Quality Evaluation for Existing Structure of Highway Bridge after Years of Shutdown

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Abstract. To evaluate the quality of an existing structure which is lack of information in the highway bridge after years of shutdown. An evaluation method is proposed, which is based on the fuzzy mathematics and catastrophe theory. Comparing traditional methods, the method avoids determining the uncertain index weights. A fuzzy set is utilized to classify the evaluation rating. Based on a girder bridge of Pingxiang-Hongkoujie Highway, an evaluation index system and grade classification standard for existing structure of the highway bridge after years of shutdown is established. In addition, the method of catastrophe-fuzzy theory evaluation is applied in the practical engineering. The results show that the method of catastrophe-fuzzy theory evaluation can get an objective evaluation result, the quality evaluation system can be used as a basis for similar projects and bridge quality.

1. Introduction

Highway construction projects due to funding strand breaks and other causes of downtime, the existing structure during the long term in a state of no regulation, resulting in structural damage to nature and human [1]. In order to return to work on the basis of the existing structure, it is the key to determine the availability of the existing structure and the quality level of the structure.

At present, the research work of bridge structure are experts in Hainan Province Highway Survey and Design Institute of Anhui province and the traffic planning and Design Institute of project to both the structure of bridge disease and restart the plant design are analysed [2], and the main factors were analyzed according to a single, not of existing structure system are discussed. The overall interaction between the various components of the bridge actually. The study of existing evaluation methods of the quality of the bridge, has been from the general scientific evaluation methods similar to the check list based on system engineering, gradually to the development of comprehensive evaluation method, fuzzy mathematics and other disciplines on the basis of the cross[3-6].The comprehensive evaluation of the most widely used and the high degree of recognition method for fuzzy comprehensive evaluation of fuzzy mathematics and AHP method based on this method, but the index weights determined by people's subjectivity influence greatly, the accuracy of the evaluation results of the weight distribution often influence[7].However, in the existing method, the catastrophe theory can compensate for the subjectivity of index weights is too large, and in civil engineering has been applied[8-10], but the mutation theory rank is not intuitive, although Shi Yuqun[11] was improved from algorithm, but the evaluation grade determination still belongs to the classical set, as fuzzy set exact. In this paper, the membership function of fuzzy comprehensive evaluation method is used to divide the evaluation level, and the two methods are improved and complementary.

Therefore, this paper based on catastrophe theory and fuzzy mathematics theory to establish the highway bridge structures is a quality evaluation model, based on the existing specification of bridge quality classification standard, the resumption of work on Jiangxi Hong Ping expressway project is to evaluate the quality of bridge structure.

2. Catastrophe fuzzy comprehensive evaluation method

Mutation - fuzzy evaluation method is a comprehensive evaluation method based on catastrophe theory and fuzzy mathematics, the basic principle is mainly based on catastrophe theory and the values of control variables in the righteous fall within the set will enable the system status change properties to construct the evaluation model, which is characterized by considering the relative importance of each index. Using a combination of qualitative and quantitative methods, to reduce the subjectivity of the evaluation process. Mainly includes the following steps.

2.1. Construction of evaluation index system

The construction of index system mainly uses the analytic hierarchy process (AHP) to establish the hierarchical structure, and the importance of each layer is sorted. The order of the main indicators can be used to sort the expert rating, but also based on the norms of the indicators of the weight of the indicators to determine the degree of importance. The decomposition of each layer is shown in figure 1.

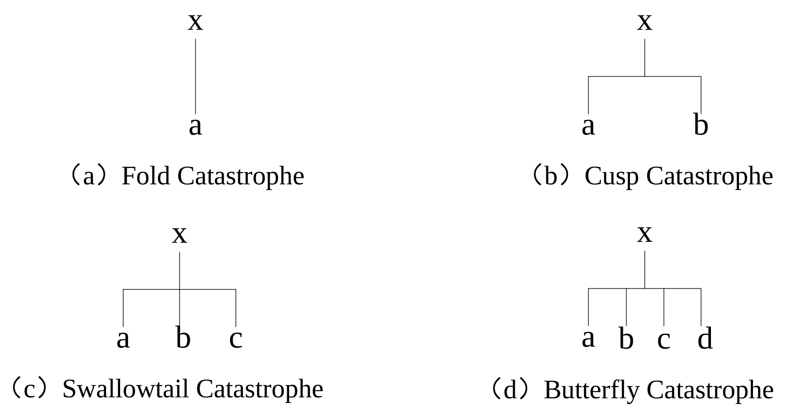

Fig.1 Catastrophic Model

2.2. Standardization of evaluation index data

The underlying index of both quantitative indicators, there are qualitative indexes, each index classification standard is not the same, some index value is greater the higher the level, the greater the value of some index grade is low; for the quantitative index of different, there are differences in the dimension.

Therefore, the need for data normalization of the underlying indicators of different situations, that is in accordance with the control standard of certain raw data will be converted into [0,1] range of dimensionless index value, conversion method of visible (1) - (2).

The more optimal index: $$y=\begin{cases}1 & 0\le x\le x_{\min}\\ \dfrac{x_{\max}-x}{x_{\max}-x_{\min}} & x_{\min}<x<x_{\max}\\ 0 & x_{\max}\le x\end{cases} \quad (1)$$

The smaller the better index: $$y=\begin{cases}1 & x\ge x_{\max}\\ \dfrac{x-x_{\min}}{x_{\max}-x_{\min}} & x_{\min}<x<x_{\max}\\ 0 & 0\le x\le x_{\min}\end{cases} \quad (2)$$

2.3. Basic model and normalization of catastrophe theory

There are four kinds of basic models of catastrophe theory, the most common are folding mutation, cusp mutation, swallowtail mutation and butterfly mutation model, and the potential function of each mutation model is seven.

According to the basic principle of catastrophe theory, we obtain the first order derivative of the potential function of the catastrophe model and the other derivative is zero. The two order derivative of the potential function is obtained, and the derivative is zero. The first order and two order derivative equations are used to eliminate the state variables, and the decomposition equation of the relation between the state variables and the control variables can be obtained. When all the control variables in the bifurcation equation satisfy the different set of points, the system will have a sudden change. Therefore, can calculate the 4 kinds of common mutation model and bifurcation equation, bifurcation equation can be obtained by the normalization formula of catastrophe model.

The unitary operations on the underlying index by using the formula, according to the principle of complementary and non-complementary, can be obtained by numerical mutation of ranking index, and then repeat the above steps sequentially on the higher index to compute numerical mutation of each layer of index, until the top level index, determine the total mutation level value.

For the definition of the principle of complementary and non-complementary, non-complementary principle that if all control variables of a system, such as the mutation does not exist obvious interaction or not can compensate each other between the control variables in the model of a，b，c，d evaluation index. Then, when the system state variable x is calculated according to the normalized formula, the minimum value of the mutation value x corresponding to the control variables should be selected as the mutation value of the state variable. On the contrary, there are interactions between various control variables is complementary principle of a system or can make up for each other, you should take control of the average level of numerical variables corresponding to mutations such as x_a， x_b， x_c， x_d the state variable numerical mutation.

2.4. Evaluation grade determination

In the various evaluation methods, the subordinate degree of the underlying index is the evaluation index. The comprehensive evaluation index and the top value also has a certain classification standard, so the evaluation result has come to: 1 (intact), II (good), III (bad), IV (difference) and V (dangerous) the meaning of evaluation results. There is no absolute grade in the evaluation value of the catastrophe progression evaluation method, and the final value is the mutation value of the evaluation object. On this issue, Shi Yuqun proposed a mutation value transform into transformation method in evaluation of the value, but the conversion of post evaluation grade value is still no clear criteria for the underlying index grading standards differences, the evaluation results will also exist large error.

On the basis of the above, the membership function of fuzzy mathematics based, and applied to all levels of evaluation grade determination, which can solve the value of the mutation cannot determine the evaluation grade and transform evaluation classification too much subjective problems. Finally, according to the subordinate function value and the total mutation membership function, the evaluation object is analyzed and evaluated comprehensively

3. The application of catastrophe fuzzy theory to the quality evaluation of existing structures of suspension bridges

3.1. The quality evaluation index system for existing bridges

In the literature and norms of the country, the main construction of the bridge is mainly new and service, the establishment of the index system is divided into the type of structure, the type of material and the division ac-cording to the standard. In this paper, based on the above method, with reference to the relevant norms, and to the girder bridge as an example, combined with the principle of AHP, a construction method of existing bridge girder suspension structure quality evaluation index system. Due to the analysis of the suspension bridge project has not completed the construction of the superstructure, so the existing structure of the quality evaluation index does not take into account the superstructure and ancillary facilities. If the other bridges in the project, according to the actual situation to add or reduce components. In addition, for both the binding site downtime will exist and the interface between the structure and the new structure, this part is the focus of work quality evaluation rehabilitation project, and other parts of the new and old bridge evaluation index is similar.

If we directly evaluate the underlying index, we can only get the qualitative results, which has a large subjective factors. On the basis of the above analysis, the above indexes are divided into quantitative evaluation of material properties, geometric deflection and appearance defects. Mainly divided into the following areas:

(1) The integrity of pile foundation is tested by low strain reflected wave method. The pile length and the length of pile are classified to realize the quantitative evaluation of pile foundation integrity.

(2) The evaluation of new and old structure combine parts, generally divided into reinforced concrete interface for performance and performance; the performance is divided into reserved steel reinforcement length, weight deviation and reserved reinforced steel strength three part; combined with the performance surface of concrete is also divided into chloride content, concrete carbonation of concrete and concrete strength. Through the test of the above indexes and the classification according to the relevant standards, the quantitative evaluation of the combination of the new and old structures is realized.

(3) In addition to the combination of new and old parts, other structures and new beam bridge, the old bridge structure is not very different. Therefore, according to the new bridge and the old bridge index.

The structure is divided into several aspects, such as the performance of reinforced concrete, the concrete performance, the geometric deviation and the apparent defect. Among them, the reinforced performance is divided into reinforcement spacing deviation, rebar diameter deviation; concrete performance is divided into the content of chlorine ion, carbonation of concrete, the concrete strength of the three part; the apparent defect is divided into crack width, spalling reinforcement area, honeycomb aspects.

3.2. Classification criteria for quality assessment of existing structures for suspension bridges

The classification of bridge evaluation index directly determines the accuracy and authenticity of the evaluation results. The classification is too small is not easy to distinguish the quality of bridge structure, reasonable use and maintenance of the bridge; if the classification is too much, the grade difference is small, resulting in grading standard itself is uncertain and fuzzy. Based on the research of literature classification at home and abroad, the classification of durability, safety and quality evaluation of bridge structure is mainly distributed at 2-6 level.

This paper consider the underlying index classification according to "highway bridge maintenance standards" (JTG H11-2004) and "highway bridge technical condition evaluation standard" (JTG/T H21-2011), in order to ensure the consistency of the bridge overall evaluation and the underlying index evaluation level, the evaluation grade is divided into five levels, namely I (intact), II (better and (III) poor), IV (difference) and V (dangerous).

4. Engineering application

4.1. Engineering survey

Ping Hung highway project in June 2008 shut down until the end of 2012 to return to work. In this paper, relying on the bridge in the project analysis, the bridge before the resumption of the superstructure has not yet been constructed. The construction of the column is completed, and the rest of the construction is different to the beam of the column.

4.2. Quantitative analysis of the underlying indicators

By means of field testing, the structural defects such as apparent defects and geometric deviation are obtained. Then, the test results of reinforced concrete and reinforced concrete are obtained. Then, based on the trapezoidal distribution of membership functions in the specification and fuzzy mathematics, the detection values are normalized with the formula (1) (2).

The method of expert scoring is used to rank the importance degree according to the weight of the index. It is necessary to use the complementary and non-complementary principles to judge the relationship of each level of the index before the calculation.

4.3. Calculation and evaluation results

By dimensional complete bottom index normalization, index classification standard, a ranking of all levels of indicators, evaluation criteria of determining and calculating model selection and other preparatory work, in turn to each index evaluation, the comprehensive evaluation results see table 3.

Tab.3 Result of Comprehensive Assessment

Index	Index Mutation Values	Evaluation Result
Pile	(0.536,0.984,0.575,0.524,0.536)	(0,0.737,0.575, 0.524,0.536)
Foundation	(0.935,0.972,0.971,0.931,0.849)	
Pier	(0.792,0.887,0.893,0.953,0.877)	
Abutment	(0,0.737,0.741,0.910,0.911)	

The bridge is an index structure in between can each make up for lack of non-complementary principles, in accordance with the principle of the minimum value of the index value of the mutation as both the structure of the evaluation value, so that the final evaluation value is {0,0.737,0.575,0.524,0.536}.

According to the principle of maximum membership degree in fuzzy mathematics, the maximum value is in the second level, the value is 0.737, and the next is the third level, the value is 0.575. Based on the results of comprehensive evaluation based on catastrophe theory, it can be seen that the existing bridge structure has a grade of grade II.

5. Conclusion

According to the highway construction project for a long time to shut down, both the structure of quality defects and diseases in different degrees, resulting in difficulties and return to work before return to work both bridge structure quality cannot accurately assess the problem. Taking the existing structure of the bridge as the research object, this paper studies the quality evaluation method by using the fuzzy mathematics and catastrophe theory:

（1）On the basis of bridge structure and to resume the project is special structure, based on beam quality and safety evaluation research literature and the existing norms, methods by AHP and normative finally obtained a set of reasonable and suitable for highway bridges to both the structure of the quality evaluation index system, the classification standard applies to a highway bridge to the existing structure of quality evaluation.

（2）The quality evaluation theory of existing bridge is analyzed and compared, and the fuzzy comprehensive evaluation method and catastrophe series comprehensive evaluation method are used to evaluate the quality of existing bridges. The fuzzy comprehensive evaluation method for evaluation of catastrophe progression method comprehensive evaluation index of the top income value cannot accurately determine the lack of evaluation grades, and can compensate for the catastrophe progression method comprehensive evaluation in fuzzy comprehensive evaluation method to determine the weight value of the subjectivity of the problem of excessive. Based on the analysis and improvement of the two evaluation methods, a fuzzy comprehensive evaluation method is put forward.

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