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Development of a Bridge Maintenance Consulting System

Développement d'un système de maintenance des ponts

Entwicklung eines Beratungssystems für Brückeninstandhaltung

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SUMMARY

A diagnostic system used for the quantitative diagnosis of bridges has been developed. Diagnostic evaluation methods for fatigue, diagnosis, bearing capacity and remaining life are presented.

RÉSUMÉ

Un système de diagnostic a été développé pour récolter des données sur les ponts. Le document expose les méthodes d'évaluation de l'état de fatigue, la capacité restante et la durée de vie restante.

ZUSAMMENFASSUNG

Beschrieben wird ein neuentwickeltes Diagnosesystem für Brücken. Aufgeführt sind Beurteilungsverfahren zur Diagnose von Ermüdungserscheinungen, Tragfähigkeit und verbleibender Lebensdauer.

1. INTRODUCTION

Japanese railroads have improved in train speeds, and increased traffic volume, and stricter conditions are imposed on their use. On the other hand, since structures deteriorate, reasonable measures of lengthening their lives have become necessary. For that purpose, a quantitative analysis of actual conditions such as damage, and the bearing capacity or durability of existing bridges and measures such as appropriate repairs and reinforcement are required.We developed the BMC (bridge maintenance consulting) system. This system is designed to systematize the quantitative soundness diagnostic technology which have been used by some specialists and help maintenance engineers perform quantitative soundness diagnosis easily.
The kind of evaluation and diagnosis which the BMC system can handle is described in the following.

2. SOUNDNESS OF STEEL BRIDGES AND ITEMS FOR EVALUATION

The soundness of a steel bridge is judged from its bearing capacity or durability and usability as a measure of the extent of being put to use not merely from the degree of deterioration.
(1) Damage: degree of deterioration of structures
(2) Bearing capacity or durability: what load can a structure endure? What durability does it have?
(3) Usability: convenience of use and reasonability and adaptation to the performance requirement of users.
The foregoing is described in the following.

3. EVALUATING DAMAGE

The BMC system is used for measurement and analysis and the evaluation of bearing capacity and remaining life based on these data.Items for diagnosis and evaluation regarding fatigue damage of steel railroad bridges are as follows.
(1) Will fatigue damage occur? (fatigue limit)
(2) When will fatigue damage occur (predicting the age when fatigue damage occurs)
(3) Knowing the range of measures for similar structures (defining a range)
(4) Deciding when measures should be taken (emergency of measures)
(5) Investigating the cause of fatigue damage
(6) Selecting and confirming measures and method

Fig. 1 shows the flow chart of standard evaluation of fatigue damage.

First, an evaluation is made of a fatigue limit only from detected working stress values. An assessment is made here to see if fatigue will

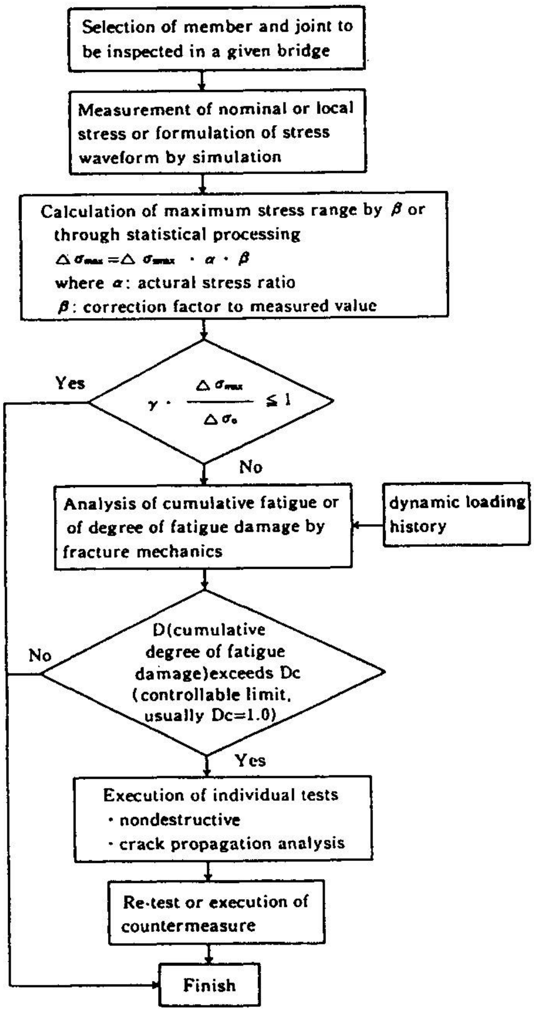

Fig.1 Flow of fatigue damage evaluation

pose a problem at this point in the future. If it is decided that it will be problematic, go to the next step. In the next step, an evaluation is made of cumulative fatigue including the influence of repetition. Load history and stress history are introduced to calculate the degree of cumulative fatigue damage (D) and remaining life. Table 1 shows one guideline for evaluating soundness against the degree of cumulative fatigue damage and remaining life. The degree of cumulative fatigue damage here shows the extent of accumulated fatigue damage. $D \geq 1.0$ shows that a member is considered to have reached its fatigue limit. That is, $D=1.0$ shows that a fatigue crack occurred in a member, and has become long enough to make the member lose its performance or function. However, to be conservative in evaluation, $D=1.0$ can be an indicator of the occurrence of a crack.

<table>
<tr><th colspan="2">Cumulative fatigue damage(D)</th><th>Classifications of evaluation</th><th>Reflection on inspection</th></tr>
<tr><td colspan="2">$D \geqq 1.0$</td><td>A1</td><td rowspan="2">Implementing detail inspection</td></tr>
<tr><td colspan="2">$1.0 > D \geqq 0.8$</td><td>A2</td></tr>
<tr><td colspan="2">$0.8 > D \geqq 0.5$</td><td rowspan="2">B</td><td rowspan="2">Important items of inspection</td></tr>
<tr><td rowspan="2">$0.5 > D \geqq 0.2$</td><td>$D \geqq \dfrac{\text{Age}}{\text{Assumed design life}}$</td></tr>
<tr><td>$D < \dfrac{\text{Age}}{\text{Assumed design life}}$</td><td>C</td><td>Parts of watch in inspection</td></tr>
<tr><td colspan="2">$D < 0.2$</td><td>S</td><td>Routine inspection</td></tr>
</table>

Table 1 Classification of soundness evaluation based on cumulative fatigue damage

4. EVALUATING BEARING CAPACITY

4.1 Calculating Bearing Capacity

In the case of steel railroad bridges, the bearing capacity of an existing structure is evaluated as a stress ratio or bearing capacity. The evaluation formula is Formula (1).
Stress ratio (SR) = $\sigma_m/\sigma \times 100\%$ .... (1)
σ_m: maintenance limit stress intensity
σ: maximum stress intensity acting on a member when a train is coming in at an allowable maximum speed.
$= \sigma_d + \sigma_l + \sigma_i + \sigma_c$
The allowable maximum stress intensity acting on a member is the one when service load acts on the current section performance.
The maintenance limit stress intensity (σ_m) is the allowable stress intensity used in evaluating the strength of an existing structure. The maintenance limit stress intensity is explained below.

4.2 Maintenance Limit Stress Intensity

The value set here is the allowable stress intensity set in designs, for which the factor of safety was reviewed. That is, in existing bridges, working load can be identified, so the factor of safety can be reviewed. Specifically, the maintenance limit stress intensity is obtained by increasing the allowable stress intensity under temporary load in new designs by 25% and adding the influence of fatigue to some extent. Formula (2) is used to calculate maintenance limit stress intensity.
$\sigma_m = \sigma_{fo} \cdot \gamma_1 \cdot \gamma_2/\sigma_m$............(2)

Here, γ_1 and γ_2 are factors considering the influence of fatigue.
The actual stress ratio (α_n) is the ratio of measured stress to design working stress and is set on the basis of the result of the measurement of many actual bridges.
The actual stress ratio here is 0.65 for members with a span of 10 m and under and 0.75 for members with a span of 10 m and over.

4.3 Classifications of Evaluation for Bearing Capacity

The calculated bearing capacity is evaluated as a stress ratio and classified by a measure of soundness as shown in Table 2. These values can change depending on the level of maintenance set by each business organization. Shown here are actual result-based values.

Soundness evaluation classification	Stress ratio (SR %)
AA	SR $\leq$ 100
A1 or A2	100 < SR $\leq$ 120
B	120 < SR $\leq$ 150
C or S	SR > 150

Table 2 Measure of Classifications of Soundness for Bearing Capacity Ratios

4.4 Flow of Bearing Capacity Calculation Using BMC System

Input data necessary for evaluation are shown below.
(1) Data necessary for evaluation and the flow of diagnosis
Main input data necessary for execution are as follows.
(A) Technical data of bridges
(B) Technical data relating to load (track deviation, cant, centrifugal force, positions to watch)
(C) Cross-section (original cross section and reinforced cross section), the amount of corrosion
(D) Data necessary for calculation of maintenance limit stress intensity and shock load (train speed, engine type)
(E) Structural data of floor framing
(2) Load input
The kind of load that is used for evaluation includes dead load, shock load and centrifugal load in addition to train load. As for train load, the axial load and wheel base of each train is stored in the data base for use in calculation. Other loads are inputted at time of calculation.
(3) Calculating working cross-section force
The cross-sectional force of each member is calculated, using a structural analysis module, on the basis of the form of the structure. The kind of structure that can be treated includes the following.
- Simple girders (main girders of deck bridge plate girders)
- Floor framing of through bridge plate girder and truss bridges
- Main trusses, oblique girders, curved girders, and lattice girders of truss bridges
(4) Inputting cross-sectional forms of members
The cross-sectional forms of members to watch are inputted. They are cross-sectional deficiencies due to corrosion, etc. and cross-sectional characteristics of reinforcement made during use. These data can be stored in the data base of the system.
(5) Selecting maintenance limit stress intensity

The maintenance limit stress intensity can be set from the quality of members and operation conditions.

5. EVALUATING DURABILITY (remaining life)

5.1 Definition of Remaining Life

It would mainly be corrosion and fatigue that determines the physical life as durability of a steel bridge in use [3].
Corrosion is evaluated from time to time by the foregoing bearing capacity evaluation. However, fatigue is defined as a condition that may appear in the form of a crack with unparalleled progressiveness not seen in other damage as a result of the accumulation of deterioration in concealed sites (critical damage). Fatigue damage is considered as one of indicators to determine durability and the time until the function of a member will be damaged by fatigue is considered remaining life [4].
The BMC system can perform remaining life evaluation in the two cases as given below.

5.2 Flow of Remaining Life Evaluation in BMC System

The theoretical flow of remaining life evaluation is shown in Fig. 2.

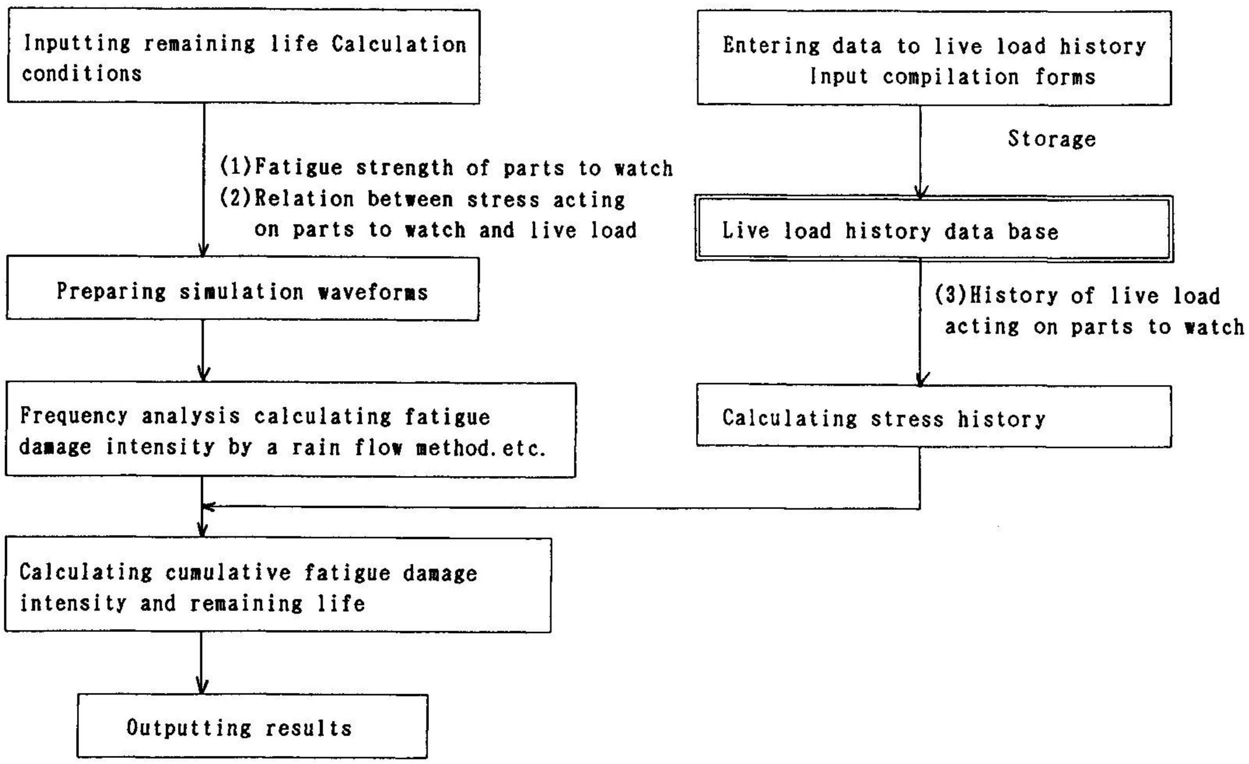

Fig.2 Flow chart of remaining life evaluation and calculation

5.3 Input Data

(1) Fatigue strength of joints to watch
Concerning the fatigue strength of joints to watch, the strength of a joint as shown in the fatigue provision of the current design standard[5] is used for railroad bridges in principle. However, as for the strength not specified in the provision, the Guidelines for Fatigue Design for Steel Structures and Explanation[6] are referred to.

(2) Stress acting on joints to watch
Stress used for fatigue assessment is service stress. Generally speaking, assuming that the history of live loads in the past and live load conditions assumed for the future and axial loads and wheel bases of typical trains which can be defined at this point are live load (if there is no special specification, the current load will continue), stress waveforms are obtained by simulation using this load. The stress waveform thus obtained may be used as service stress as it is. However, actually acting stress is smaller than the design value and generally conservative, so it is recommended that the product obtained by multiplying the calculated stress waveform by actual stress ratio is used as service stress [1, 4].
If the maximum stress range calculated by loading of trains whose axial loads and wheel bases are known is σcs, and the actually-measured value under the same condition is σma, the actual stress ratio (α) can be shown as follows.
$\alpha = \sigma_{ma}/\sigma_{cs}$
Consequently, the service stress waveform used for evaluation can be obtained by multiplying the calculated stress waveform used for evaluation by α.
Actual stress ratios are used even in current designs[5] .

(3) History of live loads
The history of live loads (or the history of stress) is necessary for the evaluation of cumulative fatigue. However, it is difficult to obtain such data in many cases. Three kinds of live load histories are allowed to be used for railroad bridges.
(A) History of annual passing tonnage (standard method)
(B) History of types of all trains and traffic volume (accurate evaluation)
(C) Only projected passing tonnage and age of a particular railroad line are known (same as design)
The system has input data files which permit automatic input.

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