Monitoring the movement of the bearings at the Ponte 25 de Abril

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ABSTRACT: The bridge „Ponte 25 de Abril“ spans the Tejo River in Lisbon, Portugal, with a middle span of 1,013 m. After the final extension of the bridge in 1999 the movable parts of the bridge began to fail. The enormous accumulated movement on high speed caused by the train traffic could not be taken by them. In 2001 a consortium of Koch de Portugal and Maurer Söhne had exchanged the expansion joints by special swivel joist joints. The same team removed the old roller bearings and installed special sliding bearings. The movements of all 8 bearings are monitored and transmitted wireless. The processing units are prepared for additional measurement systems, which can be installed easily. In addition to full time control of the bridge bearings, an insight to the general health of the bridge is gained by the chance of monitoring significant changes of the bridge's main movements.

1 INTRODUCTION

When the bridge „Ponte 25 de Abril“ (fig. 1), spanning the Tejo River between Lisbon and Almada was opened on August, 6th 1966 it was already the 5th longest suspension bridges of the world. It bridges 2,280 m total length, with a middle span of 1,013 m. The enormous increase of traffic up to 140,000 vehicles per day in 1990 and the need of a train connection crossing the river forced the next engineering challenge on this bridge. In addition, time took its toll and a substantial renovation of the bridge became unavoidable. In 1995 a consortium headed by the companies Koch de Portugal and DSD, Germany, finished the renovation and the completion of the originally second phase of the bridge in 1999 [1]. Earlier, during the design of the bridge, this second phase had been planned as a railway deck underneath the road deck. Supplementary the road deck was widden by one lane in both directions. Together this makes a today's traffic of 160,000 vehicles and 140 trains per day possible. Although the geometry of the original bridge had already been built for this railway deck and the reinforcement of the bridge took modern trains with a total weight two and a half times higher than those envisaged in the sixties in consideration, the movable parts of the bridge began to fail. With each train crossing, the bridge moves a total of up to more than 200 mm at a speed of maximum 15 mm/s in longitudinal direction at both abutments (fig. 2). The design of the bearings and expansion joints of the bridge were not changed for the completion of the bridge. The enormous accumulated movement on high speed could not be taken by them. Only massive maintenance on these elements kept the bridge from major closings. In 2001, the expansion joints had been exchanged by special swivel joist joints built by Maurer Söhne and installed without interruption of the traffic by a consortium of Koch de Portugal and Maurer Söhne. In 2004 the same team removed the old roller bearings and installed all 8 special sliding bearings in time slots of maximum 5½ h. Both elements have to face a maximum movement of 1600 mm on extreme limit states resulting from earthquakes. But even more challenging was to find a solution for the accumulated sliding path and high movements speeds. A standard PTFE sliding bearing would have failed in less than 4 years because of the accumulated sliding path only. Taking the high movement speeds into consideration this would have happened at a fraction of that time. Therefore the inventive sliding material MSM® by Maurer Söhne was used which had been tested and designed for these special conditions. Nevertheless the movement and especially the accumulated sliding path of the bridge have to be controlled. Especially the total accumulated sliding path was of interest regarding the possible wear of the sliding bearings. This was archived by an advanced permanent monitoring system, measuring and recording the movements of the bridge bearings continuously. Since January 2005 the system has been completely installed and all measured data is accessible via internet.

Figure 1. The Ponte 25 de Abril, Portugal [1]

2 BEARING DESIGN AND EXCHANGE

The original bridge bearings were roller bearings made of regular constructional steel. Each bearing consisted of 3 rollers and one hinge above the upper bearing plate to accommodate rotations of the bridge. At the time of their exchange, damages of the guidance had to be fixed almost weekly and deformations of the rollers, unevenness of their contact plates and limited functioning of the hinge were detected. A further maintenance of the roller bearings was rejected.

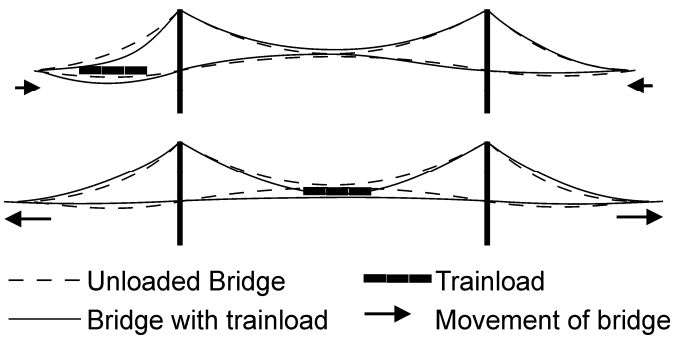

Figure 2. Movement caused by traintraffic

Starting from 2003 Maurer Söhne gained experiences with a new sliding material called MSM® [2]. MSM® can accommodate twice as much compression stress, can take at least a 5 fold accumulated sliding displacement, and a 7.5 times higher sliding velocity as regular PTFE used for present sliding bearings [3].

Several tests have been accomplished for MSM® according to EN 1337-2 [4] on conditions as they have to be faced for the bearings of the Ponte 25 de Abril and showed the applicability for these extreme requirements. For two reasons the exchange of the bearings was only possible during time slots form 3.30 to 5.50 h. Due to fast and significant movements of the bridge with each train crossing were all major works on the bearings during train traffic impossible, while any kind of interruption to the road or train traffic schedule was refused. In only two nights per bearing, the remaining parts of the original bearings were prepared for the exchange and the new sliding bearings were inserted. The unevenness was compensated by special fast hardening filler. Further the hinges were blocked by means of stabilizations fitted into the connection of the bridge and the upper bearing plate.

The installation procedure required the fit of the new bearings “into” the original ones, while some parts of them remained. This challenge was made even more complicated by the demand of not changing the rotation point and having a defined load centre to the superstructure. A sliding bearing with a lower sliding plate for the displacement and a second sliding level towards the superstructure for the rotating element solved this problem. A detailed adaptation to the site situation and precise planning of the installation made the project a success.

The bearings transmit vertical loads of 7,500 kN and 16,500 kN. Sliding displacements of up to ±140 mm on service conditions have to be accommodated on displacement velocities of a maximum of 15 mm/sec. In case of a severe earthquake total displacements of ±800 mm have to be permitted by the bearings.

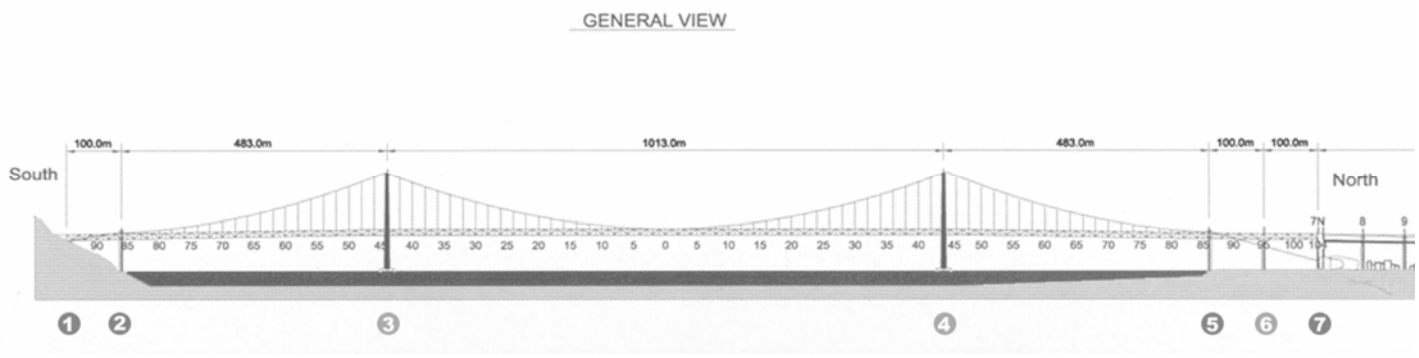

Figure 3. General view of the bridge, and location of piers, i.e. bridge bearings to be monitored [5]

3 MONITORING SYSTEM

The monitoring system is divided in 2 completely separated sets. The first set consists of 2 bearings at the southern abutment and 2 bearings at the pillar for the cable bend (location 1 and 2 in fig. 3). The second set is located at the northern abutment and pillar for the cable bend (location 5 and 7 in fig. 3) and includes as well 4 bearings.

Each set has its own communication system for transmission of all data and remote maintenance. These communication systems are connected to a server via General Packet Radio Service (GPRS) by means of a regular Global System for Mobile Communications (GSM) link. The communication systems allow the monitoring and general support without physical access to the loggers. To each bearing an individual logger is integrated for the intermediate processing and storage of the collected data (see fig. 4 and 5).

The loggers are stored in specially weather proofed housings, which consider the aggressive sea water climate of the bridge location. Particular care was taken to minimize the power consumption of the loggers. By reducing the power consumption to app. 30 to 50 mA the rejected heat could be lowered sufficiently to reach the intended service life time of all components of the loggers. Further the use of a solar panel for power supply is enabled by this limitation. Nevertheless a regular power supply was chosen due to easy access and existing power supply at all bearings. Still an accumulator battery is installed to bypass possible power fail by blackouts or damage of the power supply.

All loggers per set are connected by local area network (LAN) and can be accessed through each single logger on site. A connection to the loggers is eased by a universal serial bus (USB) port at each logger for a connection to a regular notebook or desktop computer. Still basic information can be read direct at a 2 x 16 alphanumeric character liquid crystal display (LCD) integrated in each logger.

All loggers are set up with a hardware based automatic operation system called “watch dog”. This operation system uses a control loop, which causes a shutdown of the logger if the loop does not finish in a certain time. Afterwards the system will restart itself. Even on a severe disturbance for example by a stroke of lightening close to a logger, the system will reactivate correctly.

For an unexpected interruption the monitoring system is equipped with an alarm operation. If no data is transmitted by a logger for a defined time the communication system will send a short message service (SMS) with an alarm and description of the defect to a defined mobile telephone number.

Once a day the internal clock of all loggers is adjusted by a precise time received by means of the communication system via internet.

The main task for the communication systems consists in data transmission to the server and allowing an online and real-time access to the monitoring data of the entire monitoring system.

For the intermediate storage of the data at the loggers a non-volatile Flash memory is used. This proofs as a robust and compact solution.

All displacement measurements are filtered from noise distortion like vibration of the connection of the displacement sensor to the bearing. Especially for the calculation of the accumulated sliding path of the bearings it is essential to exclude such influences from the registered data.

The entire system is to a large extend self-sufficient and self-recovering, which is especially of great interest for extreme events like a severe earthquake to assure the monitoring of such an event without lack of data.

The design of the monitoring system was developed in close collaboration with the owner of the bridge Rede Ferroviária Nacional REFER EP, Portugal, the supervision engineers from Parsons Corporation, New York and the main contractor Koch de Portugal. Subcontractor for the hardware details have been E. L. B. Elektronik, Germany. Econosite, Germany did the web design for the data access via internet.

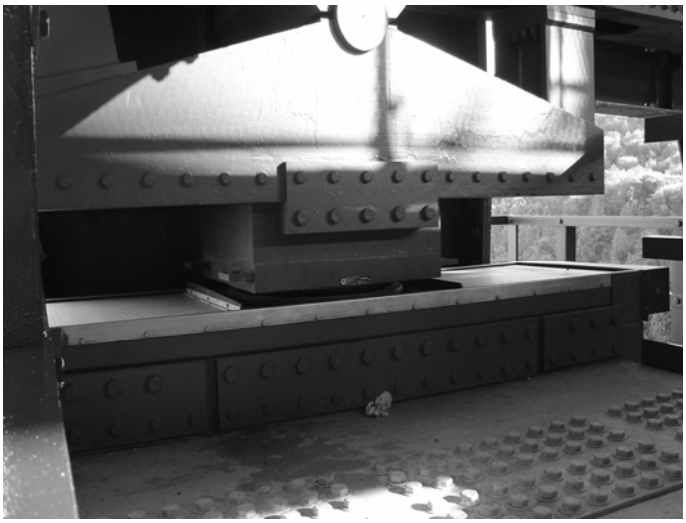

Figure 4. MSM® spherical sliding bearing at Pier 5 East

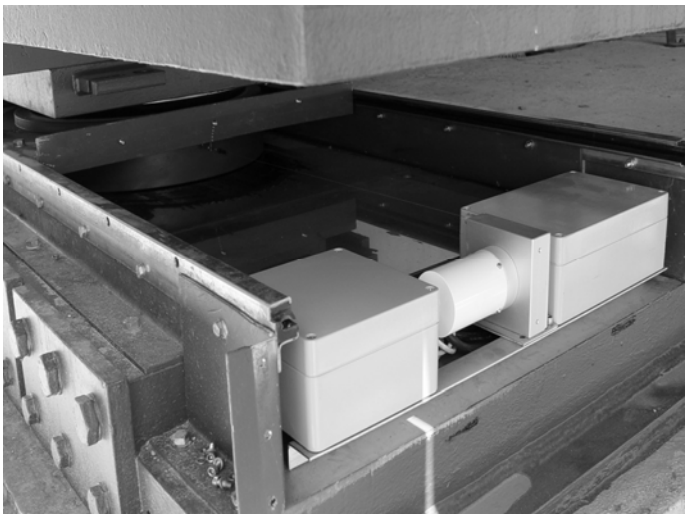

Figure 5. Monitoring System of the bearing at Pier 7 West

4 MEASURED AND PROVIDED DATA

Each bearing is equipped with a displacement sensor for the measuring of the bridge bearings movements along the longitudinal bridge axis and a temperature sensor for the evaluation of the environmental conditions. Additional sensors can be added easily to the modular design of the logger by remaining inputs of the existing system. Even all software is prepared for such an extension. Further system relevant data for the operation of the loggers are measured, such as current state of the charger of the accumulator battery, power consumption, power supply and the field strength of the GSM modem.

The monitoring system attaches most importance to the movements of all 8 bearings. Therefore it is monitored on a measurement frequency of 50 Hz and recorded as a backup completely for the last 96 h. The detailed recording of these 96 h will allow a focused examination of special events like earthquakes. In addition the accumulated sliding path is added up constantly and recorded every single minute at each logger. This allows storing the movement history of all 8 bearing on a one minute resolution for a total of ten years at their logger independent from the server. The maximum displacement at each bearing is logged and restored every day.

An abstract of the basic data of all bearings is given on the internet site for the status file as shown in the table of fig. 6. More abstracts from the internet site for the monitoring of the Ponte 25 de Abril can be taken from [5].

A refresh of the status file, by requesting a connection of the server to the communication system is available and the present status file can be downloaded. All status files, minimum one per day, are archived on the server. In addition to the data shown in fig. 6, the downloaded status file will include the related relevant data for the operation of the systems.

More detailed data of the movement is provided on an extra site location, where an explicit query of the data stored at the loggers can be configured. The bearings, a span of time by date and time and the resolution can be selected. An estimated file size will be given and an email address to send the file to can be entered.

A special event log can be requested with all alarms or failures in power supply, sensor connection or network, which are logged automatically in addition to the minimum once a day recorded accumulated sliding path and temperature. A selection similar to the one for the detailed data of the movement is provided for the request of the data file.

Detailed displacement data taken from the 96 h backup can be requested as well. A selection of the bearings and date and time of the first requested data set can be chosen. A file according to the selection with the maximum resolution of 3,000 data sets per minute will be send to the entered email address by the server.

All data is provided in a login and password protected Hypertext Markup Language (HTML) portal in the internet and can be accessed, whereever a connection to the internet is available. No special software or hardware lock will be required. Detailed data can be downloaded to all chosen email addresses. The provided data files are given as Comma Separated Values (CSV) file, which can be easily used with all kind of processing or database software. The single data is transmitted from each set of the monitoring system and will be combined to one file by the server. The time for this procedure for the transmission of the email depends on the requested data, but will take about 20 minutes for a normal request.

Pier	1		2		5		7	
	West	East	West	East	West	East	West	East
Bearing ID:	P1W	P1E	P2W	P2E	P5W	P5E	P7W	P7E
Service date:	18-Sep-2004	11-Sep-2004	23-Oct-2004	16-Oct-2004	20-Nov-2004	13-Nov-2004	04-Dec-2004	27-Nov-2004
Service time:	296 d	303 d	261 d	268 d	233 d	240 d	219 d	226 d
Movement total:	2567. m	2735. m	1791. m	2119. m	2438. m	2392. m	2518. m	2489. m
Duration of measurement:	172.6 d	172.6 d	172.7 d	172.7 d	173.4 d	173.5 d	173.4 d	173.6 d
Average movement/day:	14.87 m/d	15.84 m/d	10.37 m/d	12.27 m/d	14.06 m/d	13.78 m/d	14.51 m/d	14.33 m/d
Max. displacement:	226.7 mm	225.5 mm	221.8 mm	217.7 mm	258.2 mm	259.0 mm	271.6 mm	269.5 mm
Temperature:	22.5 °C	22.0 °C	22.5 °C	23.5 °C	23.0 °C	23.5 °C	22.5 °C	22.5 °C

Figure 6. Abstract of the status display

5 CONCLUSION AND PROSPECTS

Combining the latest technology of bridge accessory with monitoring systems an economical solution for the bearings as elements of major importance to safety, which are exposed to high strain was found. In addition to full time control of the bridge bearings, an insight to the general health of the bridge is gained by the chance of monitoring significant changes of the bridge main movements. Further general reactions of the bridge can be detected. As first results significant slower movement and less accumulated sliding path on the pier 2 were recorded (compare “Movement total” and “Average movement/day” fig. 6) and a remarkable influence of solar radiation was noticeable since the system was inaugurated in January 2005. The collection of data is designed for a long period and the analysis has just begun. Specific additional sensors might be installed as a result of this analysis. More insights are expected and will give a better chance to understand more about this best known land mark of Lisbon and its conservation for the future.

6 SUMMARY

The new sliding material MSM® with advanced properties of wear regarding pressure, movements speed and accumulated sliding path made an effective refurbishment of the bearings of the Ponte 25 de Abril in Lisbon possible. Its essential importance to the traffic in Lisbon made new concepts for the installation necessary. For the monitoring of the bearings and the bridge in general a sensor system was included in the bearings. For the intended measuring of the accumulated sliding path and assured collection of data during an extreme event like a severe earthquake a stable, redundant and most reliable monitoring system was developed and implemented. In addition a wireless data transmission and alarm procedure was integrated to allow all time direct data download and remote maintenance. For control of the bridge and analysis a comfortable access via internet was established. First results were gained and further analysis in progress.

7 REFERENCES

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