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From the Nibelungs to the digital twin

The German Federal Institute for Materials Research and Testing (BAM), Berlin, is breaking new ground in future-oriented structural testing and monitoring of buildings. As part of the DFG priority program SPP 2388 "One hundred plus – Extending the service life of complex building structures through intelligent digitalization" (SPP 100+), which uses the historic Nibelungen Bridge in Worms as a demonstration and validation object, the BAM is carrying out a project to develop new, pioneering methods for digital structural monitoring and proactive maintenance management. On board: smart ASC sensor systems from the ASC AiSys® ECO series.



Safety and sustainability

"The DFG's priority program aims to investigate the fundamentals of innovative solutions for industry, authorities, road administration and society," explains Dr. Ralf Herrmann, scientist at department 7.2 "Civil Engineering" in the Structural Health Monitoring (SHM) division of the Federal Institute for Materials Research and Testing. He is actively involved in the BAM's priority topic "Transport Infrastructures".

The condition of a structure can be affected by evolving material fatigue as it ages due to stress. Although bridges and other critical infrastructure are generally designed for a long service life, wear and degradation can take effect after around 40 years. In order to ensure serviceability, stability and traffic safety, maintenance, renovation and reinforcement measures are all the more successful the earlier they can be planned and then carried out at the right time.

To extend the economic usability of complex structures while maintaining an adequate level of safety using data-based methods, significantly more measurements are required at a much earlier stage than is common today. "In our research project, we want to remedy this deficit and develop a predictive maintenance approach that can be quickly transferred to other comparable structures based on valid reference data," says Herrmann. But it is also about the sustainability of transport infrastructure. "We want to help keep structures in optimum condition with less effort so that they can be used for longer. This also applies to structures of historical and engineering significance, such as the Nibelungen Bridge in Worms, as well as bridges in the highway and railroad network.

Comprehensive basic data

Since May 2023, two complementary structural health monitoring systems have been in operation on the Nibelungen Bridge Worms as part of SPP 100+, which collect basic data on current stress conditions at relevant measuring points. This includes acceleration, strain, inclination and displacement measurements (for example at roadway crossings) as well as climatic conditions (temperature and humidity). In addition, available as-built documents are provided by the operator such as plans, recalculations and test reports; as well as additional non-destructive tests including concrete cover measurements, radar tests to verify the tendon position, concrete strength tests and evaluations of carbonation depth and chloride penetration depth are carried out by the SPP projects.

Herrmann: "These comprehensive basic data provide a realistic picture of the structural loads and environmental impacts, and are supplemented by the recording of additional load-related vibrations caused, for example, by a single heavy goods vehicle at night, a weekend storm or high traffic volume during peak times." Thanks to the regular input over the long-term, the BAM team learns to better understand and assess a wide variety of load scenarios and the forces acting on bridge components as a result.

Smart reference data for preventive monitoring

In the first SPP phase, each of the 20 projects can add further, individual sensor applications to the validation structure or carry out their own measurements. In July 2023, BAM used this opportunity to install smart ASC AiSys® ECO-3321-008-CAN accelerometers specially configured for the conditions of the test bridge. By expanding the overall system to include vibration monitoring, additional reference data for the predictive monitoring of the condition of this and similar bridges is now being recorded, digitally transmitted and evaluated.

The innovative MEMS-based acceleration sensor systems from ASC offer a good complement to traditional, reference-based monitoring methods. Their precise, dynamic real-time deviation measurement expands the range of applications. They are easily installed and, therefore, very flexibly applied – which offers valuable additional possibilities.

One advantage of smart sensor technology, according to Sebastian Degener, laboratory engineer in the SHM department of BAM's Faculty 7.2 "Civil Engineering", is its CAN bus capability. It allows for novel measurement concepts and makes it easier to implement high-performance sensor systems. Not only can sampling rates and measuring ranges be configured flexibly, but filter settings and frequency analyses are also integrated already. "This allows us to adjust the setup efficiently without having to go to the bridge every time and pull new cables to the data acquisition systems. We now do this in the office on the computer, which saves a lot of time."

Digital twin for safe bridge operation

"This enables us to provide well-founded answers to specific technical questions – including for other bridges that have been in service for a long time," explains Herrmann. Smart sensor systems on the structure can be used to record data and link it digitally to a data platform. There, they are integrated with structural information, basic historical knowledge and external factors. Mathematical algorithms use this complex mix of data to calculate models for estimating the condition of the bridge: its digital twin. Using this model and continuously adding further data and load profiles, future requirements, change processes in the structure and materials as well as maintenance and repair requirements can be estimated in good time.

"We expect our pilot project to provide us with insights on how AI methods can be used to define certain classifications that can be quickly transferred to other buildings of similar design, geometry, materials, load situations and age class," says the BAM expert. "So that we don't have to spend over a year again collecting and evaluating measurement data for each further, individual object."

Because installation and sensor calibration for reliable long-term results can take up a lot of time. This is also because the digital twin has to be "fed" with weather data across an entire year. "After that, however, it should be quicker for comparable structures," says Herrmann. "Using a few defined measuring points, the necessary additional data is obtained from the individual bridge, linked with the reference data and algorithmically extrapolated."

Flexible sensors to record building dynamics

Digital data transmission and evaluation in real time based on the ASC AiSys ECO provides a solid yet flexibly adaptable basis for such an enormous monitoring scope. "With these smart ASC sensors, we can record and efficiently analyze the complete dynamics of a structure. In addition, we obtain a lot of 'soft' information, partially used in research and partially stored for future purposes. The captured data is currently being analyzed in order to classify vehicle movements," reports Degener. This includes, for example, the number of vehicles passing the bridge every day; or peak acceleration values, which are recorded at 10-minute intervals and identified as either cars, trucks or heavy goods vehicles.

Degener is working on a standardized interface to ensure that all data imported into a repository is compatible with each other and that everyone involved in the digital twin project speaks the same language. "Without a clear description of the measured data, it can neither be used nor shared efficiently. The standardized provision and integration of data creates added value that could not be achieved through separate analyses."

Innovative partners for pioneering solutions

"We are familiar with many suppliers of sensor solutions and their products so that we always keep an impartial, independent overview of the technology," says Herrmann. "What we particularly like about the ASC team in the field of research is that we can discuss ideas

and requirements, clarify questions and solve problems in direct conversation. That's not a given in this market."

Digital sensors offer exciting new possibilities due to their special new features – such as high-frequency data sampling, advanced filtering and data reduction, double integration and drift correction, real-time adaptive DC offset compensation, phase correction and elimination of unwanted influences, as well as integrated data processing and output.

One challenge is to keep the measurements stable over the long term, despite a wide range of changing conditions. This requires reliable sensors of maximum precision and long-term stability. "The combination of high-quality capacitive sensors with robust housing technology is not easily found; certainly not at an acceptable cost," says Herrmann. "For the end customer as well as for us in research, a manufacturer's overall offering is important. In addition to product quality, flexibility and service, this also includes the quality of production, packaging, delivery times and much more."

"Our task at the Federal Institute as a departmental research institution is to unearth issues. We want to make things 'difficult' for ourselves and solve previously unsolved problems. The easy way in this project would have been to use standard analog sensors from conventional production. However, we wanted to break new ground and work with innovative manufacturers such as ASC Sensors – to identify pioneering solutions and make them marketable for future users."

The Nibelungen Bridge Worms

To test the practicability of scientific hypotheses and create a basis for broad application, the methods developed for model generation, digital integration and derivation of structural condition indicators were to be tested and validated on a demonstrator structure. The Nibelungen Bridge in Worms was selected as that validation structure for the SPP 100+.

The road bridge connects the Rhineland-Palatinate town of Worms across the river Rhine with the Hessian towns of Lampertheim and Bürstadt. With the Nibelungen Tower, it houses a Worms landmark, is a listed building and considered a pioneering achievement in German bridge construction. The previous structure, destroyed in the Second World War, was rebuilt 1951 to 1953 and named after the Nibelung saga. Due to increasing traffic volumes and the need for renovation, the "new" Nibelungen Bridge was opened in 2008 alongside the original one. Since its renovation, completed in 2013, the two lanes of the "old" bridge lead into the city and the two lanes of the "new" bridge lead out of it.

The river bridge has a total span of around 350 meters, which was divided into different measuring sections for the SPP. The project led by BAM uses a section of around 100 meters. The extensive monitoring activities, which began in summer 2023, are expected to be completed and evaluated by 2026.



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