gradually exposed after the large-scale construction. According to existing bridge quality and durability and its service level, our country still need to make a considerable effort to become a powerful bridge country.
Table 1. The basic situation of China Transportation from 2001 to 2010

| Time          | 2001   | 2002   | 2003   | 2004   | 2005   | 2006   | 2007   | 2008   | 2009   | 2010   |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Number of     | 284117 | 299397 | 310773 | 321626 | 336648 | 533620 | 570016 | 594629 | 621907 | 658100 |
| Highway Bridges length (10000m) | 1064.97 | 1161.22 | 1246.61 | 1337.64 | 1474.75 | 2039.90 | 2319.18 | 2524.70 | 2726.06 | 3048.31 |
| Number of dangerous Bridges | 10131  | 10804  | 10443  | 13303  | 14659  | 63094  | 98623  | 97795  | 95742  | 93525  |
| Length of dangerous bridge (10000m) | 35.79  | 39.1   | 37.84  | 46.89  | 53.74  | 117.82 | 306.87 | 292.76 | 276.24 | 2613.45 |
| Proportion of dangerous bridge (%) | 3.57   | 3.61   | 3.36   | 4.14   | 4.35   | 11.82  | 17.30  | 16.45  | 15.39  | 14.21  |

Table 1 shows that the number of highway dangerous bridges in our country is within 5% from 2001 to 2005. In 2006, both the construction scale and the number of dangerous bridge have grown with leaps and bounds, the number of dangerous bridge had accounted for 11.82% of the total highway bridges. In 2007, it was 17.30% the peak in history. In 2008, a plan, dangerous bridges reconstruction should be completed in three years, had come out by the Department of Transportation. From that time, the proportion of dangerous bridge have declined year by year. It will be expected that the total number of dangerous bridges will fall to the level of 2001 at 2020.

By the end of 2009, a dangerous expressway bridge and 4332 ordinary highway bridges that is 134610 meters had been included in the library of dangerous bridges in Hunan province. It is included 1878 fouth type dangerous bridges that is 57950 meters and 1417 fivth type dangerous bridges that is 37350 meters. A total number of highway bridges is 2838 that is 84762 meters in Hengyang. Among them, the number of national and provincial highway bridges is 192 that is 11835 meters, the number of county road bridges is 200 which is 4932 meters, the number of rural highway bridges is 2446 which is 67995 meters. In Hengyang, there are 320 highway bridges which is 9015 meters were included in the provincial dangerous bridge library. It is included 108 third type dangerous bridges which is 2547 meters and 212 fouth and fivth type dangerous bridges which is 6468 meters.

With the increase of a number of dangerous bridges, the bridge collapse accidents are more often in our country. According to media statistics, from 2007 to 2015, there are many bridge collapse accidents that included 13 bridge accidents during construction and 7.4 “deadly bridge” every year on average. The bridge collapse accidents happen so frequently. On the one hand, it will affect highway functions, On the other hand, it is a serious threat to personal safety. So, We must pay enough and extensive attention to. That how to deal with these dangerous bridge is an urgent task need to be solved through a limited funds to produce the greatest economic benefits.

In recent years, many domestic and foreign scholars have researched on disease bridges and old bridges reinforcement or reconstruction, and Some achievements have been obtained. The new technology and new materials have been applied. However, there is not a practical comparison analysis to decide the old dangerous bridge to be reconstruction or reinforcement maintenance. Therefore, the practical comprehensive assessment for old bridges reconstruction or reinforcement is necessary.
2 Comparison Summarize Of Dangerous Bridge Reinforcement Or Reconstruction

Many scholars have studied on bridge reinforcement or reconstruction when the bridge defects happen\[5\]. Such research methods and results are as follows.

2.1 Coefficients comparison method

The method is based on reinforced life coefficient index and reinforcement cost coefficient index\[6\]. When a coefficient of strengthening life $n_2=N_2$, meanwhile, if the reinforcement cost coefficient $n_1$ less than the critical reinforcement cost coefficient $N_1$, it means that the reinforcement is economic and reasonable; If $n_1$ greater than $N_1$, it means that the reinforcement is not economic and it should be rebuilt. $N_1$ and $N_2$ are shown in Table 2 (take bridges original design life of 50 years for example). The coefficients comparison method is only applicable to concrete and prestressed concrete bridges’ evaluation, the bridge made of special material should adopt a comprehensive evaluation method.

| Operation life (years) | Critical coefficient of reinforcement cost $N_1$ | Critical coefficient of reinforcement life $N_2$ |
|------------------------|-----------------------------------------------|-----------------------------------------------|
| 0                      | 0.7                                           | 1.0                                           |
| 10                     | 0.6                                           | 0.8                                           |
| 20                     | 0.5                                           | 0.6                                           |
| 30                     | 0.4                                           | 0.4                                           |
| 40                     | 0.3                                           | 0.2                                           |
| 50                     | 0.1                                           | 0                                             |

This evaluation method is of not operational due to lack of management and maintenance data, especially the technical and economic data of bridge components seriously in our country. The method is theoretically rigorous and the method is a feasible economic analysis method can not apply to practice, because a reinforcement life coefficient and a reinforcement cost coefficient can not be calculated accurately.

2.2 Structural reliability method

The structural reliability is the probability of engineering structures complete the expected functions within the specified time and under the specified conditions. The specified time is a reference time which combined with the structural service period and considered various basic variables relate to time when a structures take a reliability analysis. The specified conditions is normal design and construction and operation conditions except human error influences. The expected functions are that a structure can withstand all sorts of possible load and should have a good working performance and sufficient durability during a normal construction and operation period as well as overall stability when accidents happen. The term “specified time” in reliability is the structural design period which is general 50 years in most countries. So, the longer specified time is, the lower reliability becomes. According to “General code for design of highway bridges and culverts”(JTJ D60-2004) , the design reference period of highway bridge is 100 years in China.

Based on the reliability theory, Highway bridge reinforcement or reconstruction analysis takes into account design parameters and objective functions and constraint functions as well as materials and construction quality which are of random, fuzzy and unascertained\[7\]. With the method, The bridge structural target reliability or failure probability is more scientific and quantitative safety. Moreover, considered the failure probability and failure loss caused by different functions, and considered the operation and maintenance cost economic indicators, The method reduces cost and achieves best economic benefits and meets the economic reasonable design requirements.
Take structural reliable degree as the control parameter, the method is able to deal with bridge structural uncertainty and make the contradiction between the safety and economic as well as the contradiction between the short-term investment and long-term benefits obtained optimal coordination. Thus, under security conditions and application conditions and economic conditions, the highway bridge design scheme can lead to the best results.

However, the method can only be used for qualitative analysis. It is difficult for quantitative calculation because a lot of parameters are empirical and it’s too complex and is not practical for large-scale old and dangerous bridge maintenance.

2.3 CPI/CPD method based on “ALARP rule”

The structural risk assessment of ALARP criteria is ALARP risk decision criteria proposed by the British National Health and Safety Council in 1999.

According to the classification of bridge technical condition, the first type bridge whose corresponding maintenance countermeasure is daily maintenances is not considered in this method. The bridge technical condition below the fourth type whose corresponding maintenance measures is reinforcement or reconstruction is an acceptable region for the CPI/CPD method.

When the bridge technical condition belongs from 2th type to 4th type, which is ALARP region defined by system.

In this region, bridge maintenance scheme uses contrast method which determined by cost ratio W. It is Shown in Formula 1.

\[ W = \frac{W_R + \frac{W_m}{(1+i)^N} + j}{W_m} \]  

Where CPI is the cost of bridge structural maintenance and reinforcement in order to improve performances; CPD is the cost of bridge structural performance degradation without maintenance and reinforcement; \( W_R \) is the cost of bridge structural maintenance and reinforcement; \( W_m \) is the cost of rebuilding the bridge structure is 4 times as much as the initial construction cost; \( N \) is the time interval between bridge structure doesn’t use reinforcement maintenance and its technical status is not acceptable; \( j \) is the extended value between bridge structure uses reinforcement maintenance and its technical status is not acceptable;

Based on the results of formula (1), if \( W \leq 0.5 \), reconstruction is adopted; if \( W > 0.5 \), reinforcement and maintenance is adopted.

The CPI/CPD method based on the “ALARP” rule is abstract, and a lot of parameters are assumed, the calculation results to determine the bridge reconstruction or reinforcement are more reluctant and it is not scientific.

3 Practical analysis method to determine the scheme about bridge reinforcement or reconstruction

Practical analysis method is of reality and can be applied to large-scale bridge maintenance and reconstruction. It is the most direct means to avoid delaying about the selection of bridge reinforcement or reconstruction. The facts turn out that excessive theory analysis on bridge maintenance and reconstruction for old and dangerous bridges is just waste time. The truly effective factors are actual effects of bridge serving, it’s included the bridge’s technical state, service conditions, maintenance of sophisticated and local economic development.

3.1 Technical condition assessment of bridges based on “Standards for technical condition evaluation of Highway Bridges”

“Standards for technical condition evaluation of Highway Bridges” is a bridge evaluation Standard according to the classification of different bridge types and refine the classification of different
component types. Evaluation rules have been set according to different bridge components types, the evaluation subdivision index and quantitative standard has been put forward.

There are 5 types of technical conditions for bridges (Table 3), the model of evaluation of bridge technical conditions have been improved. At the same time, main components and minor components of the bridge have been divided clearly. The evaluation of technical conditions for main components and minor components of bridges have been described in detail. So, this evaluation method is more scientific.

| Technical condition assessment level | Bridge technical description |
|-------------------------------------|-----------------------------|
| First type                          | New state, Functional integrity |
| Second type                         | Slight defect, no influence on bridge functions |
| Third type                          | Moderate defects, maintain normal bridge functions |
| Fouth type                          | Major components have large defects, a serious impact on bridge functions, can not guarantee the normal use |
| Fivth type                          | The main components have serious defects and can not be used normally, endanger a bridge safety and the bridge is in a dangerous state |

As “Highway bridge maintenance management system” twenty-fifth article said: bridge maintenance project is divided into minor repairs and maintenance, medium repair, heavy repair and reconstruction.

The bridges of first type and second type should adopt minor repairs and maintenance to prevent obvious diseases emergence. To prevent disease accelerating expansion and not affecting bridge operation, the third type bridges should adopt medium repair without delay. To ensure the safety, according to the special inspection results and technical certification analysis, management measures should be taken in time and reconstruction should be made for fouth or fivth type bridge. In Hengyang City, In addition to special conditions, reinforcement and maintenance should be adopt for the third type dangerous bridge. Based on practical analysis, reinforcement or reconstruction should be adopt for the fouth type bridges. All of the fivth type bridges should be reconstructed.

3.2 Practical analysis on the bridges.

According to the actual situation of Hengyang, All of the small and medium span bridges belong to the fouth type bridges should be reconstructed. Reinforcement maintenance should be adopted for greatest long span bridges belong to fouth type bridges and comprehensive analysis method should be adopted to determine the optimal selection. The evaluation criteria of comprehensive analysis method includes bridge service life and growth rate of road traffic and road load as well as traffic infrastructure investment proportion, location and maintenance, etc. Details are shown in Table 4.
According to the comprehensive analysis method, Scheme Comparison for fourth type bridge in Hengyang have been made. The results show that the number of fourth type bridges is 80, among them, 25 bridges need to repair and reinforce and 55 bridges need to reconstruct.

### 4 Conclusion

According to "highway bridge maintenance management system" and "Standards for technical condition evaluation of Highway Bridge" (JTG/T H21-2001), the program about bridge reinforcement or reconstruction can be determined except fourth type bridges.

Based on a basic situation of the bridge by the Standard, practical comprehensive analysis on a reinforcement or reconstruction about fourth type bridges have been made. It can provide a guidance for reinforce the bridge efficiency and reasonable under the limits funds.

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**Table 4 Evaluation criteria for comprehensive analysis method**

| Evaluation project                                      | Evaluation weight                                                                 | Evaluation result analysis                                                                 |
|--------------------------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| 1. Service life (20 points)                            | From 0 to 50% of design life, the score is determined from 0 to 20 points with interpolation method. | Score: 70-100, demolition and reconstruction are adopted. Score: 0-70 (excluding 70 points), reinforcement and maintenance are adopted. |
| 2. Growth rate of highway traffic volume (10 points)   | Growth rate of road traffic is no more than 5%, 5 points. Growth rate is between 5% and 10%, 8 points. Growth rate is more than 10%, 10 points. |                                                                                           |
| 3. Growth rate of road load (10 points)                | Growth rate of road load is no more than 5%, 5 points. Growth rate is between 5% and 10%, 8 points. Growth rate of more than 10%, 10 points. |                                                                                           |
| 4. Transportation infrastructure investment accounted for the proportion of fiscal revenue (20 points) | Accounted for 0-10%, the score is determined from 0 to 20 points with interpolation method. |                                                                                           |
| 5. Impact on local traffic (Local people and public opinion on behalf of the 100 evaluation) (20 points) | 0 to 100 peoples agree to remove and reconstruction the bridge, the score is determined from 0 to 20 points with interpolation method. |                                                                                           |
| 6. Maintenance level (20 points)                       | According to the maintenance standards of 10 classes (from good to poor), the score is determined from 2 to 20 points. |                                                                                           |