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Reliability-based Control Criteria for Measured Monitoring Data

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ABSTRACT

Most operating bridges collect data from measurement systems with various types of sensors and evaluate their health conditions. Since the statistical distribution of measured information may have different characteristics depending on the types of sensors or characteristic events developed during the measurements, however, it is not easy to keep managing the measured data in a consistent manner. The paper introduces a systematic way of resetting the safety control criteria for the measured monitoring data based on the statistical aspects of the measured data. The proposed statistical approach has been examined with actually measured time-history data from a bridge structure.

1. INTRODUCTION

For an efficient maintenance of a structure, some structural responses are measured and managed by pre-defined control criteria (FWHA, 2003). Usually, the methods to define such control criteria can be divided into four types; (a) using design documents, (b) using measured data by tests, (c) using analytical results, and (d) using values allowed by the design codes (Joo *et al*., 2008). However, the control criteria determined by these methods are not proper to an ordinary maintenance during operation of the structure. The purpose of setting the safety control criteria is to take a safety measures when an event occurs which can influence on the safety of the structure. Or sometimes, it is to predict possible future events by monitoring the measure data (ISO 18649).

The paper presents a method of resetting the control criteria during operation of a structure by using measured monitoring data. The proposed method is examined through an application to an actual set of measured data for four years period. However, it does not presents the control criteria themselves because they should be determined by the owner or manager based on their own purpose of operating the structure.

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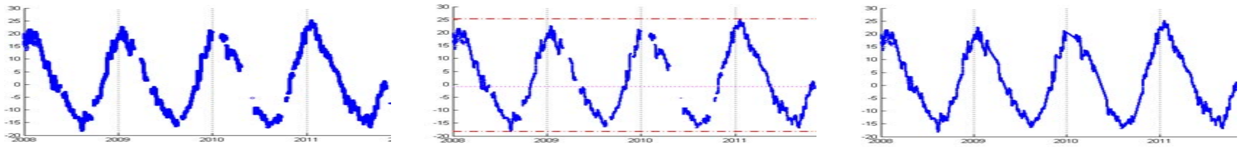


Raw data Elimination of outliers Recovered data

Fig. 1 Data processing and recovery of measured joint displacements

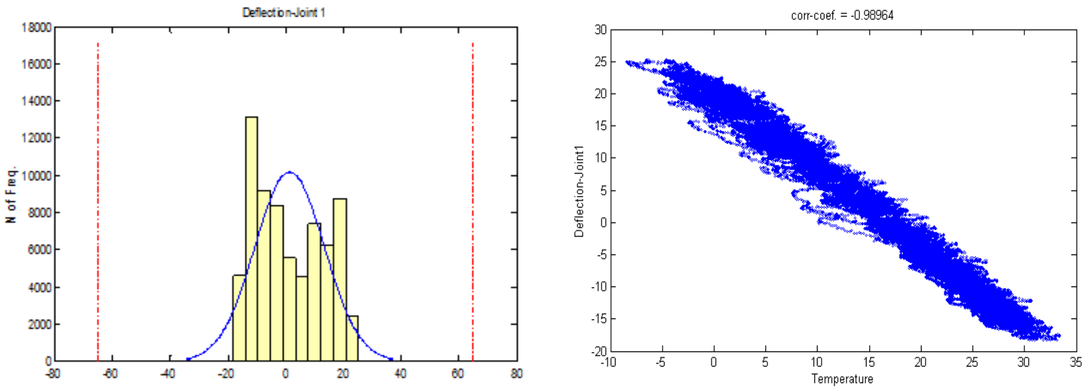


Fig. 2 Frequency distribution of joint displacements and its correlation with temperature

2. ANALYSIS AND RECOVERY OF MEASURED MONITORING DATA

2.1 Data Processing and Recovery

Usual measured raw data possess missing parts as shown in the left figure of Fig. 1 due to several reasons (Kim, 2011). In order to recover the missing parts of the data, outliers of the data should be eliminated and the missing parts can be recovered by any numeric tools. In the current approach, ARX is applied to recover the missing parts by using the data after eliminating outliers and the temperature data.

The recovered data averaged at every 10 min. shown in the right figure of Fig. 1 are redrawn in a frequency distribution with rectangles as shown in Fig. 2. The dotted red lines are the control limits for joint displacements defined before operating the bridge. Also, the correlation of the recovered joint displacements with temperature is investigated in the right-hand figure of Fig. 2 with its correlation factor of 0.99.

2.2 Examination of Pre-defined Safety Control Criteria

Fig. 3 compares the pre-defined safety control limits with the measured tendon forces from load gages. It can be clearly observed that the measured data do not stay around the middle of the control limits as shown. Depending on the locations of load gages, the frequency distribution of measured data show different aspects. Some of them stayed inside the limits but some of the others stuck close to one of the limits. A peculiar aspect can be observed from the measured tendon forces in the last figure among the six cases where the measured data are lower than the lower control limit. In this case, the reliability of measured data is also doubtful with widespread data below the lower limit.

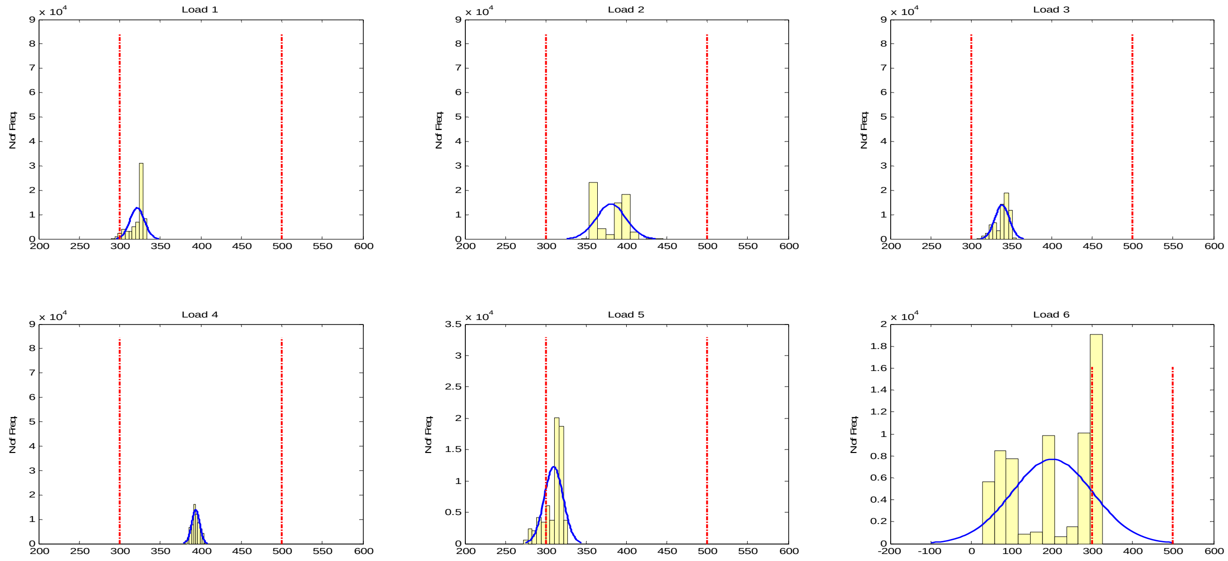


Fig. 3 Comparison of measured tendon forces with the safety control criteria

Table 1 Probability of exceedence according to the control span

Control Span	Probability of exceedence P_e (%)
m ± 2σ	4.5500×10^{0}
m ± 3σ	2.6998×10^{-1}
m ± 4σ	6.3342×10^{-3}
m ± 5σ	5.7330×10^{-5}

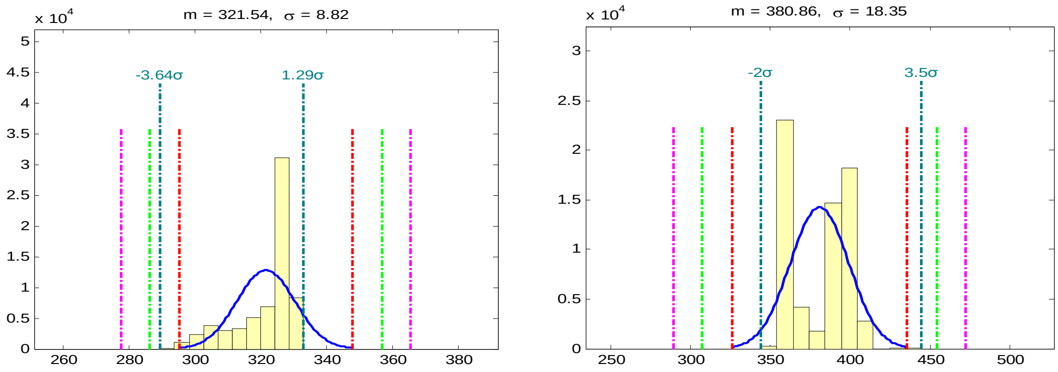
3. STATISTICAL EVALUTION OF SAFETY CONTROL CRITERIA

3.1 Basis for the Control Span

If the lower and upper limits in a normal distribution density function are equally distant from a mean by multiples of σ, then the area outside the limits can be described as a probability of exceedance. Table 1 shows the probability of exceedance depending on the control span. Since the limits of safety control criteria should be determined by the owner or manager of the infrastructure based on multiple yardsticks for judgment, such control span according to the probability of exceedance can be used as a guideline for determining the control limits.

3.2 Exercise with Sample Data

For case 1 and case 2 of the figures in Fig. 3, the minimum and maximum values of measured tendon forces are indicated as a multiple of σ in Fig. 4. Also the limits with $m\pm3\sigma$, $m\pm4\sigma$, $m\pm5\sigma$ are drawn with dotted lines sequentially each side of the frequency distribution. In most cases, $m\pm3\sigma$ could be selected as a proper control limit to monitor the safety of the infrastructure as predicted from Fig. 4 as well. However, the decision should be made by the authority after examining the statistical properties of the measured data closely



(case 1) (case 2)

Fig. 4 Comparison of measured tendon forces with the safety control criteria

3. CONCLUSIONS

From the investigations on the statistical properties of the measured monitored data, the following conclusions could be made.

a) The pre-defined safety control criteria before operating a structure are not adequate to the measured monitored data.

b) It is necessary to reset the safety control limits based on a long-term history of measured data.

c) A statistical evaluation of the measured data can provide a useful guideline of determining safety control criteria. However, the final decision of the safety control criteria should be made by the authority.

d) A normal distribution was assumed for the measured data in the current approach. However, the frequency distributions may not be fit to the normal distribution in actual. A further study on this aspect may be needed.

ACKNOWLEDGEMENTS

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