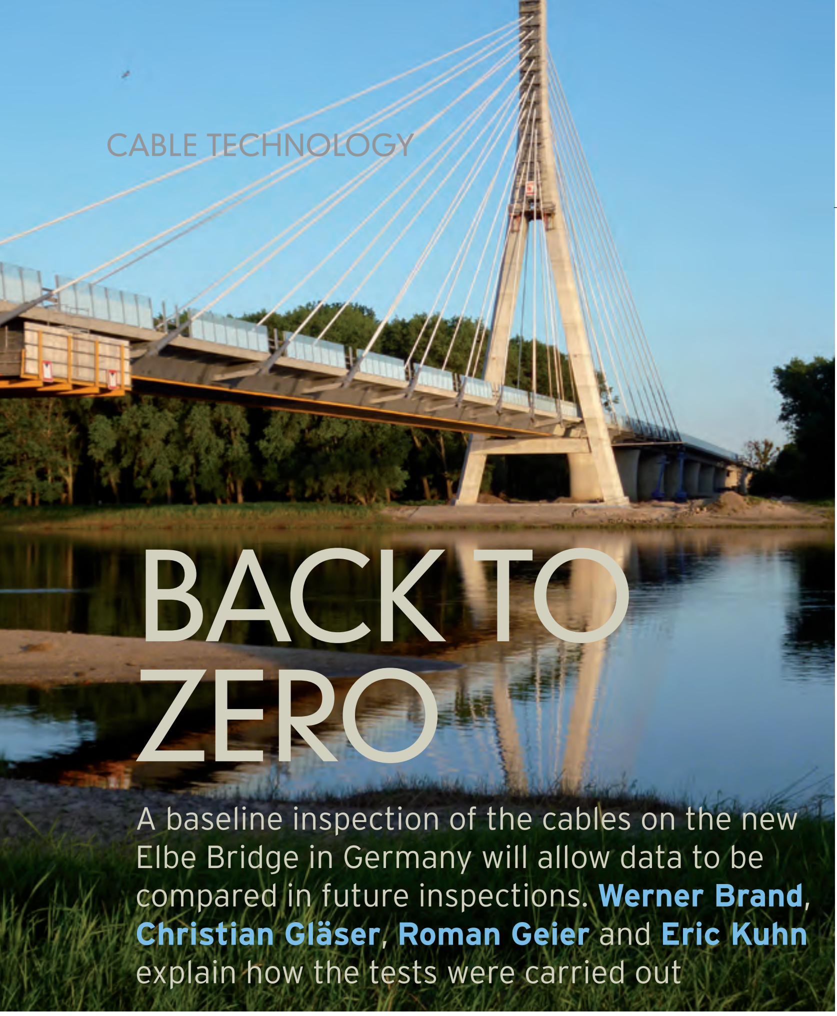


BACK TO ZERO

A baseline inspection of the cables on the new Elbe Bridge in Germany will allow data to be compared in future inspections. **Werner Brand**, **Christian Gläser**, **Roman Geier** and **Eric Kuhn** explain how the tests were carried out

Regular inspection and monitoring of structures enables owners to be confident in the condition of infrastructure; damage and potential defects can be promptly identified before they become dangerous. The basis for monitoring and inspection of existing bridges and civil engineering structures in Germany is the DIN 1076 which was first published in 1930. This standard demands that a main inspection is carried out on a six-year cycle with a simple inspection every three years.

Other than that, special inspections are only required in response to incidents, or the identification of damage to the structure. On a cable-stayed bridge, however, the cables are particularly exposed and as far as strand cables are concerned, there is no accepted standard for testing and inspection, something which technical working groups are currently working to resolve.

The existing DIN 1076 requirement for a hands-on examination, for example, might result in a simple assessment of the outer sheath, rather than an actual investigation into the condition of the tensile elements. Hence the German guideline *ZTV-ING, Part 4, Section 4*, states that a project-specific inspection and maintenance manual should be written, describing the inspection process for the stay cables and can also recommend alternative methods for cable testing.

On the Elbe Bridge Schönebeck, which crosses the Elbe River close to Magdeburg in Germany, a range of tests was carried out, some of which are detailed below. The bridge, which was completed within the last year, has 18 pairs of Dyna Grip stay cables supporting the deck from a single tower of 75m height.

The tender for the Elbe Bridge called for an acceptance test to determine the first two natural frequencies and the associated damping of stay cables as well as determination of the natural frequencies and the deflection of the bridge girder. The forces in all the stay cables were to be determined from the measurements. Three-dimensional acceleration sensors and a recently-developed camera system were used to take the measurements without compromising the finishing works.

The position of the accelerometers was chosen to be close to the anchors, about 1m from the end of the anti-vandalism piping so that the measurements could be taken without the need for expensive lifting devices.

Measurements were carried out under ambient excitation – wind and traffic – to capture the natural vibration behaviour of the stay cables, as well as with forced vibration by hand. From these measurements the natural frequencies, mode shapes, free vibration length of the stay cables, attenuation values and the tensile forces of all 36 stay cables could be determined.

Measurements on the main girder were taken using two high-resolution acceleration sensors for the detection of frequencies from 0Hz. The reference sensor was positioned at 40% of the length of the main span, to detect the first natural frequency. Simultaneously, the second acceleration sensor was positioned at several characteristic locations on the main girder and the back span.

For the deflection measurement, a recently-developed camera system was used. The high-resolution digital camera was positioned at the fixed point – the tower axis – on the edge beam. The target field for recording the horizontal and vertical movements was the midpoint of the main span. In this way the deflection of the main girder under loading from a truck with a weight of 16.5t was measured.

The basic principle for cable-force determination can be simplified to that of a classical stringed instrument. If the tension in a guitar string is changed, then the corresponding pitch or natural frequency changes. The same relationships are also used in the following context.

From the measurement data of the cables, the first ten to 15 natural frequencies of the stay cables were determined by use of a Fast Fourier Transform.

The traditional calculation of cable force is based on the linear relationship between fundamental and harmonic frequencies. This linear curve corresponds to the behaviour of a taut wire without sag due to its own weight and without bending stiffness. But this assumption is not valid for the stay cables on bridges, which are subject to the influences of self-weight, bending stiffness and boundary conditions.

As well as the frequency response, the free oscillation length also has a decisive influence on the specific cable force. By taking additional measurements with a reference sensor and a moving sensor, the free oscillation length of the stay cables was established based on determination of the mode shape. By incorporating these effects, the cable forces could be reliably established through vibration measurements.

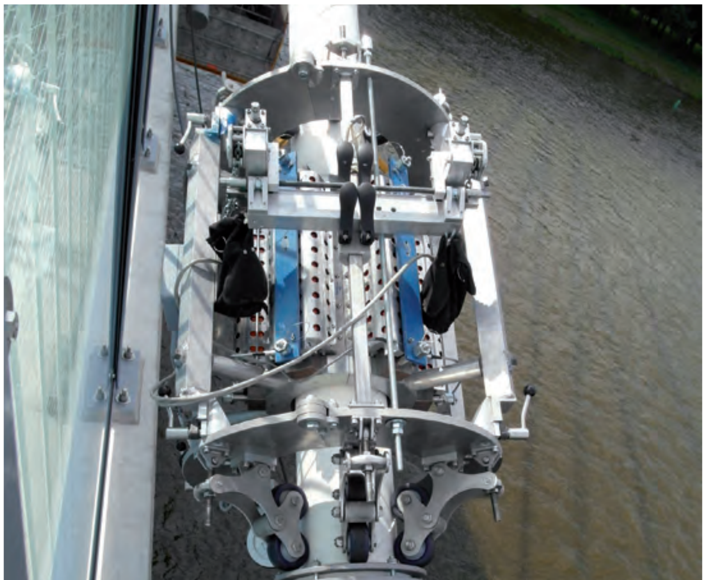
Another decisive parameter for stay cables is the damping value. The decay was established by using manual excitation for each of the selected natural frequencies and filtering the results with a band-pass filter to determine the corresponding value. This made it possible to determine the attenuation value of the first mode, as defined in the tender specification.

Measurements before and after the activation of the guide deviator were carried out at several stay cables in order to determine how they were functioning and their efficiency in terms of damping.

PE-coated strands and parallel wire systems pose particular difficulties in terms of magnetic inductive or electromagnetic inspection as far as non-destructive inspection of the complete metallic cross-section is concerned.

Both the size of the steel cable cross-sections and the relatively low filling factor – the ratio between the duct diameter and the cable cross-section – require the use of extremely strong magnetic fields. Such fields cannot be generated by permanent magnets, and high-performance magnetisation coils are used instead. What's more, applying these magnetic fields to the strand systems requires the use of large steel masses. Another challenge is that the large duct diameters of the strand cables need more sensors, and these have to be placed in a ring in the test heads.

DMT, EMPA and Alpin Technik & Ingenieurservice have developed a modular electromagnetic test unit for cable diameters up to 250mm. In the development phase, DSI provided a PE-coated strand bundle with artificially-produced wire breaks to provide realistic test conditions. This system was used on the Elbe Bridge to magnetise the 36 HDPE-coated cables to saturation and thus examine for possible damage such as wire breaks and significant weakening of the cross-section.


Device for magneto inductive cable testing

The test unit consists of six magnetisation coils that are placed around the cable to magnetise the cross-section via yokes. Sensors not only permit detection of damage but also its approximate location in the cross-section. The device is in three parts and weighs around 250kg; it is equipped with a dedicated lifting system that supports the assembly work. Data are stored right at the device, while the proper test process, including data storage in an external PC, can be monitored by radio.

A lightweight platform that can be quickly modified makes for quick installation and removal of the device. Ahead of the test, a calibration wire was fastened to each cable duct. With the distance from the calibration wire to the cable exit point being known, the signal caused by the calibration wire can be used to precisely determine the starting point of the respective measurement. At the same time, the signal can be used to check the proper function of the test device as well as the magnetisation.

To move the test device along the cable, a specially developed light-weight textile rope winch was used, which is able to pull heavy loads at high speeds. This type of towing device not only permits very fast set-up but also prevents damage. The average test output was five cables per day and the ultimate outcome was a test report issued according to DIN EN ISO 17025 by a qualified expert.

Structural health monitoring in civil construction is becoming increasingly important due to the need to minimise service and maintenance costs. The Dyna Force elasto-magnetic sensor system can measure the force applied to a single seven-wire prestressing steel strand of a multistrand anchorage without any contact. The system does not monitor only the force applied to the whole anchorage, as is the case with most load-cell applications. It is possible to detect the stress in single strands at the anchorage and therefore to provide a higher-resolution, more detailed result for service and maintenance.

Sensors were installed on the individual strands of six cables at the Elbe Bridge in order to measure the stay cable forces. For comparison, lift-off tests were carried out at the strands with sensors, and the sensor readings were subsequently collected. Deviations had a mean value of +0.5%. These sensors are a very efficient and simple way of monitoring and since they are installed on the cable stays, the access to individual strands that is necessary for subsequent lift-off tests can be avoided

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