DYNAMIC INFLUENCES ON BRIDGES

– Preventive Measurements –

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1. Introduction

The paper describes a monitoring system to determine the dynamic influence of heavy lorry traffic on bridges and deals mainly with concrete and composite concrete bridges. The general idea is not limited on bridges.

For the time being, road bridges normally become visually inspected in regular time intervals in order to detect any defects and/or to decide whether additionally rehabilitation might become necessary. The proposed method has to be seen as a supplement for these inspections and offers the opportunity to detect and regard special, single damaging effects as well as to have a permanent structural supervision. The aim of such a monitoring system is to determine the kind, frequency and magnitude of the actual actions. Using these information, a comparison between the computational bridge model and the reality becomes possible. An other aspect in the determination of the actual loading is fatigue and aging of bridges, due to the impact loading of heavy lorry traffic /1/, /2/.

2. General Loads – Computation, Reality

Every structure becomes designed on the basis of certain assumptions with regard to the structural resistance and actions on the structure, with as well can be dynamic and have to be taken into account accordingly.

Fig 2.1: Tacoma-Narrows bridge

Fig. 2.1 for example shows wind induced oscillations of the Tacoma-Narrows bridge, which finally caused the bridge's collapse in 1940.

With the ever increasing heavy lorry traffic, this influence on bridges can not be neglected any longer.

For the structural analysis of every structure, which includes bridge structures, a computational model is necessary. The general loads on the structure then are determined under certain assumptions concerning the stiffness, geometry, structural system, bearing friction and loading on the basis of common linear design methods, normally based on the theory of elasticity or other non-linear design methods. It is common knowledge that building materials as well as building execution show certain variations and that computational models can differ in some extent from the reality. Other influences due to temperature, shrinkage, differential bearing settlement are normally considered in the design, but can differ considerably from the computational assumptions.

The two composite bridges erected in the „Thüringer Forest“ and described in the following differ mainly with regard to some aspects of the cross-section and the design of the transverse ties in the reinforced concrete deck.

3. Bridge structures

For the time being the traffic project German Unity No. 16, motorway A71 between Erfurt and Schweinfurt and A73 between Suhl and Lichtenfels is under construction in the „Thüringer Forest“. This construction project is supervised by DEGES, set up by the German government and responsible for all traffic projects in the former GDR. In this context DEGES commissioned two monitoring systems for two of the major bridges. The two similar bridges, as far as the superstructure is concerned, are:

1) Valley bridge Reichenbach and
2) Valley bridge Albrechtsgraben /3/

Then valley bridge Reichenbach /4/ is situated close to Ilmenau, see fig. 4 and 5. The total length of the brigde is 1.000 m, and the span lengths are chosen according to the form of the valley. The 14 spans of the superstructure, constructed as a continuous girder, have a span-width between 40 m in the end-spans and 105 m in the bridge’s middle. In the region of the end spans with a span-width up to 75 m, the superstructure consists of a composite parallel girder with a construction height of 3,7 m, whereas for the middle spans a haunched girder, with a construction height over the supports of 5.85 and 6.5 respectively, was chosen.

Both carriageways, with a width of 11,5 m each, and a hard shoulder are situated on one single composite concrete superstructure. With the width of the inside and outside curbs of 2 m each, the overall width between the rails between the rails can be given to 28,50 m.

The bridge cross-section consists of a the steel box-girder with compression struts at the outside, connected by tension ties. After mounting of the steel box, the cross section becomes supplemented by the reinforced concrete deck. The single steel box-girder cross-section has inclined webs. The upper and bottom box-girder width remain constant in all spans, with a width of 10,50 m and 8,50 m respectively /5/.

The box girder is stiffened in transverse direction by frames and diagonal struts. The stiffening of the bottom metal sheet and webs is carried out by trapezoidal profile sections. The cantilever arms of the top reinforced concrete deck are supported by inclined circular steel section compression struts, arranged in the distance of the transverse supporting frames. Due to the inclination of these compression struts, a steel tie became necessary between the ends of these compression struts in the reinforced concrete deck.

The reinforced concrete deck is grid-like supported by haunched reinforced concrete joists. These are arranged in longitudinal direction over the ends of the compression struts, the box-girder webs and in the middle of the box girder above the diagonal stiffeners, as well as in the axis of the transverse frames. The shear bond between the steel ties in transverse direction and the parts of the steel box girder supporting the reinforced concrete slab is achieved by shear stud connectors.

After launching the first parts of the superstructure, the concreting of the reinforced concrete deck was carried out in alternating sections. Altogether 57 concreting sections with a length between 10,00 and 17,50 m were carried out.

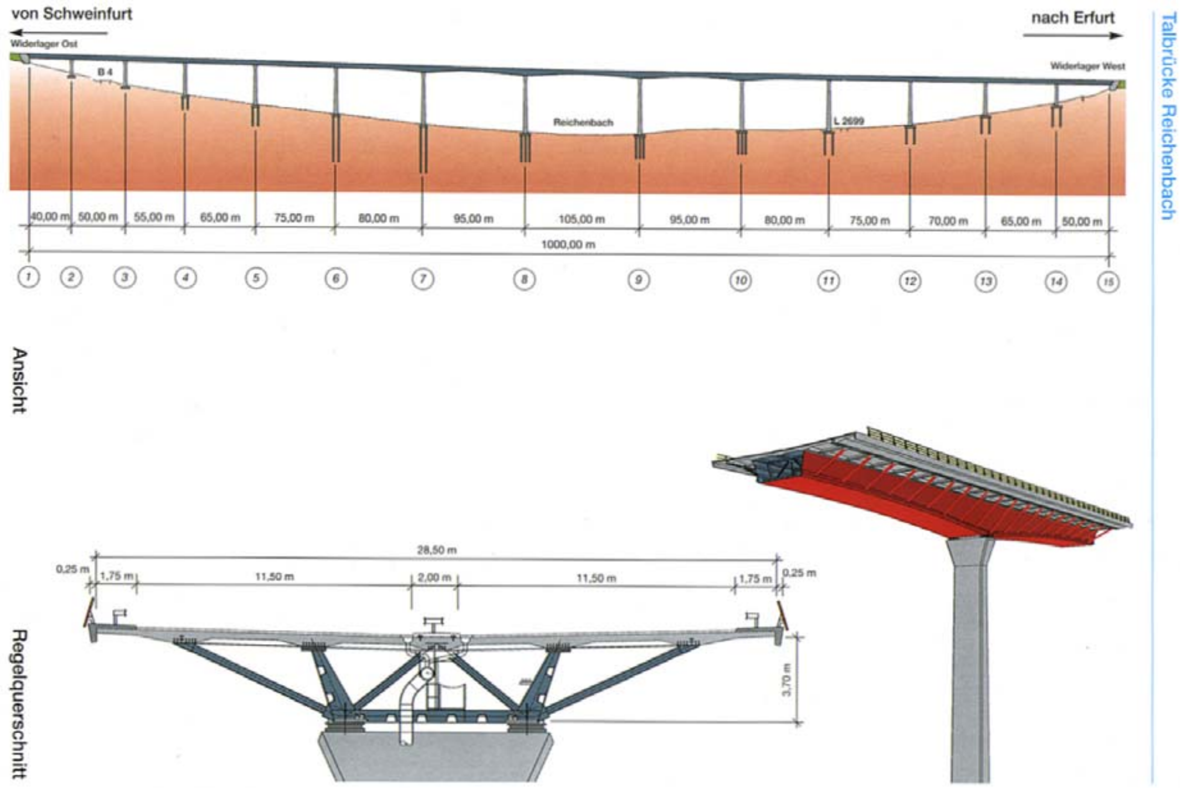

Fig. 3.1: Valley bridge Reichenbach

Fig. 3.2: Valley bridge Reichenbach – open box-girder with outside compression struts and steel ties

The valley bridge Albrechtsgraben /6/ is situates close to Suhl. The bridge has a total length of 770 m, and span-width between 45 and 70 m (see Fig. 3.3). The actual valley with a width on 170 m is bridges by an arch, supporting the superstructure in this region. The actual bridge consists of a parallel girder with a construction depth of 4,50 m.

As for the valley bridge Reichenbach, the superstructure consists of a single composite box girder, with a width of the top deck between the rails of 28,50 m. The construction principle, consisting of a box-girder with inclined webs, outside compression struts and connecting steel ties is the same as for the valley bridge Reichenbach.

Mainly the construction of the steel ties is different. While these consist of sheet-metal for the valley bridge Reichenbach, arranged at the level of the box-girder web flanges, the steel ties of the valley bridge Albrechtsgraben is arranged in the middle of the reinforced concrete deck and consists of 4 steel rods. The reinforced concrete deck is supported by a system of haunched reinforced concrete joists. In contrary to the valley bridge Reichenbach, the outer longitudinal joist is reinforced by a steel section, see Fig. 3.4.

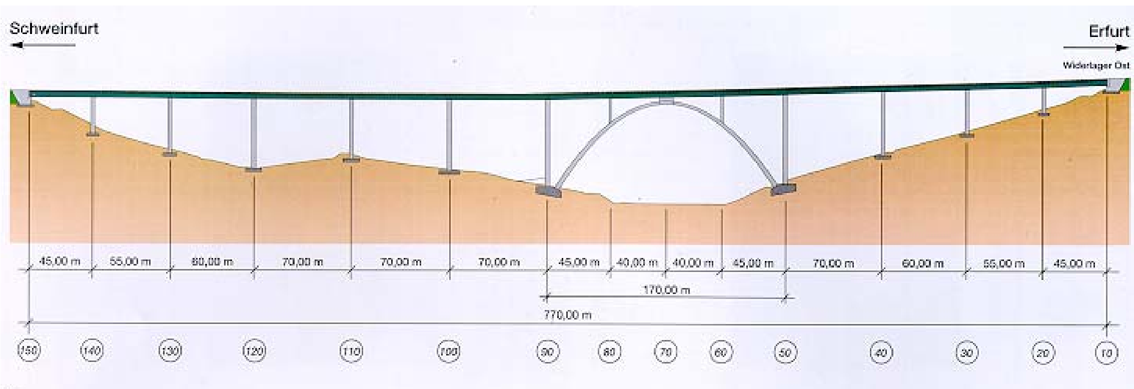

Fig. 3.3: Valley Bridge Albrechtsgraben

Bild 3.4: Valley bridge Albrechtsgraben – steel tie

4. Instrumentation

The instrumentation for both bridges is designed in such a way, that on the one hand side a comparison between reality and computational model can be carried out, and on the other hand side the impact like actions of heavy lorry traffic on the reinforced concrete deck, the steel ties as well as on the webs of the steel box-girder can be recorded. For example, the arrangement of the strain gauges on the steel ties over the supports and in mid-span (measurement points 8 to 15, 21 and 22) can be seen for both bridges in Fig. 4.1 and 4.2. The other measurement points show the location of the strain gauges in the reinforced concrete deck.

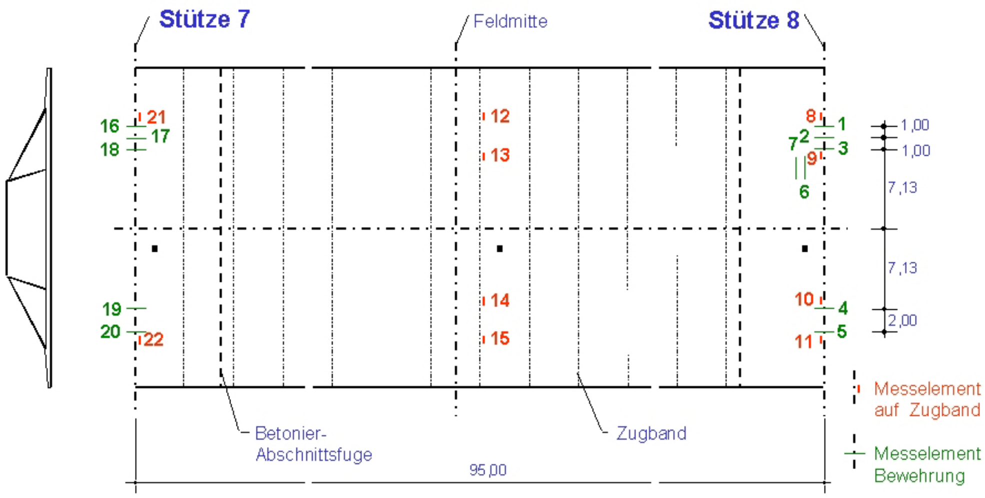

Fig. 4.1: Arrangement of the measuring elements for the valley bridge Reichenbach

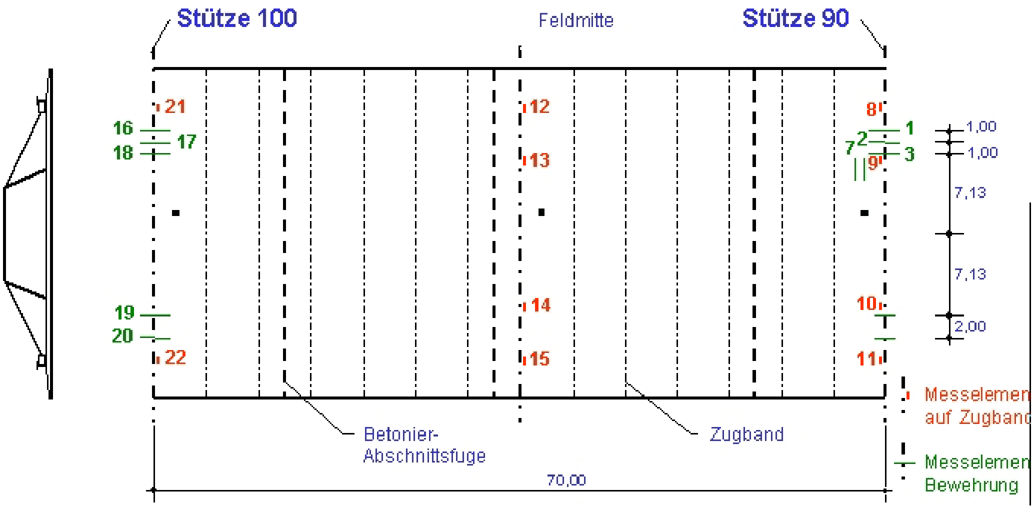

Fig. 4.2: Arrangement of the measuring elements for the valley bridge Albrechtsgraben

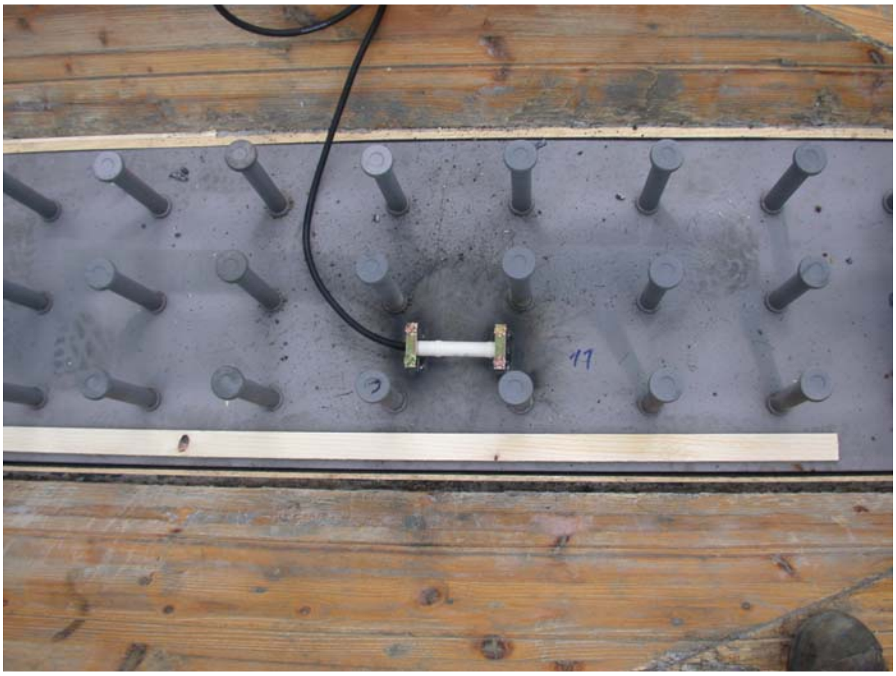

Fig 4.3: Strain gauge on the sheet metal tie of valley bridge Reichenbach

In Fig. 4.3 the arrangement of the measuring elements on the steel ties of valley brigde reichenbach and on Fig. 4.2 on one of the rods of the steel ties of valley bridge Abrechtsgraben can be seen.

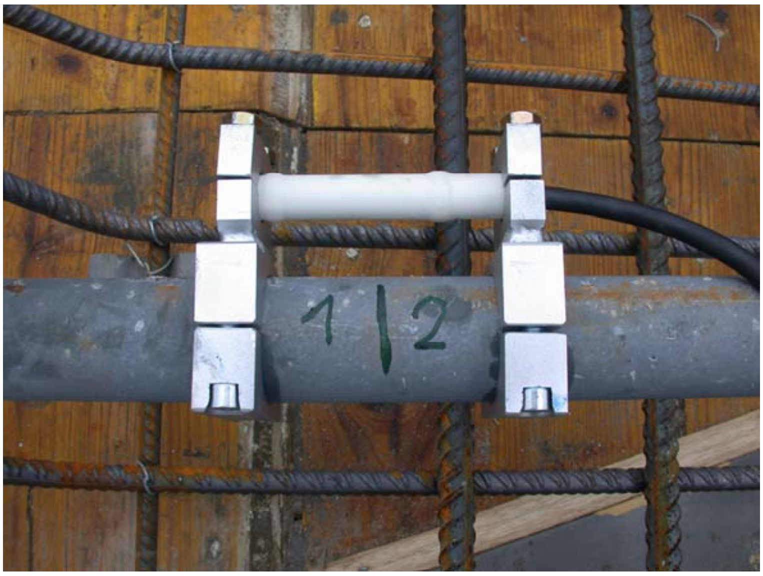

Fig. 4.4: Strain gauge on one of the rods of the metal tie of valley bridge Albrechtsgraben

Based on the measurement results the differences between the model assumptions and the reality can be shown. Furthermore, the effectiveness of the two different construction principles can be compared.

Cracks in the reinforced concrete deck can not be avoided. The strain in the reinforcement bars is highest directly at a crack. If an additional oscillatory stress occurs, the danger of reaching the fatigue strength exists. In order to examine this fact under actual loading conditions, breaking points by milled slots were arranged in the reinforced concrete decks of both bridges over the supports (see Fig. 4.5). Under these slots reinforcement bars with a length of 2 m were arranged, equipped with strain gauges, situated directly under the milled slot. The arrangement of these sensors is given in Fig. 4.1 and 4.2. The strain gauges on these reinforcement bars were especially protected, in order to avoid damages during concreting and the subsequent failure of one of the sensors, see Fig. 4.6.

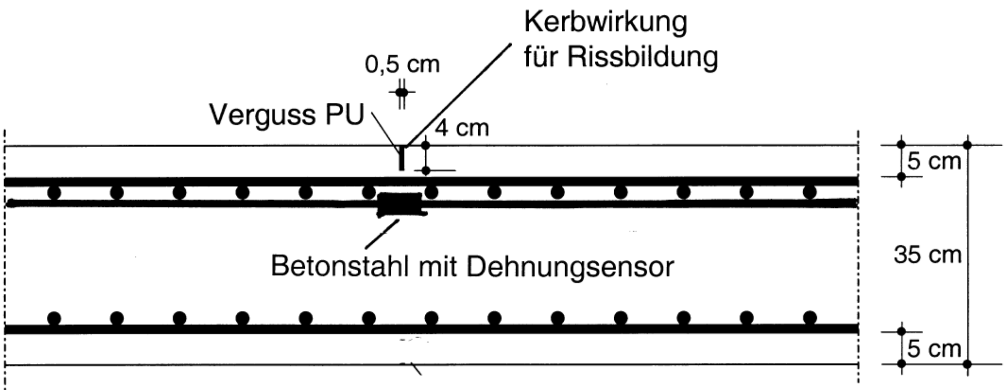

Fig. 4.5: Breaking points within the reinforced concrete slab and arrangement of the strain gauges on the reinforcement bars

Fig. 4.6: Reinforcement bars with especially protected strain gauges

In addition to the strain measurement on the reinforcement of the concrete deck and the steel tension ties, measurement on the deformation of the steel webs are carried out. The inductive displacement transductors were arranged over the supports and in mid-span, at the top and the bottom of the box-girder webs, in order to determine the action of heavy lorry traffic in these highly stressed regions (see Fig. 4.7)

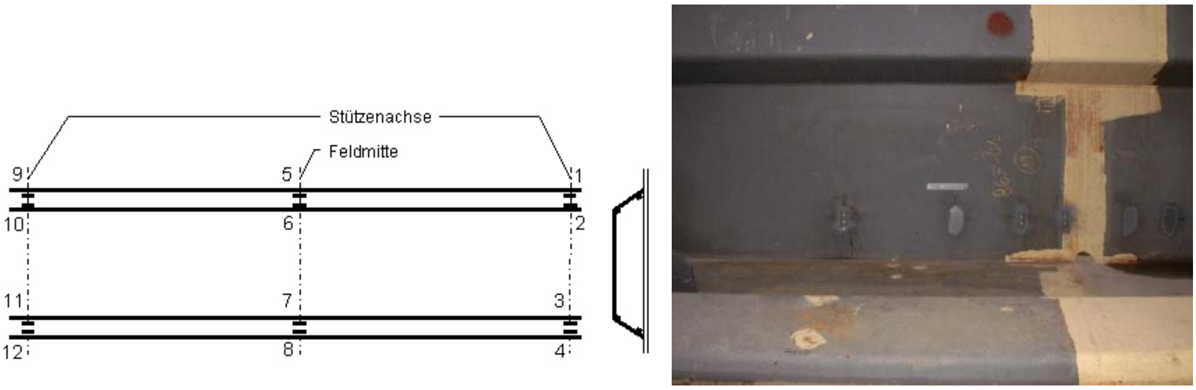

Fig. 4.7: Inductive displacement transductors on the box-girder webs

5. Test loading

At the begin of the monitoring measure, statical and dynamic test loadings were carried out with specially loaded trucks with a weight of 40 tons. These trucks drove over the bridge with different speeds (v= 20, 40, 60 and 80 km/h), while the respective strain were recorded. In order to simulate the unavoidable deterioration of the deck surface, causing an impact loading on the bridge, a groove was milled in the road surface of the bridge deck. Fig. 5.1 indicates the location of these grooves and describes the measurements at each location.

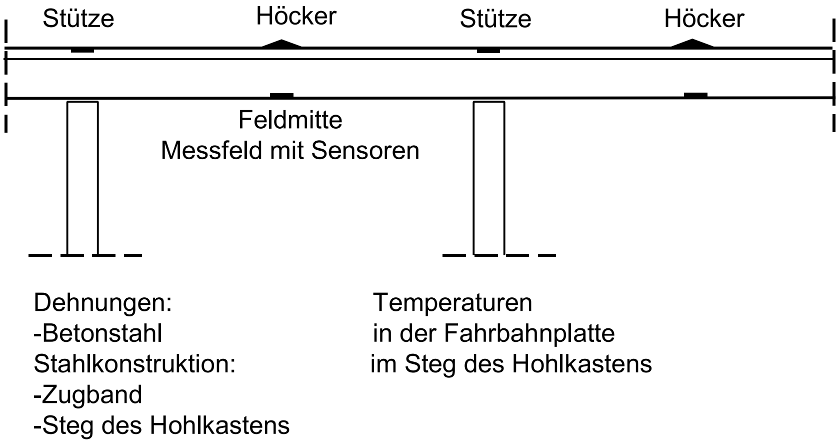

Fig. 5.1: Location of the measurement points and grooves in the road surface

6. Data recording and processing

The permanent supervision system is designed in such a way that the data recording takes place with a frequency of 100 hertz. For the test loading all data were recorded, but for the permanent supervision a filter programme only records the minimum and maximum value occurring within 10 seconds, which is taken as the time one lorry takes to cross a measurement point and the next lorry arrives. The measurement values are stored on a computer in the measurement station located in the bridge. These data can be transferred via telephone to the institute for further processing. Fig. 6.1 shows the instrumentation of the measurement station during the configuration in the institute.

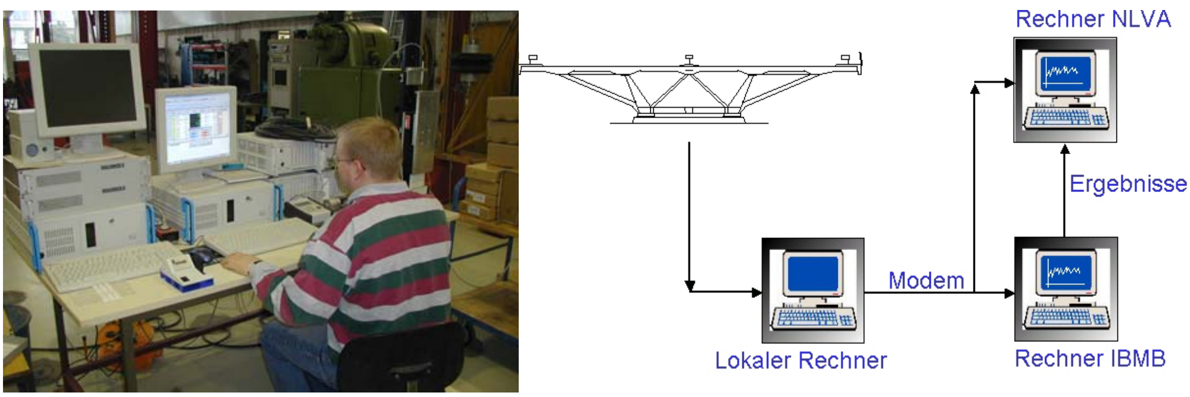

Fig. 6.1: Configuration of the measurement station in the institute

The following figure 6.2 shows as an example one result of the calibration. It shows the longitudinal strain in the reinforced concrete deck slab over the support for the passing of two lorries with the speed of 60 km/h. With the results of this calibration the measurement values of the long-time supervision can be assigned to actual loading events. These values are taken continuously from all measurement points in both bridges.

Fig. 6.3 shows the temperature development in the reinforced concrete deck.

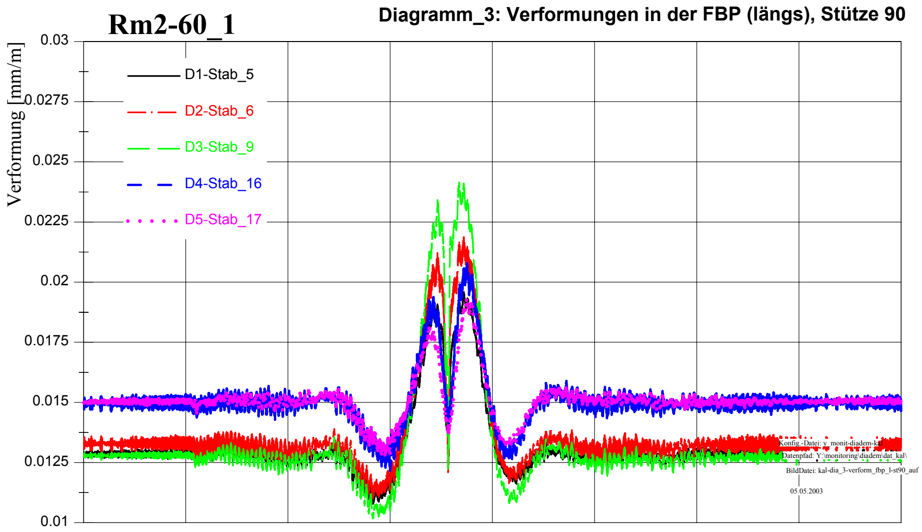

Fig. 6.2: **Deformation in the in the reinforced concrete deck slab over the support for the passing of two lorries with the speed of 60 km/h.**

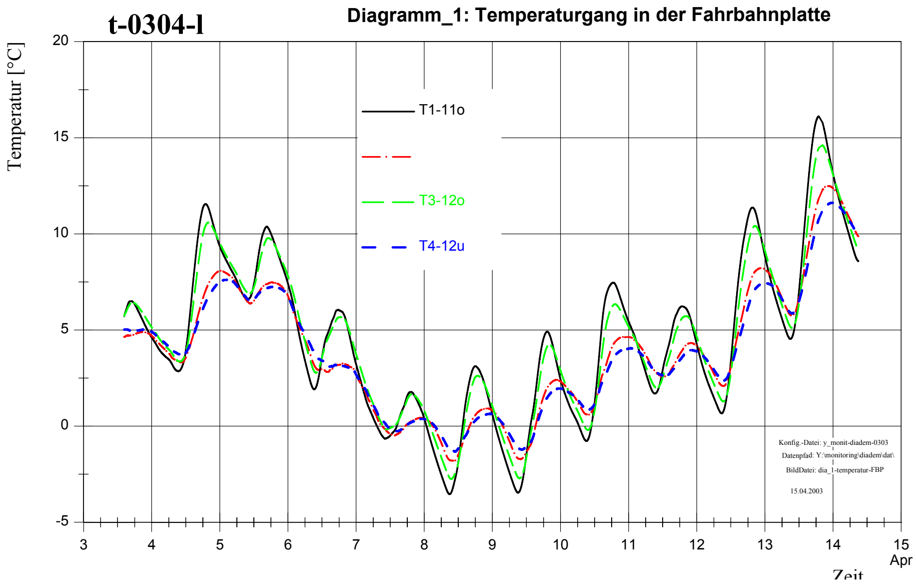

Fig 6.3: **Temperature development in the reinforced concrete deck slab.**

Especially the dynamic action effects and the loading degree have an important influence on the aging process of a structure. In certain cases the information obtained by such a monitoring measure can lead to the decision that a bridge has to be graded down, i.e. the allowable traffic load has to be reduced of other actions have to be taken. This, for instance could be a reduction of the allowable speed on the bridge in order to reduce the dynamic effects of heavy lorry traffic or lorries have to keep a certain distance between each other.

7. Summary

Bridge monitoring will never replace the visual bridge inspection and supervision by trained personnel. Such a monitoring system should be used on a temporary basis in order to obtain data which make it possible to determine the optimal maintenance and repair strategy. The knowledge obtained from such a system should enable us to work towards a standardized federal bridge management system, which allows not only a more economical use of the available financial resources, but also, if ever possible, an unhindered traffic flow.

By the use of realistic loading collectives a better service live prediction will be possible. Depending on the height and number of loadings, criteria for the damaging degree on structures can be determined, depending on the type of road and typical traffic. On the other hand side, if the damaging effect of heavy lorry traffic is known, a mileage dependent and fair road tax for this type vehicles can be set.

These data will also be used for the assessment of current design loads, especially with respect to the vibration coefficient currently set in the respective standards.

The monitoring system described above is currently in use in two major valley bridges and will be in operation for another two years.

This research project is sponsored and supervised by the Federal Ministry for Buildings and Housing, the state owned DEGES and the Federal Road Construction Agency (BASt).

8. Literature

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