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Damage Assessment and Remaining Life Prediction for Structures

Evaluation des dommages et de la vie restante des structures

Schadensbewertung- und Restlebensdauer-Prognose für Tragwerke

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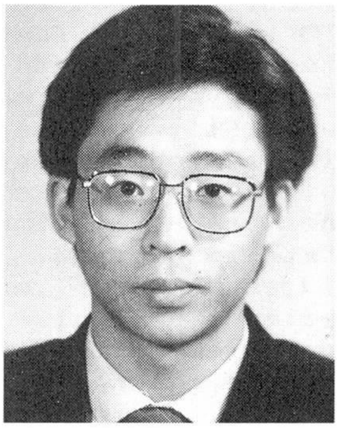

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SUMMARY

This paper firstly gives a brief review on the research of damage assessment and remaining life prediction for existing bridge structures in China. Secondly, a discussion on this topic is also presented. Finally a prototype expert system for damage assessment of railway bridges is introduced.

RÉSUMÉ

Après une introduction sur les recherches et l'évaluation des dommages et de la vie restante des structures de pont en Chine, et des commentaires sur les méthodes existantes, l'auteur propose un projet de système expert pour déterminer l'état des dommages et de la vie restante des structures de ponts ferroviaires.

ZUSAMMENFASSUNG

Der Beitrag gibt eingangs einen kurtzen Überblick über die chinesische Forschung bezüglich Schadensbewertung und Vorhersage der Restlebensdauer von Brückentragwerken. Nach einer Diskussion der Problematik wird der Prototyp eines Expertensystems für Schäden an Eisenbahnbrücken vorgestellt.

1. INTRODUCTION

The safety of railway transportation has been focused serious attention of railway administration, research and design branches, not only because railway accidents always induce heavy loss of the life and property of peoples, but also because the most important is it is directly related to traffic schedule of railway transportation. Of a lot of factors affecting railway traffic safety, it is the service state of railway track and railway structures which plays a significant role to. Firstly, railway construction, especially railway bridges have a long service life and difficult rehabilitation characteristics. Secondly repair expense of railway bridge is very great. Hence railway maintenance branches has a very important, long-time task which is bridge service state inspection. Since 1950's, damage assessment of railway bridges has been investigated and a lot of experimental data and experience have also been obtained. But due to the complexity of the problem, it is still a very important research project to start deepgoing investigation on damage assessment and remaining life prediction method for existing structures. At the end of the paper, a prototype expert system to diagnose damage state of railway bridges will be briefly introduced.

2. BRIEF REVIEW ON THE RESEARCH

For a long time, railway bridge inspectors and researchers in China have been searching for a reasonable and effective method to assess service state of railway bridges. But up till present, no well method has been developed, owing to the limit of experience and research work as well as the complexity of the problem. Existing approaches may be classified into two kinds: physical inspection and mechanical measurement, such as structural outward appearance observation for cracks and dynamic response test. Physical means for interior inspection include ultrasonic method etc. Not all of the existing methods is effective.

In Northern China, railway has served for a considerablly long time. Bridge damage is more serious. Hence Harbin Railway Administration Bureau has paid more attention to the research and practice of damage state inspection and assessment for bridges. Since 1979's, a lot of situ test data for dynamic response and time-domain properties of railway bridges have been accumulated, and a great deal of experience for diagnosing damage state of bridges has been obtained. They applied maximum transver dynamic displacement of bridge pier and some peculiarities of vibration wave of pier-head displacement as identifying rule to sum up into 10 types of damage for bridge pier.

China Academy of Railway Sciences started the investigation and research work on this topics in last 1970's. At the first stage of research, CARS has gathered a lot of situ dynamic test data for existing bridges, which have been also analyzed, for example, the effects of damage on frequencies, modes, time-domain and frequency-domain peculiarity of bridges. Classifying the test data of about 80 bridge piers, CARS has suggested a standard for damage diagnosing of bridge pier.

The investigation on damage assessment for superstructure of bridges in China started in middle 1980's. CARS firstly did a lot of inspection work on riveted and welded steel bridges. Then a great amount of tests on fracture mechanics and fatigue properties of situ samples of bridge elements. For these kinds of bridges, CARS has done about 10-year investigation and has obtained some preliminary results. In recent years, CARS still does an amount of researches on damage assessment method for reinforced and prestressed concrete railway bridges, as well as strengthening method for damaged bridge rehabilitation.

According to present research state, the investigation and research on damage assessment and remaining life prediction approaches for existing railway bridges must be continued.

3. PREPARE WORK IN DAMAGE ASSESSMENT PROCEDURE

Prepare work for damage assessment of existing structures is composed of two stages:

* situ inspection and testing
* laboratory testing and analysis

The main objective in the first stage is to acquisite practical structure geometric, physical and mechanical knowledge and information about the bridge to be assessed. The methods to inspect the bridge include outward appearance observation, physical measurement for cracks etc. as well as mechanical test to measure free vibration frequencies, modes and dynamic response to loading etc.

3.1 Situ Inspection and Testing

Outward appearance observation

Outward appearnace observation for railway bridges is one of the routine duties of bridge maintenance branches. From the inspection, we can obtain basic knowledge and information about bridge service state, such as

cracks: length, location, direction, depth etc.
crust of reinforcement: location, extent etc.
deterioration of concrete: location extent etc.
inclination of bridge pier: direction, degree etc.
link of bridge and piers: state, relative displacement etc.

foundation: state

Interior defect inspection

On the basis of outward appearnace observation, interior defect inspection for existing bridges is mainly to survey interior damage of bridge structures by means of physical method, for example using ultrasonic approach to measure crack depth and interior cracks of structures.

Situ mechanical testing

The aim of situ mechanical testing is to acquisite basic mechanical properties of the bridge to be assessed, generally using dynamic testing to measure free vibration frequencies, modes and dynamic response to vehicle loading. In addition, situ testing work also include obtaining samples for laboratory test and some basic material property experiment such as concrete strength test etc.

3.2 Laboratory Testing and Analysis

The main tasks in this stage composed of data treatment for the first stage, necessary laboratory test of situ samples in order to deliever sufficient information for damage assessment and remaining life prediction of the bridge assessed. Laboratory test is generally to measure fundamental properties, fracture mechanics and fatigue properties of samples of bridge structure and materials.

Time-domain and frequency-domain analysis as well as dynamic parameter identification are very useful to assess bridge service state. The second work in this stage is posttreating dynamic testing data recorded in situ test, including analysing and identifying physical and modal parameters, time-domain and frequency-domain peculiarities of the bridge.

4. DAMAGE ASSESSMENT AND REMAINING LIFE PREDICTION

From the prepare work, we have obtained some knowledge and information for geometric, physical and mechanical properties of bridge assessed. The remained work is to assess service state of the bridge and to predict its remaining life. How to do this work? The first problem is how to model and quantify damage.As discussed above, damage phenomena are very different and complex. So it is considerablly difficult modelling damage of structures.

As an example, we investigate effects of damage on dynamic properties of bridge pier in following so as to find some variables sensitive to damage.

(1) Frequencies of bridge pier
Dr. Sun [2] investigated frequencies of bridge pier with and without cracks in 1991. The first four frequencies of a pier is listed in Table 1, from which we may know the effect of damage on frequencies of bridge pier.

Table 1. Frequencies of a bridge pier (Hz)

Mode	1	2	3	4
Normal pier	17.05	18.93	113.95	137.21
Cracked pier	16.39	17.42	110.51	-----

(2) Modal shape of bridge pier
Convex point may be found near cracks in modal shape of cracked pier.

(3) Modal damping of bridge pier
Chen [3] found that modal damping of damaged bridge pier becomes greater and greater as damage becomes larger.

(4) Maximum pier-head displacement
With the reduction of pier stiffness, maximum pier-head displacement under vehicle loading becomes greater.

(5) Time-domain peculiarity
Forced vibration response wave is smooth, similar to harmonic wave for good state bridge piers, but it may emerge some singular peculiarities for damaged piers.

(6) Frequency-domain peculiarity
Power spectrum of damaged pier may be found with some differences to that of normal pier, such as with a wider band and smaller value at low frequency, a continuous spectrum and a greater number of peaks etc.

For superstructure of railway bridge, the effect of damage is more complex. In general, dynamic response parameters reflect the synthesized properties of structures. Some local damages have no evident effect on dynamic parameters. From identification of system parameters, we can only obtain a global and average damage description.

Here we classify damages of structures into two categories: local damage and global damage. The first may also called nonstructural damage, and the second structural damage. "Nonstructural" and "structural" do not mean without or with effect on structural capacity. But nonstructural damage only affects local stress and deformation of strcutures, and does not greatly affect macroscopic global displacement of structures. However the second is directly reflected from global mechanical response, such as frequencies, modes etc.

The first kind of damage includes local cracks, corrosion of reinforcement, exposure of concrete etc. The second is the worsening of structural materials.

4.1 Damage Tolerance Method

For the first kind of damage, we can use several characteristic variables to measure it. For example, using crack length l, crack depth a and crack open displacement d to describe a local crack in structures. In general,

Characteristic variables: $\{ A_i \ / \ i=1,2,...n \}$

Assume the damage produce a response quantity J to local stress, deformation etc. of the structure:

Response quantity: J

Through fracture analysis and material test, we may obtain a critical value of J as Jc. A simple method to define local damage is

$D=J/J_c$		
$D=0$	when $J=0$	undamaged structure
$D=1$	when $J=J_c$	local failure

This method for the first kind of damage is similar to the main idea of Damage Tolerance Method of fracture mechanics.

4.2 Combined Damage Theory-System Identification Method

According to damage theory, if there are cracks or vacancy in materials, elastic modulus of material will be reduced. The author [5] obtained:

$$\underset{\sim}{\tilde{E}}=(\underset{\sim}{I}-\underset{\sim}{D}):\underset{\sim}{E}$$

where $\underset{\sim}{\tilde{E}}$ and $\underset{\sim}{E}$ are elastic tensors of damaged and undamaged materials respectively. $\underset{\sim}{D}$ is called damage tensor. $\underset{\sim}{I}$ is a unit tensor. In case of isotropy, it can be simplified as

$$\tilde{E}=(1-D)E$$

where D is a damage scalar.

Applying system identification method, we can obtain elastic modulus distribution of damaged bridges. Therefore damage state of the bridges may be also identified.

The approach discussed above is called Combined Damage Theory-

System Identification Method.

4.3 Remaining Life Prediction

In order to predict remaining life of existing structures, it is necessary to model damage evoluting property of bridges. In general,

$$\dot{D}=f(D, t, F)$$

or

$$\delta D/\delta N=g(D, N, F)$$

where F represents external act. N represents loading cycles.

It is a very complex work to obtain the damage evoluting equation. Firstly we have to do deep investigation on damage mechanism. Secondly we must grasp a lot of experiment results for bridge materials and elements with and without typical damages.

If damage evoluting equation has been developed, remaining life of bridges assessed can be predicted from the present damage state and the future loading spectrum of the bridges.

$$Nr=Nf-Ns$$
$$D(N+dN)-D(N)=g(D(N), N, F)(N+dN-N)$$
$$D=Ds \quad \text{when } N=Ns$$
$$D=1 \quad \text{when } N=Nf$$

where Ds represents the present damage of the bridge.

5. A PROTOTYPE EXPERT SYSTEM FOR BRIDGE PIER ASSESSMENT

The expert system, DREPM-DP, is a prototype system developed by China Academy of Railway Sciences, which is based on an expert system tool DREPM. In acquisition of knowledges, domain knowledge and expert knowledge as well as an analyse module are used. The system has two kinds of knowledge representation method: frame representation and productive representation. A ask-answer blackboard is designed, which makes the system has a good human-machine interface.

DREPM-DP has been used to assess damage state of about 20 bridge piers. The diagnosing results are identical to practical situation.

Example: Haoshi River Bridge on Han-Dan Railline
The piers of the bridge is of a circular cross-section, enlargement foundation on rough sand with gravel layer. Bridge maintenance branch reported that Pier No.3 rocked greatly when train passed the bridge. In 1988, Zhengzhou Bridge Inspection Branch did situ vibration testing to the bridge. According to the

results recorded in the test, DREPM-DP gives such diagnosing results:

Pier No.2: little worse state, D=0.4
Pier No.3: very worse state, D=0.1
Pier No.4: worse state, D=0.25

6. CLOSE REMARKS

Damage state assessment and remaining life prediction for railway bridges are closely related to transportation safety. Deepgoing investigation on how to assess the state and to predict the life is very significant at present. According to the discussion above, it has been found following topics must be done futher studies:

(1) Modelling method for damage of bridges
(2) Damage criterion and damage-servicability relation
(3) Damage evoluting properties

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