Independent bridge remote monitoring system for dynamic measurements at the Steinbachtal Bridge in Germany

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1. Description of the structure and of the remote monitoring system

The Steinbachtal Bridge is located in the county of Thuringia and carries the South Harz Autobahn A38 from Göttingen to Halle. The autobahn A38 is still under construction, however the earth transports required for road building works had to pass over this bridge. Therefore, the Steinbachtal Bridge was built as a advance construction measure in 2000 even though the highway had not yet been built. The bridge spans the Steinbach, some agricultural roads and the highway L 2020, which are located between the two localities Bodenrode and Steinbach. It is constructed in the form of a one-element superstructure. The length of the bridge is 372m, the spans between the total of five piers is are between 54m and 78m, and the maximum structure height is 35m. Due to its slim composite design the structure reacts sensitively to heavy load traffic, especially the super heavy soil transport during the construction period. Additionally, a structural overhaul of the bridge will be carried out in 2005, which will reduce the loads through the self-weight of the bridge for a short period. A picture of the bridge is presented in Fig. 1.

Fig. 1. The Steinbachtal Bridge on the Southharz Autobahn (A38) near Bodenrode, Thuringia, Germany.

1.1 Reasons and objectives behind the installation of the Robo®Control system

In order to monitor the construction site traffic and changes in the load due to construction works for the refurbishment of the bridge, the Deutsche Einheit Fernstrassenplanungs- und –bau GmbH (DEGES) decided to install the mageba remote monitoring system Robo®Control. The system measures 4 different parameters on the structure using different measuring principles. The following measurements are carried out:

- temperature using fibre optical and conventional sensors
- movement by using magnetostrictive measuring technology
- strain with fibre optical and conventional sensors
- vibration by using fibre optical sensors

The arrangement of the sensors is shown in Fig. 2. The objectives to be achieved by the installation of the remote monitoring system were as follows:

- to determine and categorise heavy traffic load on the basis of the vibration behaviour of the bridge,
- to determine the loads in the structure due to the changed permanent weight during reconstruction measures starting from September 2005,
- to get information on movements in the bridge actually caused by temperature, and to compare the data with the theoretically calculated values.

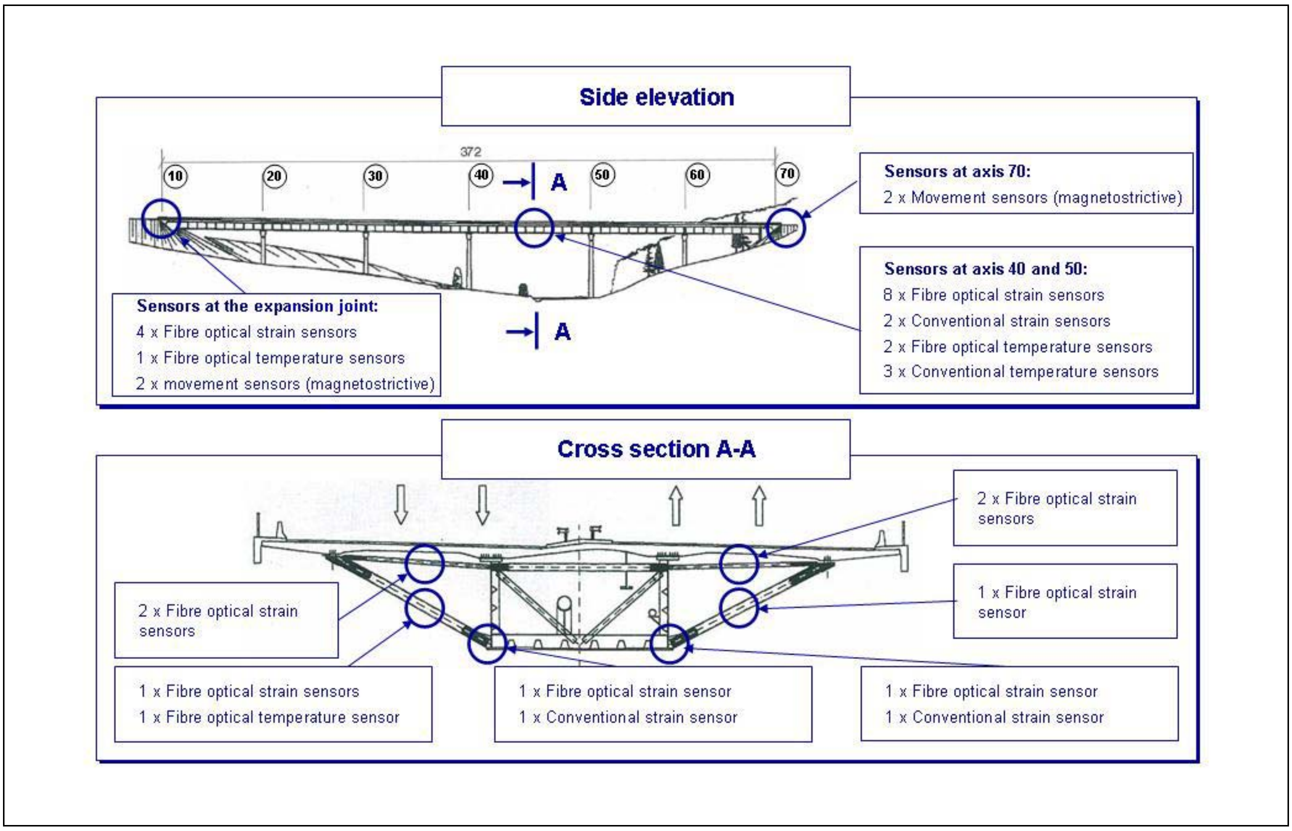

Fig. 2. Arrangement of sensors in the bridge cross section of axis 40-50 at Steinbachtal Bridge.

1.2 Measurement principles of Robo®Control

The temperature is measured using both conventional and fibre optical temperature sensors. At the same time, the movements of the structure, caused by thermal fluctuations, in the western and eastern bridge abutments is measured at the bridge bearings. For this magnetostrictive movement sensors are used. Additionally, the strain in the steel box girder caused by traffic loads and construction works is recorded in the bridge bay between axis 40 and 50 (field at the bridge centre) by using both fibre optical and conventional strain sensors. On the basis of the acquired data conclusions can be drawn on the loads actually caused by dead the weight, and these can then be compared to theoretically calculated values.

The measurements enable one to make conclusions on the actual movements of the bridge, and the stresses in critical components as well as in the steel box girder. In addition to the above mentioned sensors, 4 fibre optical strain sensors were installed between axis 40 and 50 for measuring vibrations. The occurring stresses are measured with a sample rate of 100Hz at various locations throughout the bridge cross section. This way the site traffic (load and speed) and resulting structural behaviour can be measured and the long term reactions of the structure can be checked.

1.3 Calibrations performed

In order to determine the structural behaviour of the components caused by heavy traffic loads and also to enable facilitate categorisation of traffic, a loading and calibration test was carried out on the 16th September 2005. For the test, 3 trucks of different weight (20t, 40t and 50t), each crossing at different speeds, were used (5km/h, 30km/h, 60km/h and maximum speed). The data acquired during the test was evaluated by mageba in respect of categorization of events with regard to speed and weight (= crossing of trucks heavier than 20t).

1.4 Additional preservation of evidence by means of a camera

Additionally, a camera was installed on the structure in order to photographically document critical events, which were caused e.g. by trucks exceeding limit loads and/or speeds. One of these photographic documentations that was recorded on the bridge and transmitted via a GPRS modem is presented in Fig. 3. The data recorded on the construction site is transferred via a wireless GPRS modem to an Internet server and then processed. It is then also checked whether certain events, such as exceeding a critical strain, movement or temperature, have occurred that should be communicated to the customer (via SMS and email).

Fig. 3. Photos for securing evidence on the basis of the dynamic recognition of a truck on the joint structure (website)

2. Detailed description of the System

A strict and long established quality control system ensures that the systems are checked and will run for a long period of time without failure [1]. The remote monitoring system Robo®Control is relatively inexpensive. In its basic version, bridges can be monitored starting from around 30’000€ [2] including components and installation, but the price can go up to 100’000€ and more for a dynamic monitoring system where the complete bridge is monitored in various sections.

2.1 System description of the standard Robo®Control Box of type I

A Robo®Control Box of Type I (RC – Box Type I) has been installed in the abutment on axis 10. The sensors connected to this box measure information on structure temperature (3x) and movement (4x) and the data is collected and saved at an interval of 15 minutes in the box. The data is transmitted via SMS from the box at the bridge. It is continuously checked whether the sensors are still sound (only temperature), and if necessary, an alarm is transmitted. A preliminary data evaluation is not performed.

Data is transferred 4 times a day. Alarm values as well as short term measurements, i.e. measurements at a one second interval, have to be requested at least one day prior to measurement as the requests for these measurements are transmitted only once, at midnight, in order to save energy. The number of SMS depends on the number of connected sensors and on the data amount to be transmitted. On a long-term basis, data such as movement and temperature is automatically measured, saved and transferred by the RCI Box at a 15-minutes interval. The data can be viewed via a web application and downloaded as an MS Excel-compatible CSV file, if required.

2.2 System description of the advanced Robo®Control Box of Type II

In the abutment of the bridge at axis 10 the Robo®Control Box of Type II (RC II Box see Fig. 4) is installed to measure strain and to conduct dynamic measuring. Normally, the dynamic data is reduced from 6’000 values per minute to 3 values per minute by means of averaging as well as determining of minimum and maximum values. The remaining measuring data is not saved. However, should certain special events occur, i.e. exceeding of a threshold value of strain, the dynamic events are saved for a certain time and transmitted via a GPRS modem to an Internet server.

The dynamic data is analysed in advance and buffered in the RC II Box. Additionally, the measurement data of fibre optical sensors that is transmitted at light wave length is calibrated on the spot and converted into temperature-compensated strain or into temperature readings. If the buffer has reached a critical threshold (75% of the memory capacity) the data is transmitted. This applies for various types of readings, the reduced time variation curves of strain as well as the dynamic readings consisting of 6’000 values per minute per sensor.

This can happen several times a day and therefore contact to the RC II Box can be established at any time. This is in contrast to the RC I Box, where contact is only possible once a day. In addition to adjusting the calibration data, the box also offers the possibility of firmware updates enabling one to make any necessary post-adjustments comfortably from the office.

Fig. 4. The measuring data unit, the so called Robo®Control Box of Type I for conventional measuring (RC-Box I: small, silver coloured) and of Type II with an integrated laser interrogator for dynamic measurements (RC Box II: big, white).

2.3 System description – software

Critical for a clear presentation of measuring results is a well-designed software concept that is fine-tuned to the measuring problem. For the Steinbachtal Bridge project, it was important to being able to present connected data together, e.g. temperature and movement, or strain and a truck crossing the expansion joint. This was achieved by means of a well-structured database (see Fig. 5).

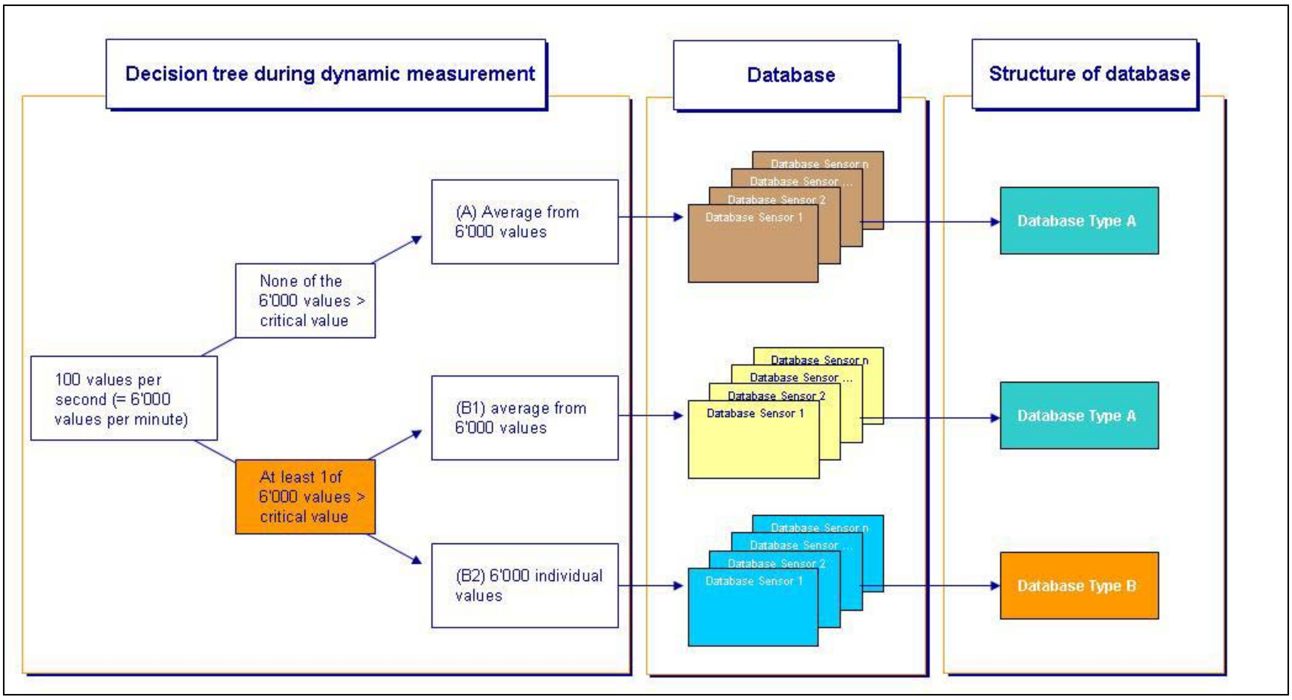

Fig. 5. Configuration and arrangement of the database enables a clear presentation of data

2.4 On site calibration

Truck crossings are categorised on the basis of two factors. For the weight of trucks the maximum strain achieved in μm/m in relation to the basic value of strain of the relevant sensor is considered decisive. The basic strain value is always recalculated as an average of all measuring values of a sensor over a minute duration.

For the speed of vehicles, the time span from the point in time is relevant at which the critical strain is achieved for the first time, up to the point in time at which the basic value is achieved again. Every component delivers typical values that have to be categorised. Therefore, the individual bridge components were divided into groups on the basis of their reaction to load. This was done, for instance, for symmetric bridge components such as horizontal beams and similar cross beams.

3. Analysis and evaluation of the data

On the basis of this classification, the sensors on the on the Steinbachtal Bridge can be divided into four different sensor categories. As only the northern part of the bridge was drivable at the time of installation, the calibration was only carried out for the northern part. During the load tests the sensors on the northern part reacted most to load while some crossings were hardly recorded by sensors on the southern part.

3.1 Automatic recognition and differentiating of dynamic events

As traffic can include vehicles with either 2, 4 or 5 axes, which are separately resolved at the sensitive component, i.e. the joint (in contrast to the main bridge structure), they have to be filtered and correctly recognised in order to enable another categorisation on the basis of speed.

This is done as follows:

- The minimum distance between two vehicles is always assumed to be 20m,
- In this case, the vehicles are not driving faster than 50 km/h,
- The minimum number of measuring points between events is therefore at least 144, which is equal to 1.44 seconds.
- The maximum distance between the axis of the individual lorries is 5m, at a slow speed (5km/h) this is equivalent to 362 measuring points and at a high speed (>60km/h) this is equivalent to less than 30 measuring points.
- The transmission is cancelled if 4 low points or 4 peaks are measured and if within double the distance that would normally be found between the 3rd and 4th axis, measured on the basis of the 4th axis, no 5th axis (= fifth low or peak point) is measured. This is presented graphically in Figure 8.
- Additionally, the recording of events is stopped when the number of peaks or low points equals 5. After counting 5 peak or low points, it is a 5-axis vehicle.
- If there are 4 peaks or low points, the load division from peak 1 to peak 2 or from peak 3 to peak 4 should be checked. If it is 40% (+/-5%) to 60% (this condition shall be fulfilled for all 2 vehicles at the same time), there are two 2-axis vehicles.
- If only 3 peaks or low points are measured within the monitored time period, the event should be handled as a 4-axis vehicle. It means that the load for the 1st to 3rd axes should be determined for categorisation. This may possibly happen when a truck axis is lifted and does not touch the ground.
- The axes are not categorised separately by the program.

The result for this classification and filtering is graphically summarised in Fig. 6.

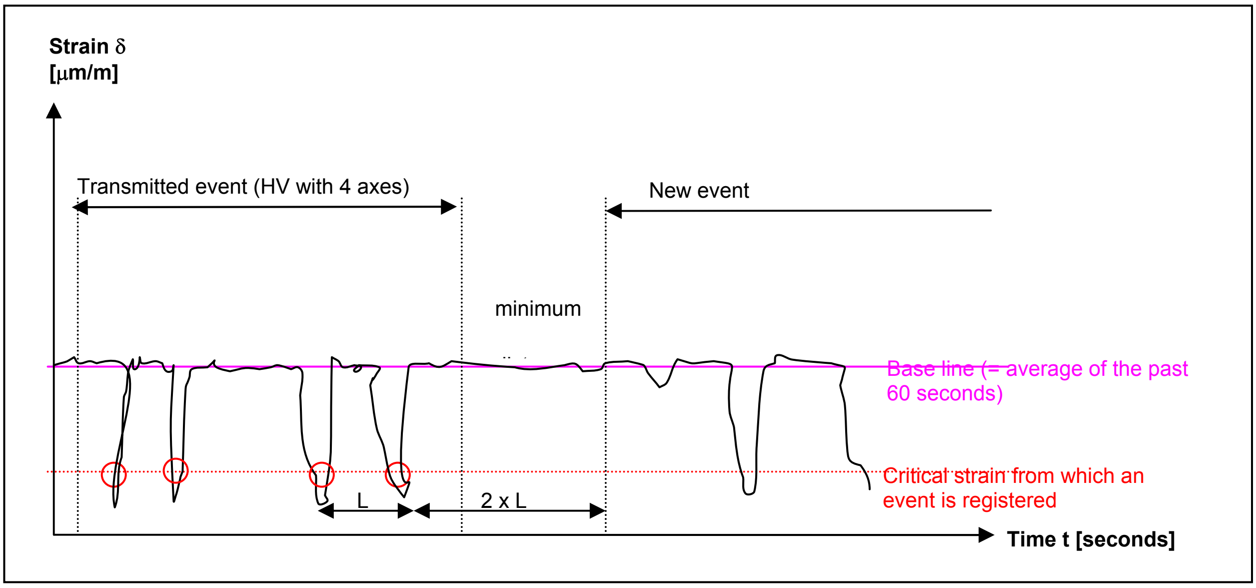

Fig. 6. Principle of dynamic recognition of a truck on the expansion joint (theoretical model).

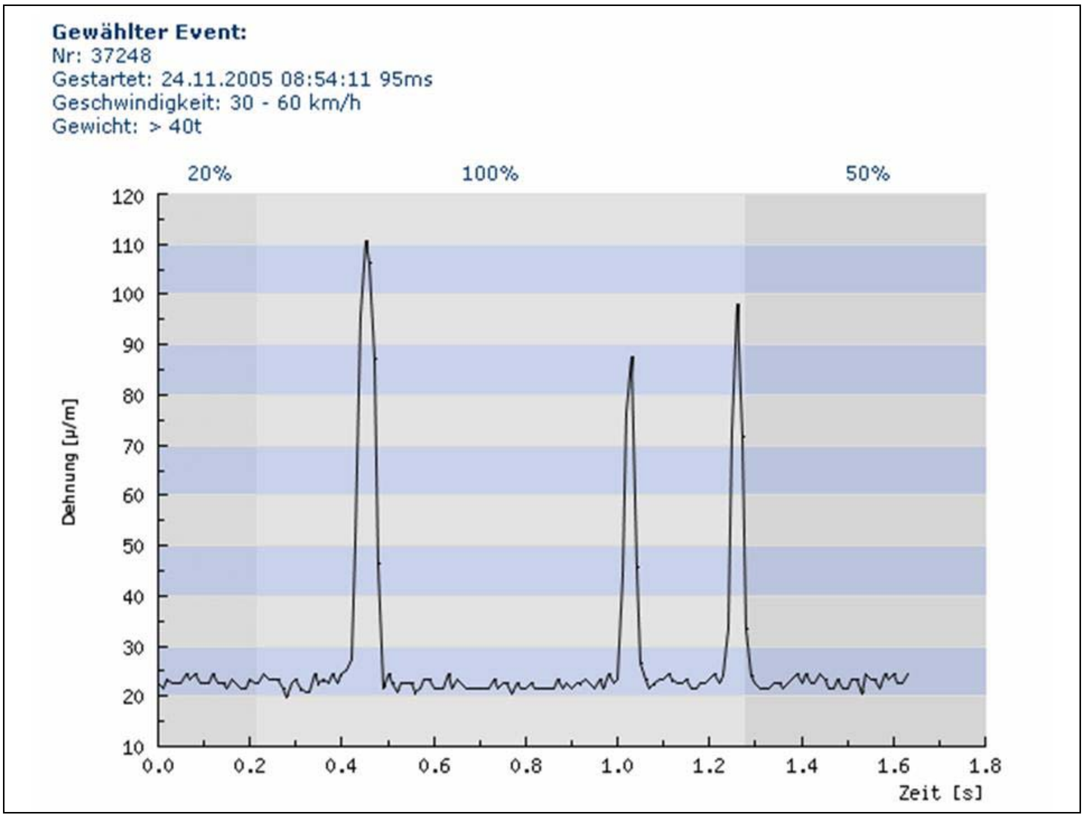

Fig. 7. Dynamic recognition of a truck on the expansion joint (actually recognised event – website display)

In Fig. 7 the results of strain measurements carried out on the expansion joint are shown. This, together with the related truck crossings, is presented in the secure Internet page. With Robo®Control the structural behaviour can be used for preserving evidence (photos, see also Fig. 3).

4. Conclusions

Over the past years a market has progressively developed for cost-effective remote supervision systems enabling to monitor the structural behaviour of smaller bridges as well as large objects. The system Robo®Control of Type I (RC I Box) developed by mageba meets this request. It is suitable for recording bearing forces, bridge movements as well as temperature, vibration and other parameters, and for transferring them to a central data server for post-processing.

This way, the engineer can comfortably and at any time and from any place have an overview of the behaviour of the structure and introduce further measures, if required. Additionally, for especially critical parameters alarm values can be set where the exceeding or falling below the limit values, the responsible persons are informed immediately. This ensures that structural safety is guaranteed at all times.

In addition to the classical structural parameters presented above, additional devices can be connected with the system Robo®Control of Type II (RC II Box) enabling one to record events that are not necessarily related to structural behaviour. This way a camera can be used for preserving evidence on a structure when certain trigger values such as expansion or vibration are exceeded.

mageba offers the possibility of cost-effective bridge monitoring with the RC Box Type I and additional high end structural monitoring with vibration analysis and preserving evidence through the system of Type II, and thereby information on the load-carrying structural behaviour, structural safety or other relevant parameters.

5. References

[1] Spuler T., "New EC-Quality Assurance Standards applied at bearings for the Great Belt Bridge", 3rd World Congress on Joints&Bearings, Toronto, 1991.

[2] Spuler T., Moor G., Siegwart M., "Affordable remote monitoring system for bridge structures", International Association for Bridge and Structural Engineering, IABSE, Copenhagen, 2006.