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## Recording of Stresscollectives of a Steel Bridge

Observation des collectifs de contraintes d'un pont en acier

Erfassung von Spannungskollektiven einer Stahlbrücke

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### SUMMARY

Due to the decreasing costs of microelectronic devices in the field of measurement, it has become possible to install permanent measurement systems in structures. Indicators related to fatigue can be developed, using the hysteresis-counting-method and hypotheses of damage accumulation. These indicators give a more realistic estimation of the load history and of changes in a structure.

### RÉSUMÉ

Du fait de la diminution du prix des dispositifs micro-électroniques de mesure, il devient désormais économique d'installer des systèmes de mesure permanents dans les ouvrages. Grâce à l'analyse continue de ces mesures, il est possible d'obtenir des valeurs caractéristiques relatives à la fatigue en tenant compte de la méthode de comptage des hystérèses et de l'hypothèse de cumul du dommage. Ces valeurs fournissent une estimation plus réaliste de l'historique des charges et des modifications dans la structure.

### ZUSAMMENFASSUNG

Die zunehmend preisgünstigen mikroelektronischen Bausteine im Bereich der Messtechnik ermöglichen die ständige Installation von wirtschaftlichen Messsystemen an Bauwerken. Bei einer kontinuierlichen Auswertung der Messdaten unter Berücksichtigung der Spannungshysteresen-Zählmethode und von Schadensakkumulationshypothesen lassen sich anschauliche, ermüdungsrelevante Indikatoren ermitteln. Diese werden zu wirklichkeitsnahen Einschätzungen von Belastungsgeschichten und Strukturveränderungen genutzt.



## 1. INTRODUCTION

Steel constructions with severe changes in the load, such as bridges, masts and cranes have to be analysed with respect to fatigue strength. In the planning stage assumptions have to be made for the load and for the structure. The maximum stress of the connecting element between the main girder and the traverse stiffening as shown in fig. 1 can be determined with a relatively high reliability. The stress-collective, however, which is a basic assumption to calculate the fatigue strength, can be estimated only approximately. The reason for this are influences such as the quantity and load spectra of the traffic, the roughness of the bridge-surface and the dynamic reaction of the coupled system composed of structure and moving vehicle.

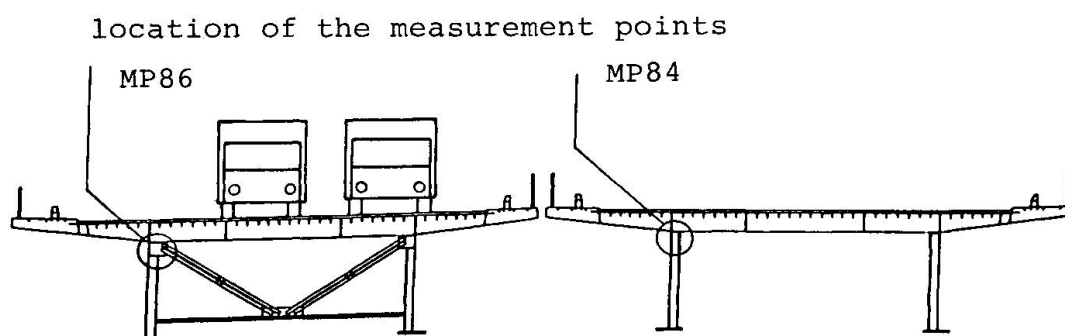


Figure 1: Cross-section of a steel bridge with transverse bracing

The surveillance of road bridges in the Federal Republic of Germany is done by inspections according to the code DIN 1076 "Ingenieurbauwerke im Zuge von Straßen und Wegen". The intention of this paper is to show how to support these inspections by the determination of indicators based on permanent measurements. The proposed procedure uses counted hysteresis-loops to provide information concerning the traffic and the structure.

Due to the decreasing costs of microelectronic devices such as processors, analogue-digital-converters and storage elements, it becomes economical to install permanent working measurement systems in constructions. The permanent observation based on measured data is already in use in special constructions such as off-shore platforms. By standardising the measuring unit and the service programs, it would be possible to observe a certain amount of constructions with respect to stress. In order to avoid a flood of data, indicators have to be determined so that changes can be detected easily. The idea of a consistent observation of structures in use is being more frequently discussed in public, e.g. at the symposium of the IABSE 1989 in Lisbon "Reliability of structures"/3/ or in the area of quality control/5/.

## 2. DERIVATION OF AN INDICATOR RELATING TO FATIGUE STRENGTH

The best way to estimate a construction with respect to its dynamic reaction or its fatigue-relevant behaviour is the analysis based on parameters obtained by parametric identification of the finished construction. Experience shows this method is restricted because of the great effort and the limited accuracy of the results received for the substructures for which fatigue strength is dominant.

### 2.1 Reducing of measurement data with the HCM-algorithm

A relatively good estimate of the dynamic behaviour of the stress of a substructure can be obtained by permanent observation of the strains with attached strain gauges. Using several measurement points in the area of the connection between the transverse bracing and the main girder the dynamic behaviour of this substructure can be described rather well. With a chosen sample frequency of 400 Hz one measurement point yields  $1.44 \cdot 10^6$  values in an hour.

When fatigue strength monitoring of a structure is the main topic data reduction can be obtained by using the hysteresis counting method (HCM) /1/. With a division in 64 classes of the stress cycle parameters, namely the stress range and the mean value, a reduction factor of 350 for the storage can be reached. The original record for a time period was therefore replaced by a hysteresis matrix. The fatigue-relevant effect caused by traffic can be observed with the help of the stored matrix. Derived stress collectives (stress range spectra) include the effects of traffic and the real reaction of the structure and are very useful for checking the assumptions made in the stage of design.

### 2.2 Further reduction of data with damage accumulation hypotheses

Through an installation of a bigger amount of measurement points and a longer time period for measurement, it makes sense to store indicators which comprise a further data reduction. With respect to a fatigue-relevant consideration, we use damage accumulation hypotheses. The increment in the damage for a time step is named indicator  $S$ , the accumulated value is named  $\Delta S$ .

With this method the hysteresis matrices are available in short time increments of about 2 minutes and therefore also nonlinear accumulation hypotheses can be used, which estimate the load history in a more realistic way.

For test purposes 8 different hypotheses are used simultaneously. There is a detailed description given in /7/. The hypotheses H6 and H8 are linear according to the specifications of the Deutsche Bundesbahn DS804 and the code EC3 of the European community.

The hypothesis H7 takes into account the decrease of the constant amplitude fatigue limit with the increase of the damage according to Haibach /4/ and Reppermund /8/. This hypothesis is therefore nonlinear.

Taking into account different detail categories along with the different damage hypotheses leads to an additional variation of the indicator  $S$ . Using all together 30 variations of  $S$  the need for storage is further reduced by a factor of 120.

The temporal development of the indicators  $S$  and  $\Delta S$  shows the effect caused by the traffic in a clear way and can be evaluated numerically (see fig.5).



### 3. PERFORMANCE OF THE MEASUREMENT

For use in the laboratory and in a construction (see part 4 of this paper) a measurement assembly was established consisting of plain microelectronic elements. The design takes into account the fact that we want to operate with self-developed programs on the measured data during the running measurement. An additional advantage for a custom made measurement assembly is the reasonable price.

Purchaseable measurement units which can provide hystereses matrices in a permanent way are used in airplane and motor car construction. Applications in the field of civil engineering are not known to us.

#### 3.1 Hardware

To perform measurements a personal computer was used with an installed analogue-digital converter unit. The evaluation was also performed with a personal computer.

#### 3.2 Measurement software

Menu-driven preliminary programs compute facts for the calibration, provide data for the chosen accumulation hypotheses and the detail categories and ask for parameters such as sampling frequency, time increments for storing the indicators and the number of the classes for the HCM.

During the measurement the digital signals are analyzed continuously by the HCM-algorithm and the results are stored in matrices. The installed configuration can serve 4 channels with a sample frequency of 400 Hz. The greatest number of classes for storing the hysteresis cycles is 64x64.

In short time steps the program computes the indicators DS with respect to 8 different accumulation hypotheses. After chosen time periods, e.g. 1 hour, the indicators S and the accumulated hystereses matrices were stored, as well as the highest and lowest values of the stress. Based on the stored extreme values of the stress, the greatest loads within each time period can be identified with an accuracy of 10 seconds.

#### 3.3 Evaluation software

To convert the stored data to other formats, to display them graphically (see fig. 4) and to store them in a data bank, a menu-driven service program system was developed. With these programs it becomes possible to check measurement results immediately after measurement.

For longer observations it seems sufficient for most of the measurement points to store only the indicators S and the extreme values of the stress. According to information from the "Oberste Baubehörde Bayerns" this volume of data can be stored within the data bank for the existing buildings.

#### 4. APPLICATION TO A STEEL HIGHWAY BRIDGE

##### 4.1 Struktur

During an inspection of a steel highway bridge crossing the Danube river cracks were detected (see fig. 1). In order to design a rehabilitation concept measurements using strain gauges were performed. The aim of a special measurement task was to investigate the stress collectives for different points of the structure and to compare them at different times.

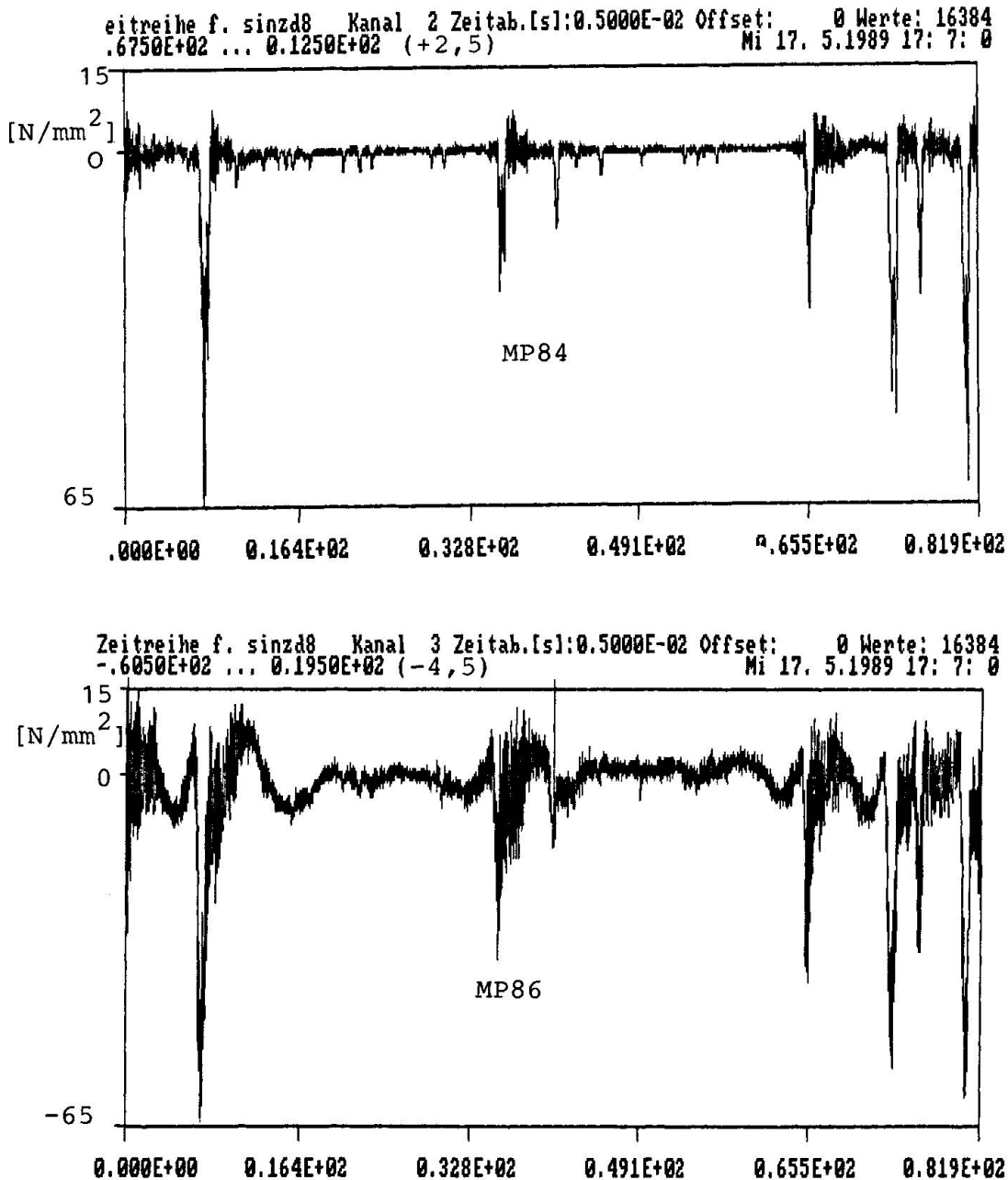


Figure 2: Stress records of MP84 and MP86



## 4.2 Results of the dynamic measurement

In the spring of 1989 measurements were performed for several days. Before and after the measurements with the HCM-concept the strain in time was recorded for control purposes. Figure 2 shows parts of 2 typical records. After the measuring points in the direction of the traffic were separated by only 3 meters and simultaneously measured, the same traffic load can be assumed. Whereas the maximum value for the compressive stress in both records is nearly the same, the record of point MP86 is more turbulent.

## 4.3 Stress collectives (stress range spectra)

During the measurements which lasted several days, the hysteresis matrices were stored after each hour, along with the extrem values of the stress and the times of their appearance. Measured stress collectives which are not yet normalized are presented in figure 3. The full lines represent a measurement lasting 96 hours, the dotted lines represent another measurement lasting 61 hours. The comparison of the measurement points shows a higher portion of greater stress values in the curve for the point MP86.

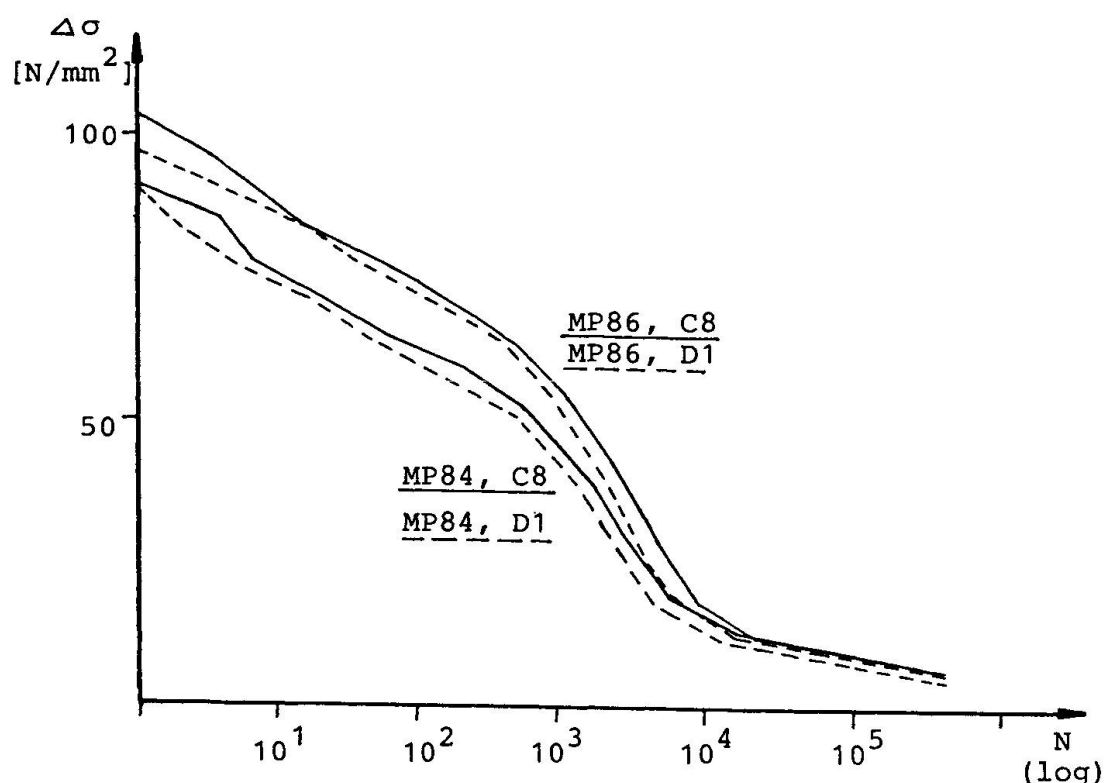


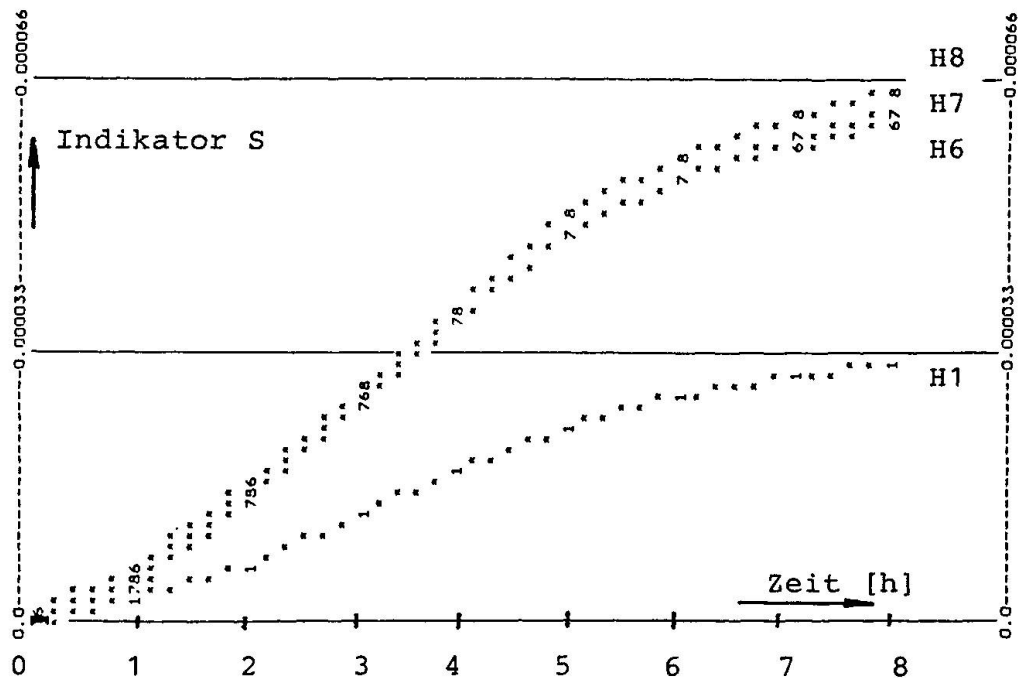
Figure 3: Stress collectives

## 4.4 Indicators S and ΔS

For a numerical and a clearly arranged evaluation of the stress of the measurement points, the indicators as described in section 2 are very suitable. As to be seen in figure 4, the curves belonging



to different damage accumulation hypotheses are qualitatively rather similar for a short time interval. An average detail category was chosen for the presented results. The stress values of the measuring points without a traffic load was not known and assumed to be zero.



**Figure 4:** Curves of S for different accumulation hypotheses

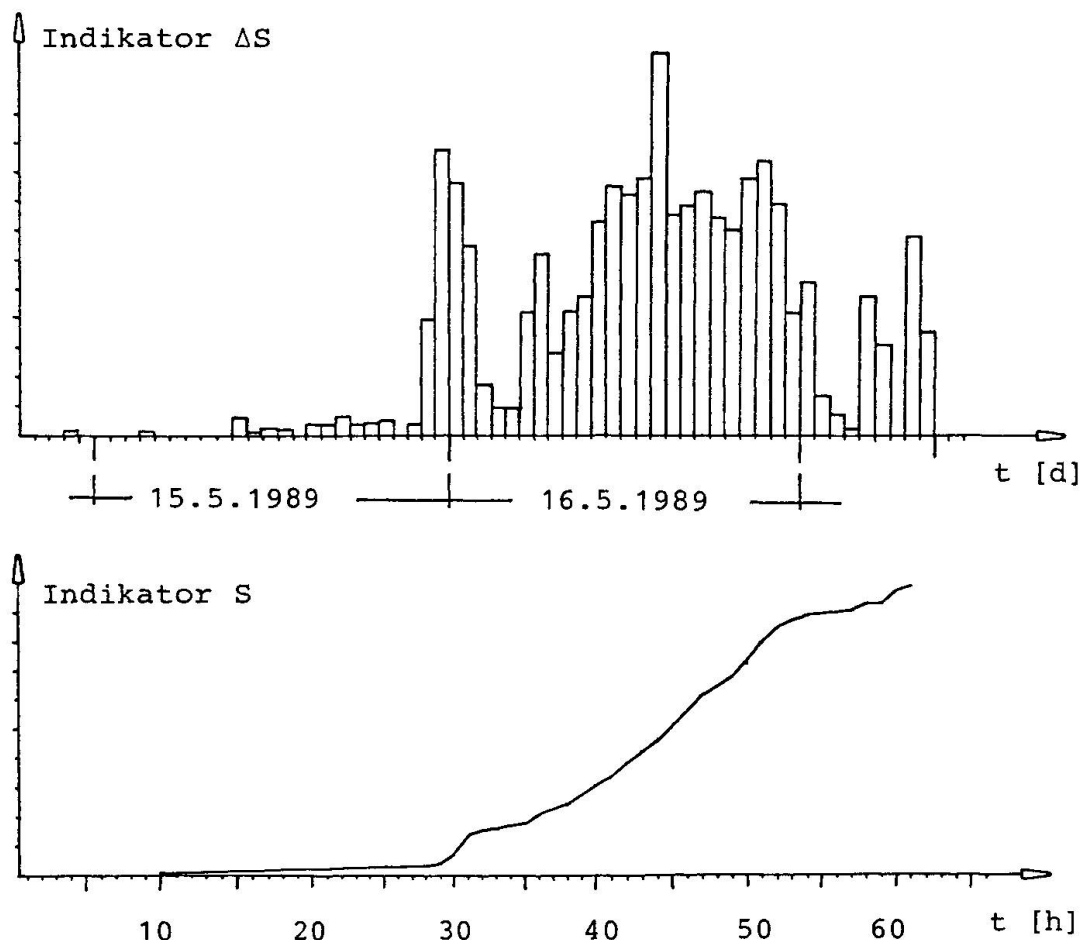
Figure 5 presents the indicators S and DS resulting from a measurement starting on May 14. In the night of the 15th to the 16th a sudden increase was detected. An important reason for that could be the ban of trucks during the Pentecostal holidays till the 15th. The loading of the bridge can be estimated very clearly by the indicator  $\Delta S$ . The other measurement points and the other accumulation hypotheses showed similar results.

The comparison of the fatigue strength of the measured elements of the structure represented by MP84 and MP86 using the indicator S yields the following data:

measurement of	MP 64	MP86
May 10 to 14; 96 hours	100%	293%
May 14 to 17; 61 hours	100%	305%

Although the maximum compressive stress of MP84 and MP86 was very similar, the fatigue strength according to the presented measurement differs by the factor 3.





**Figure 5:** Indicators  $\Delta S$  and S (61 hours)

#### 4.5 Evaluation of the measurement results

On the basis of the above explanations, it can be said that measurements covering a long time period can lead to a better estimate of the loading due to traffic with respect to fatigue strength. Quantitative statements, based on traffic load models and a dynamic analysis of a structure can be effectively added. These ideas can indicate which construction parts need more or less inspection.

#### **5. FINAL REMARKS**

The method presented here is not restricted to steel constructions, but can also be used for the observation and inspection of concrete structures. An important consideration here is the selection of adequate sensors, for which are new economical developments.

With the increasing variety and reduction in cost of microelectronic components in the area of measurements and data analysis, permanently installed measurement systems can be used in a greater number of structures. These systems can contribute to an estimate of the state of the structure without damaging it and therefore to

quality control.

The following is a summary of some advantages resulting from the permanent observation of the stress of a construction:

- Large discrepancies between the calculated stress and actual stress as well as major defects can be detected in an early stage.
- A control for the stress collective used in design is given.
- Changes and damages of the observed elements of the structure can be detected by comparing the measurement results with reference values.
- The loading of the structure as a result of traffic and the changes of the traffic in the course of time can be quantified. These results of the permanent measurement can be partly transferred to other bridges in the same highway.
- Data concerning the stress cycles are available for a later assessment of the structure with respect to rehabilitation or changes in traffic patterns.
- For future constructions updated data concerning the stress collectives is available.
- Nonlinear damage accumulation hypotheses can be tested under realistic stress histories in comparison to more conventional ones.

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