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# Traffic Load Estimation by Long-Term Strain Measurements

## Estimation des charges due au trafic au moyen de mesures de contraintes à long terme

## Abschätzung von Verkehrslasten mittels Langzeit-Dehnungsmessungen

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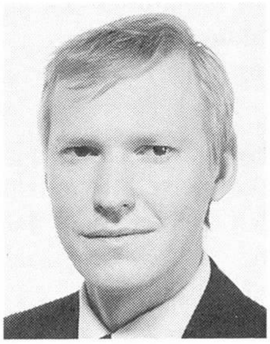

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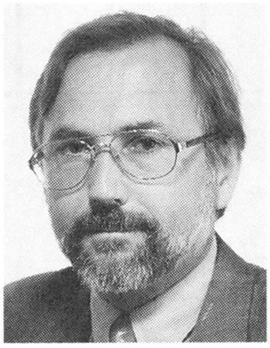

Werner Baumgärtner, born 1944, received his engineering degree at the Technical University of Munich and then worked in construction offices involved in bridges and buildings. Since 1972 he has been employed by the Technical University of Munich and works in the field of structural mechanics, especially dynamics.

**SUMMARY**

Because the installation of the equipment for in situ measurement becomes more expensive than the equipment itself, it is reasonable to use the installation not simply for short-term measurements. Using the installation for long-term measurements will result in useful information about stress history, which can be used for traffic load estimation and service life estimation. As an example first results of the long-term measurement at a motorway bridge are presented.

**RÉSUMÉ**

L'installation d'instruments de mesure est devenu plus chère que leurs frais d'acquisition. Il est donc raisonnable de les utiliser non seulement pour des mesures à court terme, mais aussi à long terme. Ces dernières conduisent à des informations très utiles sur l'histoire des contraintes permettant l'estimation des charges et de la durée possible d'utilisation de la structure. Des mesures effectuées pour un pont autotoutier sont données à titre d'exemple.

**ZUSAMMENFASSUNG**

Da die Installation von Messgeräten am Bauwerk inzwischen teurer geworden ist als deren Anschaffungskosten, ist es sinnvoll die Installationen nicht ausschliesslich für Kurzzeitsmessungen einzusetzen. Langzeitsmessungen liefern nützliche Informationen zur Spannungsgeschichte, die für Belastungs- und zur Lebensdauerabschätzung verwendet werden können. Als Beispiel werden die Messungen an einer Autobahnbrücke vorgestellt.

## 1. Introduction

In autumn 1991 the bridge Fischerdorf in Germany was opened. The Bridge crosses the danube near Deggendorf and is connecting the motorway A12 Munich-Deggendorf to three roads on the other side of the danube. To get a control of the theoretical calculations of the complex construction as shown in figures 1 and 2 measurements with static loads were projected. To get more information about the structural behaviour it was decided to use the installations for additional dynamic long term measurements.

## 2. Bridge Structure

The bridge has two main girders which cross-section is shown in figure 2. Transverse beams connect both main beams to rods which are connected to one middle arch. The cross-section of the main beams are a steel construction with a concrete deckslab. The construction bears the loads in a combination of torsion and bending of the main girders and the arch.

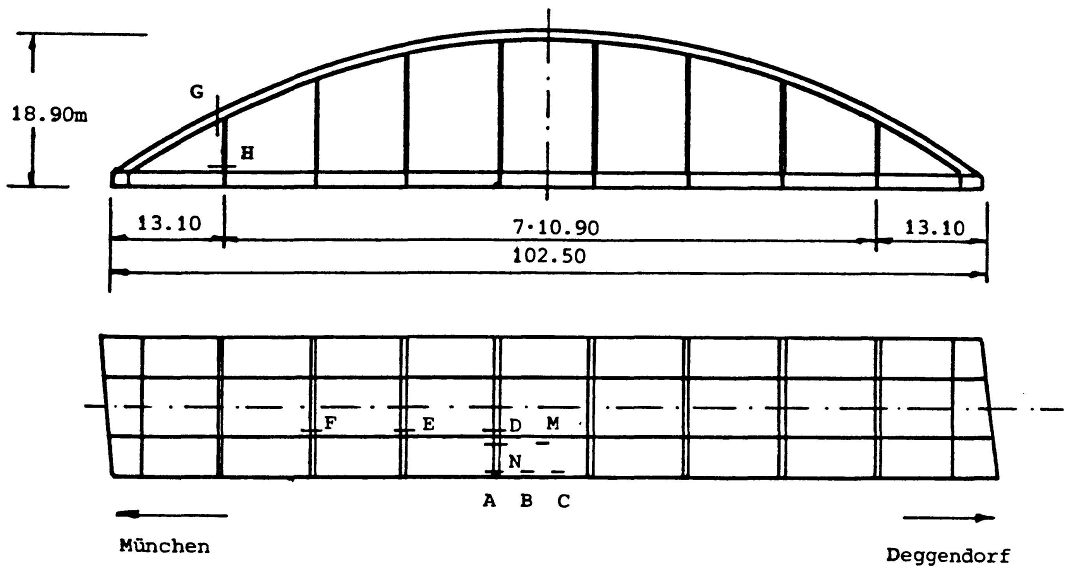


fig. 1 Bridge Fischerdorf

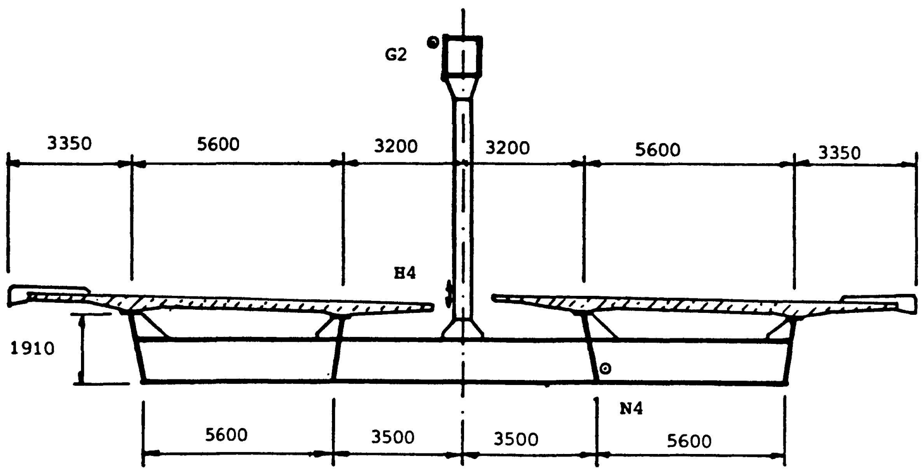


fig. 2 Bridge Fischerdorf cross-section

## 3. Measurements

### 3.1. Measurement Equipment

Fourty points were selected at which the strains were measured. Four of them were at the arch (point G1-G4) near the first rod. Another group of four points were installed at the first rod. (Points H1-H4). The transverse beams have three groups of strain gages (D1-D4, E1-E4, F1-F4). The other measurement points (A1-A4, B1-B4, C1-C4, M1-M4, N1-N4) were at different locations of one of the main griders, at the webs near the deckslab and the bottomslab.

At each measurement point one active strain gage and one for compensation were connected to one Whetstone´s half bridge to compensate temperature effects. The gages for compensation were fixed to little steel plates which were seperated from the steel construction with a special paste, with the consequnece that the plate has the same temperature as the main construction without having its stresses. To get longer stability of the strain gages some of them are capsuled. The long time measurement will also improve the stability of this different type of strain gages. Eight of the fourty measurement points can be measured at the same time. An amplifier HBM-MGA is used as a signal conditioner. The calculation of collectives or spectra are done by different personal computers with build in analog-digital-boards of type Data Translation 2801A and Analogic MS-DAS 16.

### 3.2. Stress Collectives

Two personal computers were used to evaluate the stress collectives permanently.The program was developed at the Lehrstuhl für Baumechanik [1]. The hystereses counting method (rainflow method) is used to classify the stresses into a matrix with 64 rows and columns. The calculation is done without interrupting the measurement. Also hypothesis for life time estimations are included, in this way nonlinear hypothesis can be calculated incrementally. A calculation of nonlinear hypothesis afterwards is impossible, because of the unknown time history of the stress-cycles. Additional information about life time estimation is given in [2]. At the moment the results of the collectives at different points covering one week measurements can be presented. The tree lines in figure3 show the collective after 2 hours, 20 hours and 160 hours.

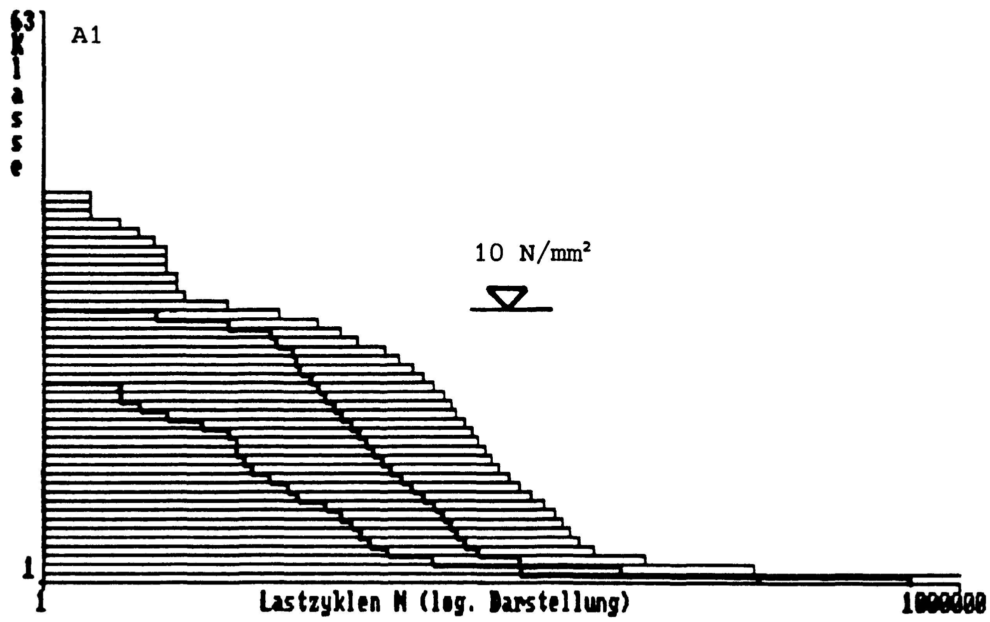


fig. 3 Stresscollectives of measurement point A1 after 2 hours, 20 hours, 160 hours

The collectives after 160 hours at points G2 and H4 of the construction is shown in figure 4

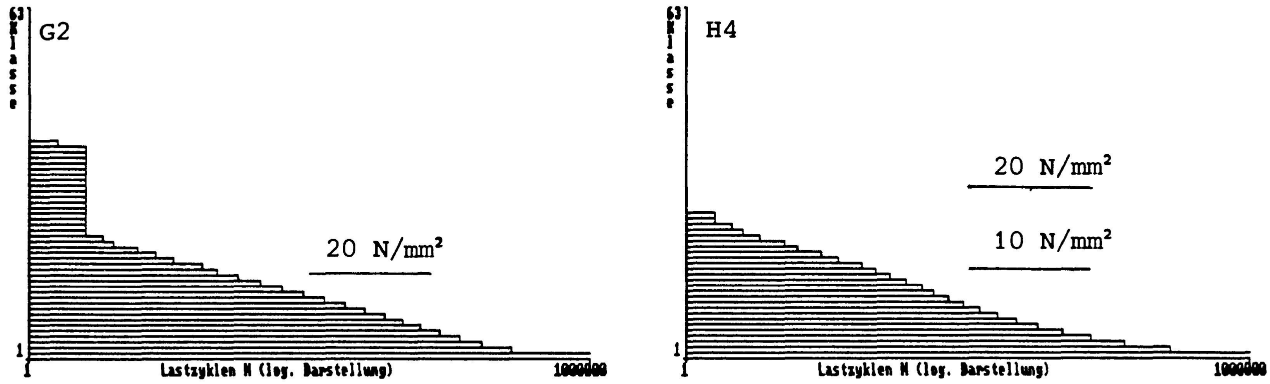


fig. 4 Stress collectives of measurement locations G2 and H4 after 160 hours

The stress cycles at the highest levels are not the result of the traffic loads but due to the temperature gradient between day and night. Therefore about one cycle per day can be calculated from the collectives. Strain-cycles due to high level stresses are measured at the arch. The point A1 near the road way shows much more stress-cycles at low level stresses than the rod and the arch, for which the local stresses are not important.

### 3.3. Time Series

After the short time measurements with static loads were done in autumn 1991, some short time measurements with dynamic loads followed. Figures 5 and 6 show the dynamic response of the first rod (location H1) to a transporter with a weigt of 91 tones. Figure 5 belongs to a speed of 30 km/h. The influence of crossing wooden plank placed on the driving lane in the middle of the bridge can be recogniced in figure 6. It shows the possible influence of dynamic effects on fatique life.

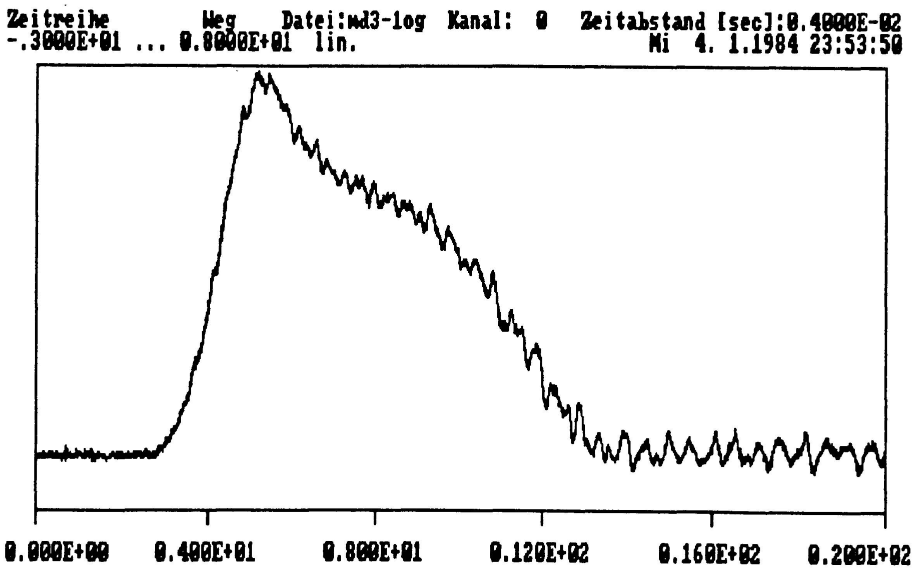


fig. 5 Short time measurements at point H1 of a transporter without a plank.

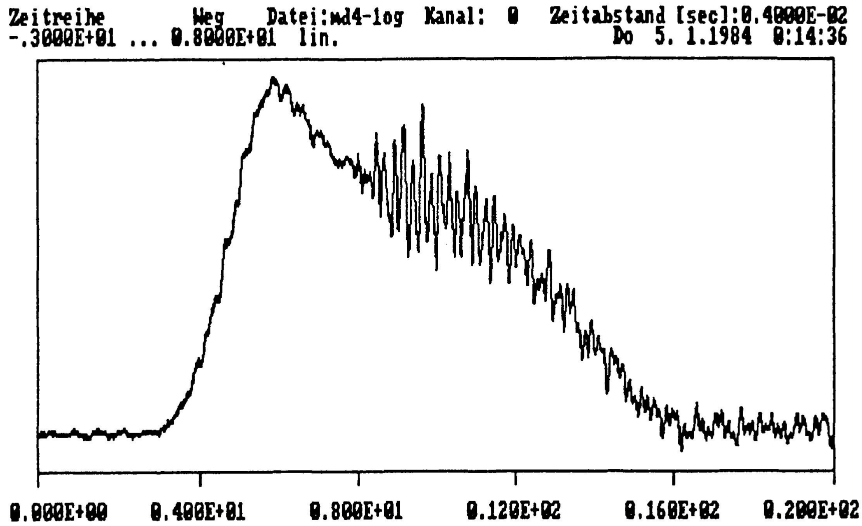


fig. 6 Short time measurements at point H1 of a transporter with a plank.

Some time series were recorded for about twenty minutes. Two clips of one of the records (figure 7) are displayed in figure 8 to show the different response of point N4 due to crossing vehicel In the first clip a static response of the bridge is visible while in the second clip a dynamic reaction of the bridge is shown. The influence on fatique life of the second vehicle is much greater than that of the first one. Therefore strain measurements as described in chapter 3.2 are necessary to calculate a more realistic life time estimation.

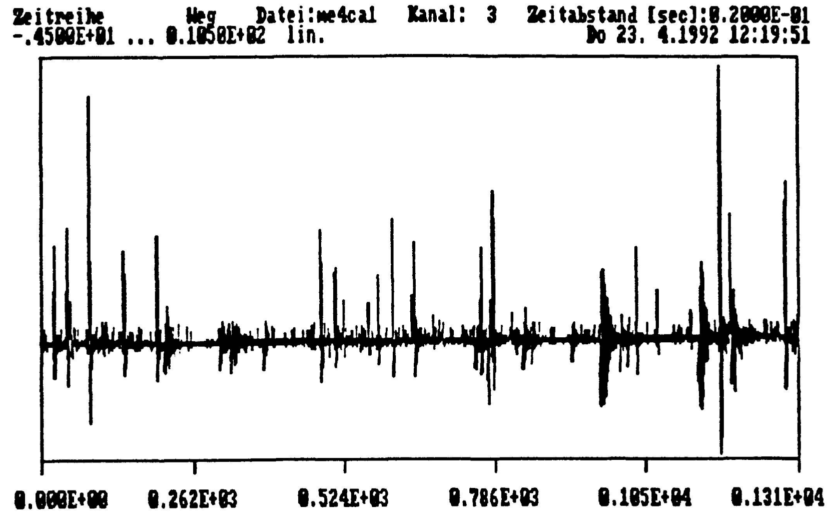


fig. 7 Time record at point N4

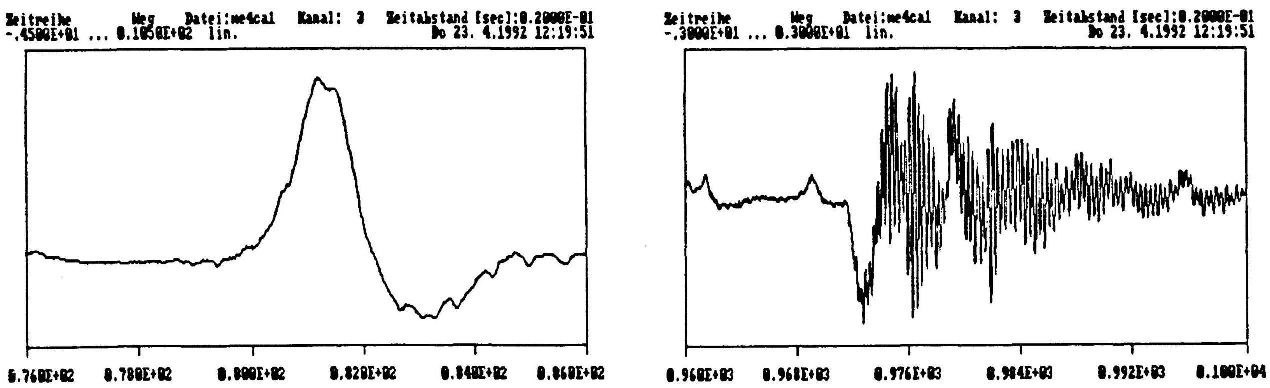

fig. 8 Two clips of the time record with showing different reactions of the bridge

The measured static response of the bridge due to the crossing vehicel in the first clip can be compared to a calculated influence line of the moment, which is porportional to the measured strains, because the vehicel is driving with a constant velocity.

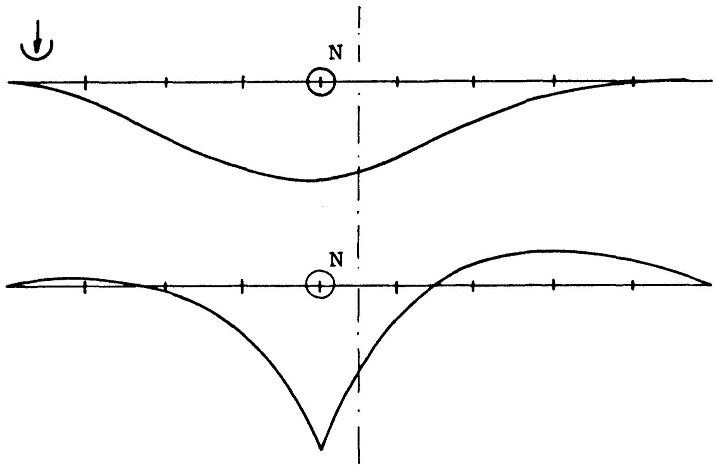


fig. 9 Static influence line of deflection and moment at point N4 calculated with finite elements method.

The frequency spectrum of the second figure has two significant frequencies which correspondends to two neighboured eigenfrequencies of the bridge.

3.4.Averaged Frequency Spectrum

Using a group of time series the spectrum can be averaged using the amplitudes of the spectra with no respect to the phases. Averaging of the complex amplitudes is impossible because a measurement without triggering results in random phases. Averaging amplitudes smooths the noise but does not eleminate the noise. The following figures show the frequency spectra with traffic load after about 1400 averages. The effect of smoothing the noise for random signals gives the possibility to determine the eigenfrequencies without using determined loads ore impacts. Averaging the traffic load spectrum has similar the effect as using a banded white noise excitation.

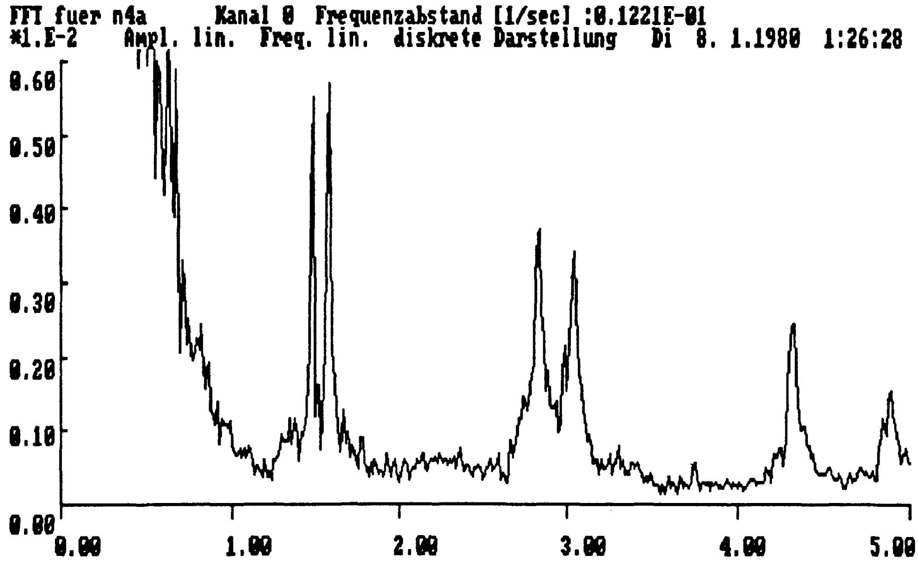


fig. 10 Averaged frequency spetrum for point N4

3.5.Standard Deviation of banded Frequency Spectrum

A possible way to control changements in traffic during time is to control the change in a banded frequency spectrum between averaged groups. Therefore in a first step the frequency spectra are averaged. In this case 10 spectra are chosen for one group. In a second step groups are averaged with a calculation of the standard deviation. In this example 140 averages of groups are done. The deviation is of the same order as the average. This is the result of the differences between day and night and at the weekend. To reduce this effect a special time control is introduced into the program, which measures the groups always at the same time and the same day. Long time observation with this time control might get information about long time changes in the traffic load.

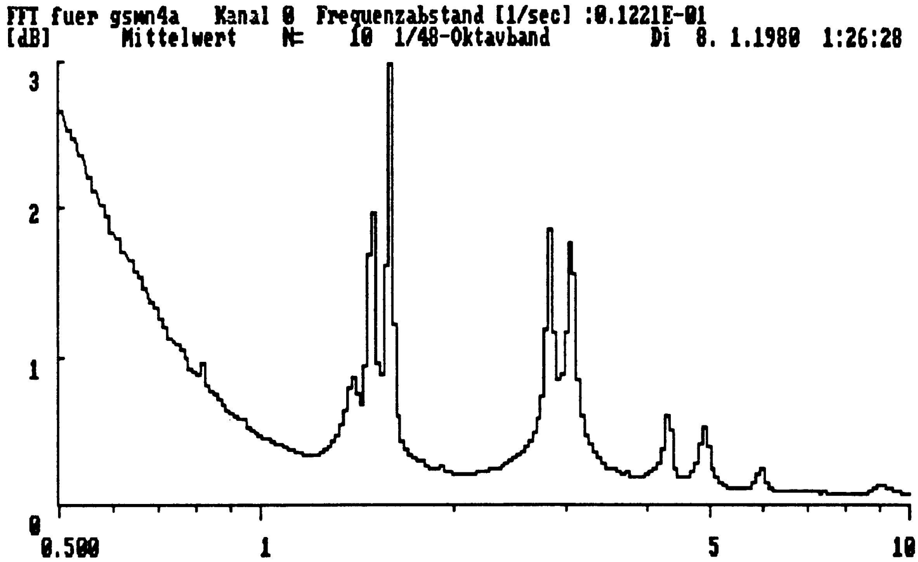


fig. 11 Averaged banded frequency spektrum at point N4

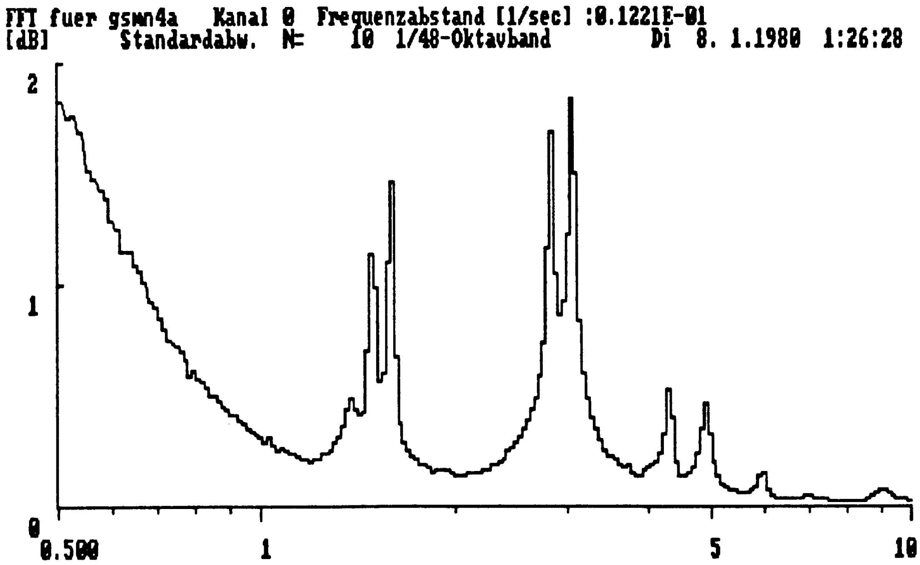


fig. 12 Standard deviation of the frequency spectrum at point N4

## 4.Traffic Load Estimation

The direct calculation of the traffic loads based on the measured stresses is difficult. All driving lanes have different influence lines. Also the speed of the vehicels are variable, therefore only stochastic calculations are possible. Another problem is the dynamic response of the bridge to harmonic loads as shown in chapter 3.3. This effect is dicussed in [3] there the response of a beam to a moving harmonic load is displayed.

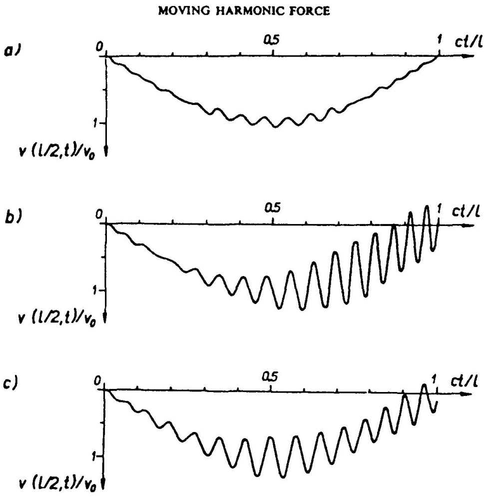


fig. 13 Deflection of a massless beam to a moving harmonic load with different speeds [3]

Changements in the traffic load will produce changing stresses at the measured points. Using long time measurements it is possible to control changing in traffic loads easily by controlling the development of numbers of stresscycles and their distribution. As an example an increase of heavy vehicles will result in an increase of the high level stress cycles. As a second possibilty a measurement of the resonant frequencies can control the development of vehicels with bad dampers, which are predistined to get in resonance with the bridge structure. This vehicels can reduce the fatique life of a bridge rapidly.

## 5.Conclusions

The results of the long term measurements can be used for life time estimation of the bridge. Using transfer function a life time estimation of arbitrary points of the bridge can be calculated.

An exact estimation of the traffic load is difficult because of the dynamic response of the bridge, but the measurements can control the development and the composition of the traffic loads. The only way to calculate the traffic load is to use statistical functions.

Because of the difficulties to develop a realistic load model it is better to measure the stresses of bridges at dufferent points. The results of this points can be used to calculate different points with respect to the dynamic eigenfunctions, the distribution in the frequency spectrum and the stress collectives.

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