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Autor: Fujiwara, Minoru / Nishikawa, Kazuhiro / Murakoshi, Jun
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Stress Histogramme and Fatigue Life Evaluation of Highway Bridges

Historgrammes des contraintes et évaluation de la durée de vie à la fatigue des ponts-routes

Spannungshistogramme und Ermüdungslebensdauer von Autobahnbrücken

Minoru FUJIWARA
Director
PWRI
Tsukuba, Japan

Minoru Fujiwara, born 1942, received his M.Eng. at Nagoya University in 1967. He has been engaged in bridge engineering works and road administration since 1967.

Kazuhiro NISHIKAWA
Head, Bridge Div.
PWRI
Tsukuba, Japan

Kazuhiro Nishikawa, born 1953, received his M.Eng. at Tokyo Institute of Technology in 1978. He has been engaged in bridge engineering works and road administration since 1978.

Jun MURAKOSHI
Res. Eng.
PWRI
Tsukuba, Japan

Jun Murakoshi, born 1963, received his M.Eng. at Tokyo Institute of Technology in 1987. He has been engaged in bridge engineering works since 1987.

Takahiro HIROSE
Struct. Eng.
Pacific Consultants K.K.
Tokyo, Japan

Takahiro Hirose, born 1964, received B.S. at Kobe University in 1988. He has been engaged in maintenance and management works of civil structures since 1988.

SUMMARY

In the case of field measurement of stress histogramme acting on steel bridge members under traffic, a measuring device to measure stress ranges and their frequencies , which is called "Histogramme recorder", has been used. This paper presents the outline of the histogramme recorder and its applications to evaluating the condition of steel highway bridges in service.

RÉSUMÉ

Un dispositif appelé enregistreur d'histogrammes a été développé pour saisir l'évolution des contraintes, tant en amplitude qu'en fréquence, se produisant dans les éléments porteurs de ponts métalliques sous charge mobile. L'auteur présente cet appareil ainsi que son application pour l'évaluation de l'état des ponts-routes métalliques.

ZUSAMMENFASSUNG

Zur Aufnahme der Spannungsgeschichte an Bauteilen von Stahlbrücken unter Verkehr wurde ein sogenannter Histogramm-Rekorder entwickelt, der die Spannungsamplituden und ihre Auftretenshäufigkeit registriert. Der Beitrag stellt das Gerät und seine Anwendung bei der Zustandsbewertung von Autobahnbrücken vor.

1. INTRODUCTION

Total number of highway bridges defined that their lengths are 2 m or over is more than 650,000 in Japan and the number is increasing still more. Maintenance technology of existing bridges including inspection, diagnosis, repair and strengthening methods is most essential to keep them in service for long period. Safety of bridges is generally evaluated based on various informations such as damage conditions, traffic conditions, structural characteristics obtained through inspection or more detailed survey. Stress histogram measurement is one of direct and effective means to evaluate structural behavior of bridges or their individual components. In the past, it had been a time-consuming work for preparing and analysing obtained data when using former measurement devices. Now we have used a much simpler measurement device, which is called "Histogram recorder", in order to measure stress ranges and their frequencies acting on bridge members under traffic for about 10 years. It can obtain stress histogram from measured stress automatically in field on time.

This paper presents the outline of histogram recorder and its applications for checking load carrying capacity and durability for fatigue of steel highway bridges in service.

2. OUTLINE OF FIELD STRESS HISTOGRAM MEASUREMENT BY HISTOGRAM RECORDER

2.1 Outline of histogram recorder

The histogram recorder used is an device which consists of strain meter, amplifier, A / D converter, processor and memories to analyze stress ranges and their frequencies of histogram by digital process of analog data obtained from strain gages or other sensors. The histogram recorder we use has 8 channels to input and 8 data memories. Appearance of devices used for stress measurement is shown in Fig. 1 and Photo 1. The histogram recorder is small in size (200mm(W)X75mm(H)X120mm(D)) and light in weight(about 2kg). Histogram analyser in the figure is used only for initial setting and operation of histogram recorder, collecting of obtained data. It contains CRT, printer, and micro floppy disk drive. Obtained data can be checked in field on time. System disks and data disks are used for analytical

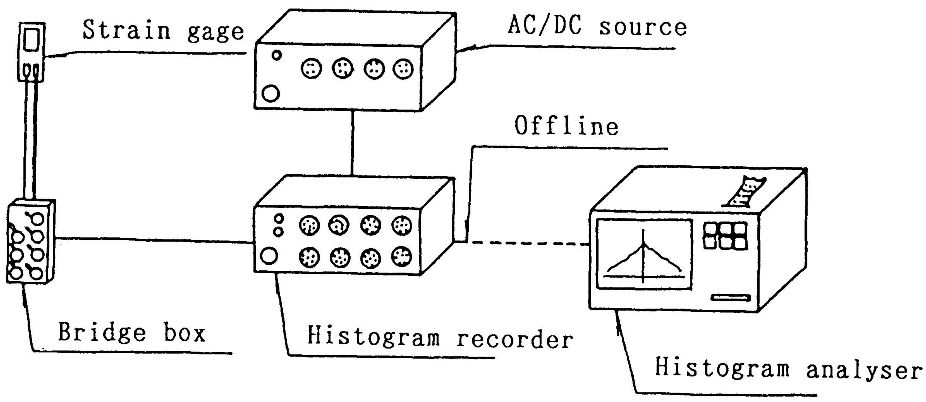


Fig. 1 System of measuring devices

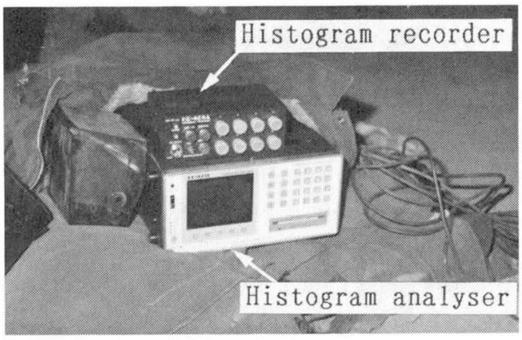
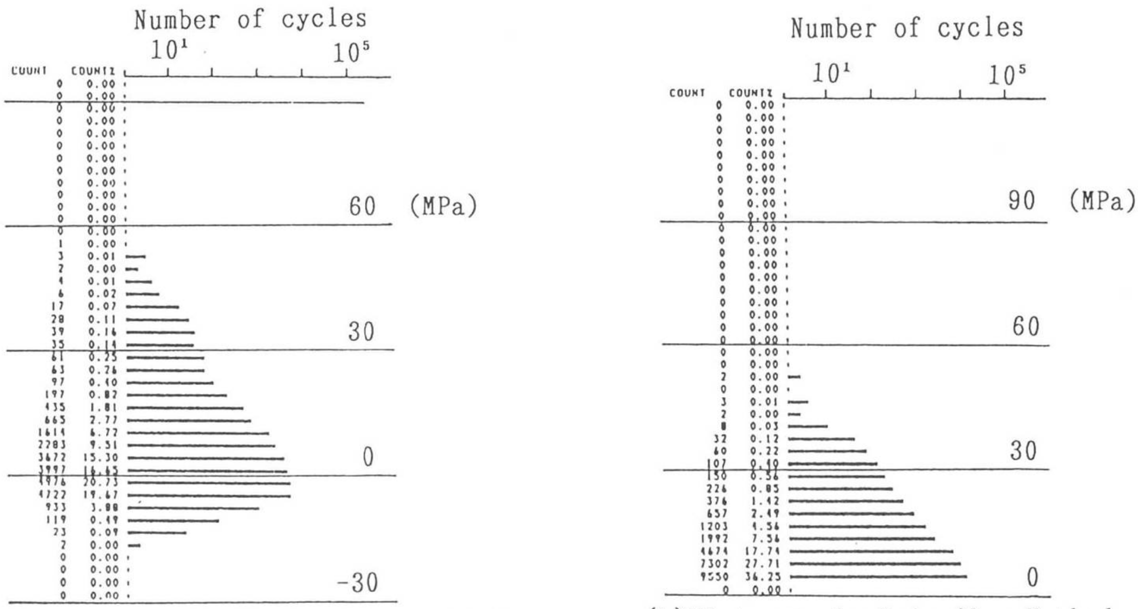


Photo 1 Appearance of measuring devices

Photo 2 Initial setting of histogram recorder in field



(a)Histogram by the Peak-valley method (b)Histogram by Rain-flow Method

Fig. 2 Stress range histograms

program setting, recording and storing the obtained data. Photo 2 shows initial setting of histogram recorder installed on a bottom flange of a main girder end in an I-shaped plate girder bridge using histogram analyser. The histogram recorder is small enough to be installed on the bottom flange.

2.2 Stress frequency histogram data and its utilization

Stress histogram measurement can be carried out automatically without disturbing traffic passing through bridge. All the operation needed to do in field are setting and data collecting before and after measuring period respectively. Obtained histogram data means the characteristics of structural response due to various effects such as traffic condition and impact by the irregurality of road surface and truck loading, etc.. These data provide us much information with respect to load carrying capacity or degree of fatigue damage of bridges in use.

Fig. 2 shows typical stress range histograms measured on a bottom flange of span center of a plate girder bridge during 24-hour period. (a) and (b) are obtained applying Peak-valley method and Rain-flow method to process measured stress respectively. In Peak-valley method, number of peak and valley appeared is recorded. The maximum stress obtained by Peak-valley method can be utilized to evaluate the load carrying capacity. Rain-flow method processing produces stress range histogram. Stress range histogram directly represents the accumulated fatigue damage of a bridge member during the measuring period. Remaining life for the fatigue damage can be estimated by applying the modified Miner's cumulative damage rule for such stress range histogram.

3. APPLICATION OF STRESS HISTOGRAM MEASUREMENT

3.1 Evaluation of load carrying capacity of an existing bridge

Almost half of highway bridges in service defined that their lengths are over 15m or over in Japan are designed by the design live load(DLL) of 14 ton truck or lighter because Japanese DLL was smaller before 1956. In trunk highway, most of such bridges have already been replaced or strengthened. However, a great number of bridges are still in use. The load carrying capacities of these bridges are generally evaluated for the present DLL. If the present DLL is simply applied to evaluate these bridges, the calculated stress naturally exceed the allowable stress. But with respect to most of these bridges, it can be considered a rare case that heavy trucks comparable to the present DLL come one after another on a bridge and make lines on it. Therefore, live load for evaluation of these bridges in use can be reduced less than the present DLL load according to the actual traffic conditions on the bridges. To clarify the live load, research based on computer simulation of traffic passing through bridge had been conducted in various research institutions in Japan. This paper proposes a more simple and practical evaluation method for administrators based on measured stress under traffic. As mentioned before, measured stress contains the various effects with respect to the structral characteristics and the traffic condition. Therfore, it would enable more rational evaluation of the load carrying capacity of these bridges.

Table 1 shows comparison between the measured maximum stresses during 24 hours and caluculated stresses at the span center of main girders of a plate girder bridge by present DLL. Fig. 3 shows the cross section of the bridge, which was designed by

Table 1 Comparison between measured maximum stress and caluculated stress

Main girder	Measured maximum stress σ_{max}(MPa)	Calculated stress by DLL σ_L(MPa)	$\sigma_a - \sigma_D$ (MPa)	$\frac{\sigma_a - \sigma_D}{\sigma_L}$	$\frac{\sigma_a - \sigma_D}{\sigma_{max}}$
G2	45.0	77.4	77.2	1.0	1.7
G3	57.0	92.3	65.6	0.7	1.2

12 ton truck. As one of limit states, we consider condition that residual deformation does not remain in bridge components, i.e. , in case of main girder, it does not yield. For example, with respect to a main girder, assuming that the acting stress mostly consists of stress components due to dead and live load, the value of $(\sigma_a - \sigma_D)$ is required to be larger than measured maximum stress due to actual live load as follows.

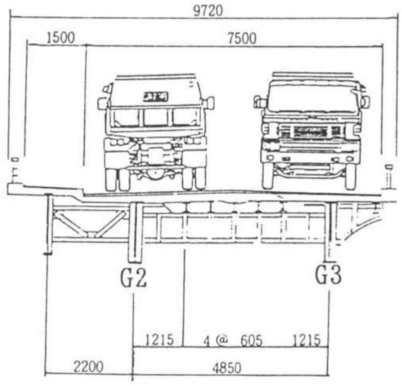


Fig. 3 Cross section of investigated bridge

$$(\sigma_a - \sigma_D)/\sigma_{max} > 1.0$$

where, σ_a = allowable stress for the steel grade of main girder

σ_D = calculated stress for the design dead load, if possible, actual dead load is better

σ_{max} = the measured maximum stress of main girder

As shown in table 1, the values of $(\sigma_a - \sigma_D)/\sigma_L$, where σ_L =calculated stress for the present design live load, are approximately 1.0 for girder G2 and 0.7 for girder G3, which mean the safety factors of main girders of this bridge. On the other hand, the values of $(\sigma_a - \sigma_D)/\sigma_{max}$ of girder G2 and G3 are 1.7 and 1.2 respectively, which are both larger than 1.0. The measured maximum stresses σ_{max} are less than calculated stresses σ_L for the the present DLL. It is confirmed that this bridge can be kept in use to present traffic unless the condition changes drastically. With extension of measuring period, more reliable evaluation would be possible.

3.2 Evaluation of durability for fatigue damage

3.2.1 Evaluation of the effect of repair and strengthening method

It had been considered that there is little chance for steel highway bridges in Japan being subjected to a load condition corresponding to present design live load, and therefore, fatigue have not been considered to be a serious problem. However, in this decade, various types of fatigue cracks caused by repetitive loading of heavy traffic, especially overloaded vehicles, have been reported mainly in secondary members subjected to stress concentration.

Photo 3 shows fatigue cracks which occurred at a connection between a main girder and a cross beam of an I-shaped plate girder bridge. Crack ① occurred top end of a vertical stiffener welded to top flange. Crack ② occurred on web at fillet-weld toe connecting web and top flange of main girder. Generally, crack ② occurred after crack penetration of top end welding of the vertical stiffener. These cracks, which are the most frequent of all cracks reported in Japan, do not

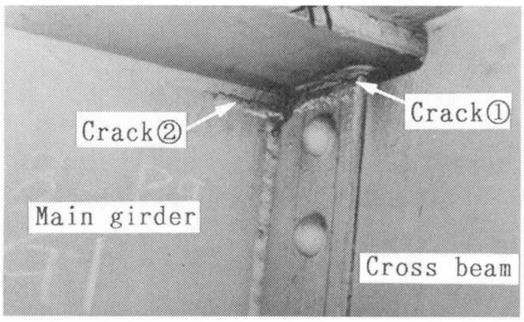


Photo 3 Fatigue cracks occurring at cross-beam connection

lead to a serious problem quickly. However, it can results in loss of durability of the bridge itself. The causes of damage are not clear enough so far. But at least, it can be said that these cracks were caused by secondary stresses due to relative deflection of main girders and deflection of RC floor slabs by wheel load of heavy traffic. The characteristics of damaged bridges and the effectiveness of repair and strengthening method have been investigated by directly monitoring stress histogram at the top ends of vertical stiffners where cracks possibly occur.

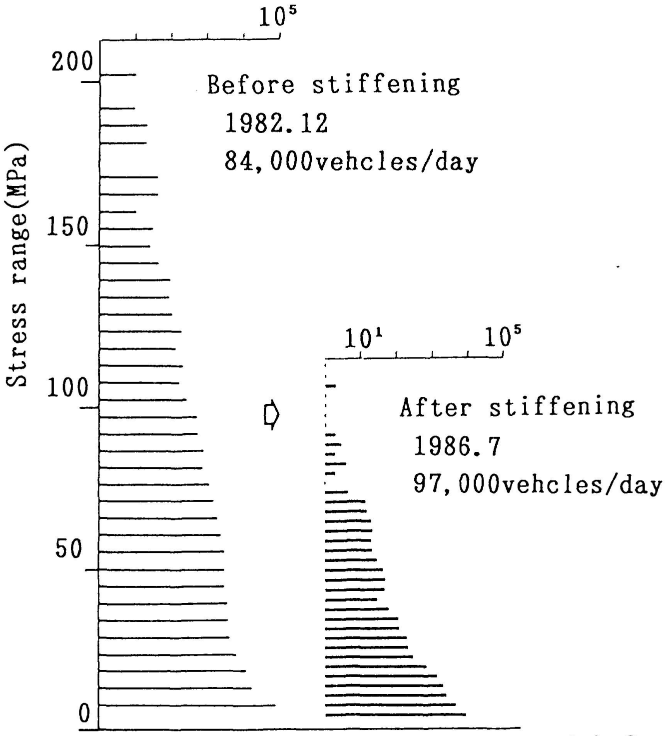


Fig.4 Stress range histograms measured before and after the stiffening

Fig. 4 shows the results of stress range histogram measured during 24 hours without traffic disturbance before and after stiffening of RC floor slab with additional stringers between main girders. The stiffening is one of the strengthening methods for RC floor slab. From this figure, the distribution of stress histogram can be seen shifted to much lower stress range after the stiffening. The fatigue life after the stiffening is estimated about 80 times as long as before. It is confirmed that the stiffening is effective for not only stiffening the RC floor slab but also reducing the local stresses at the cross-beam connection. This measurement could be carried out without disturbing traffic, therfore it is effective as one of the direct and easy approach for the investigation of fatigue damaged bridges.

3.2.2 Investigation of the characteristics of fatigue damaged bridges

With respect to the fatigue cracks mentioned in paragraph 3.2.1, to clarify structural chracteristics of damaged bridges, the relationship between structural parameter and measured local stress at cross-beam connection was investigated for each different bridge.

The equivalent stress range σeq (the root-mean-cube stress range), which will cause the same fatigue damage as the measured stress histogram for equal number of the cycles, derived from the modified Miner's cumulative damage rule is defined by the following equation:

$$\sigma eq = (\Sigma \sigma i^3 \cdot ni / N)^{1/3}$$

where, σi = stress range

ni = number of stress range σi

N = number of heavy traffic passing through the bridge during the

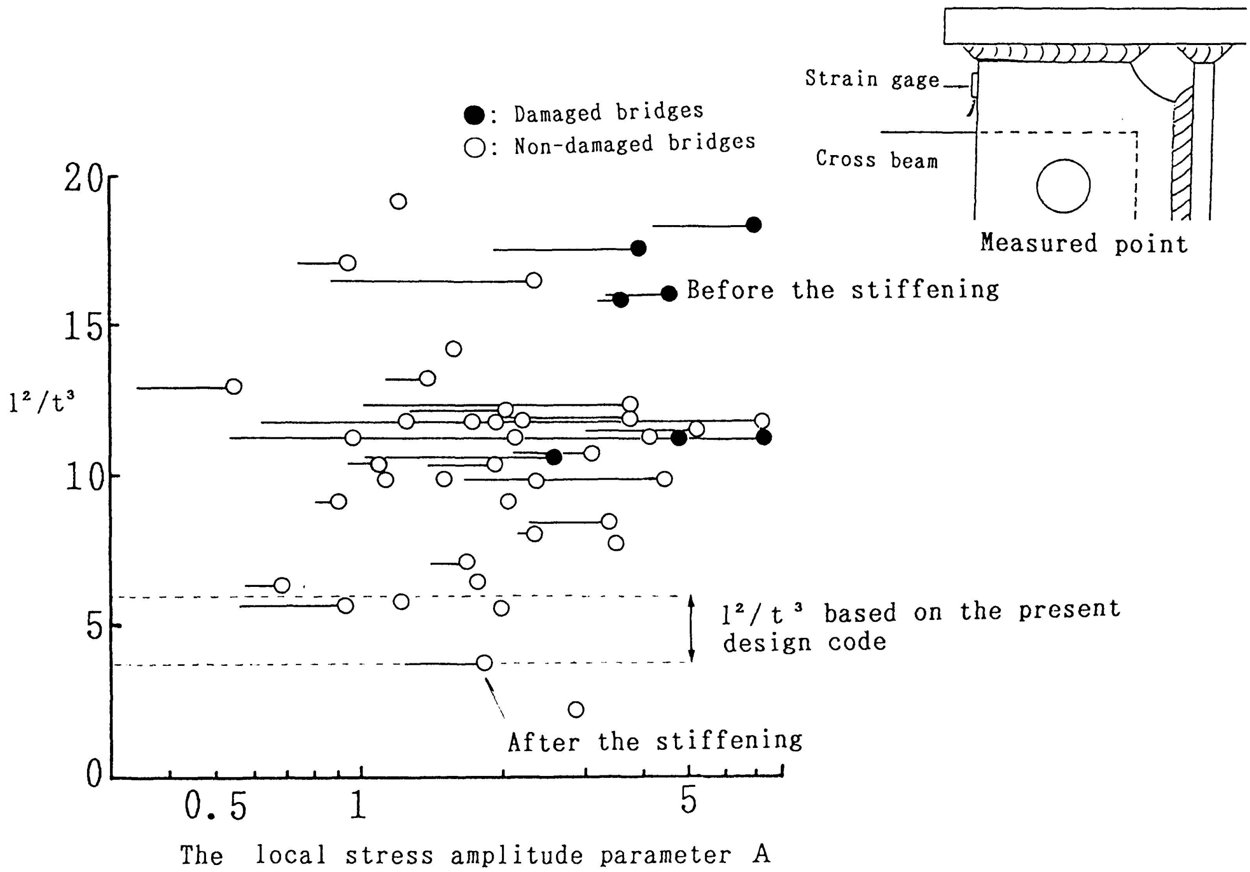


Fig. 5 Relationship between l^2/t^3 and local stress amplitude parameter A for each bridge.

measuring period($= \Sigma ni$)

Suffix i is counted from maximum stress range side. As one of structural parameters of damaged bridges, a local stress amplitude parameter A is defined as follows:

$$A = \sigma eq / \sigma eq'$$

where, σeq and $\sigma eq'$ are equivalent stress ranges obtained from measured stresses at the cross-beam connection and bottom flange at the span center of main girder respectively. σeq is divided by $\sigma eq'$ to reduce influence of the traffic condition of each bridge.

Fig. 5 shows relationship between l^2/t^3 and the local stress amplitude parameter A for each bridge. l^2/t^3 is the same order as a rotational angle of RC floor slab on main girder web where l=spacing of main girders, t=thickness of RC floor slab. The local stress amplitude parameter A in each bridge is shown by solid line for the scatter range of A at different cross-beam connections. Black dots means fatigue damaged bridges at cross-beam connection. Also indicated in this figure, is the comparison before and after the stiffening of RC floor slab with addtional stringers mentioned in paragraph 3.2.1. By such direct approach, it is confirmed that occurrence of fatigue crack is influenced by the structural parameter l^2/t^3 to a considerable degree.

The Japanese design code of RC floor slab had been revised several times for the purpose of increase of its stiffness from the durability point of view. As shown in the figure, The values of l^2/t^3 for the RC floor slab designed by the present design code are approximately 3.8 to 5.8. These values are less than those of the fatigue damaged bridges. This indicates that the fatigue cracks are unlikly to occur at bridges designed by the present design code.

4. CONCLUSIONS

This paper presents the outline of histogram recorder and its applications. We are also trying to apply the histogram recorder for long time period measurement in order to monitor condition of bridge members, especially for the change of traffic condition and propagation of fatigue cracks. Field stress measurement had been conducted on more than 60 plate girders from fiscal 1986 as a 3-year-project in PWRI. Obtained data will contribute significantly not only to preparing both durability and load-carrying-capacity evaluation metohds of existing bridges but also to introducing fatigue design to future bridge design code.

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