Transcript: Structural Health Monitoring

Takeaways:

- Structural Health Monitoring (SHM) enables continuous monitoring of the condition of structures.
- Probabilistic approaches** are important to account for uncertainties in measurements and models.
- SHM can contribute to a more sustainable construction industry by enabling targeted maintenance measures and reducing waste. SHM allows for precise measurement of properties such as the modulus of elasticity to optimize the construction and reinforcement of structures.
- SHM can help detect problems in structures early and ensure safety.

Johannes (00:00.032):

Today we are talking about Structural Health Monitoring. We are speaking with Yves Roland. Yves is from Luxembourg. He completed a doctorate and a postdoc at EPFL on data-driven risk analysis of earthquake-damaged buildings. Afterward, he was a Senior Scientific Assistant at ETH Zurich with Professor Hatzi in the Department of Structural Mechanics and Monitoring. Today, he is the CTO and Co-Founder of the startup Irmus, which also offers Structural Health Monitoring for structures such as bridge buildings, infrastructure, and so on. Welcome, Yves!

Yves (00:50.458):

Thank you very much for the invitation. I look forward to discussing the potential and perspectives of SHM with you.

Johannes (01:00.525):

SHM stands for Structural Health Monitoring. There are generally many English terms involved, which we will try to translate into German. To connect this to the previous episodes, we talked in Concretely with a bridge inspector and with the Area Unit 6 in Switzerland, which is responsible for the operation and maintenance of national roads.

Yves (01:12.186):

As much as possible.

Johannes (01:30.796):

I would like to elaborate a bit. In the operation and maintenance of national roads, specifically road infrastructure, the Area Unit is responsible for operations such as winter services, cleaning, green maintenance, and technical services. This means they also inspect the structures to some extent, checking for issues like concrete spalling.

However, the larger inspections usually occur at regular intervals, typically every five years in Switzerland, conducted by engineers, the bridge inspectors, who are essentially engineering firms. They visually inspect the structures up close, which requires more effort. They also sometimes enter the structures. In previous episodes, we mentioned that there are some limitations to visual inspection, such as chloride-induced corrosion, which is not visible from the outside, meaning the steel can corrode internally without any visible signs on the concrete surface. There are also hard-to-reach areas, such as bridge piers, that are difficult to access with aerial work platforms, and moisture issues that are only apparent when it's raining or generally wet. We also discussed the safety of these inspections, which often occur under live traffic conditions. Today, we want to go into detail about what happens after these visual inspections when a bridge inspector requests lab tests for a more detailed examination. These tests often involve numerous sensors. Before diving deeper into SHM, could you give us an overview of these lab tests, especially those involving sensors?

Johannes (03:56.169):

These tests are divided into non-destructive testing (NDT) methods and destructive methods. Yves, could you give us a brief overview of these?

Yves (04:08.058):

Yes, gladly. Destructive testing involves methods like core drilling, where a part of the bridge or structure is removed and sent to a lab for detailed analysis, either chemically or using X-rays or other methods to get a real insight into the material. Non-destructive testing (NDT), on the other hand, aims to get a better understanding of the material's condition directly on the bridge. There are various technologies, such as ground-penetrating radar, potential field measurement, and ultrasound, to name a few. The goal is to understand whether processes are deteriorating the material. You mentioned corrosion as a typical example, where we can investigate whether there is water infiltration or other issues. NDT gives a precise snapshot at a specific point in time and location, either repeated across the whole bridge or periodically, to understand how conditions change over time.

To draw an analogy with human medicine, NDT is like an X-ray or MRI, providing a very detailed view at a specific point. It is very high-resolution and useful when you know exactly where to apply it. However, it doesn't provide an understanding of how material deterioration affects the global behavior of the structure. This is where SHM comes in, providing a broader view of the material's condition.

Johannes (06:41.909):

As I understand it, these tests are typically performed when it's already known which part of the structure needs maintenance, and the goal is to determine what exactly needs to be done. This decision is made jointly by the engineer and the testing lab, deciding which tests to conduct and where.

Yves (07:06.426):

Yes, there are various use cases. For example, if a bridge is known to need maintenance, ground-penetrating radar can be used to scan the entire road surface to identify where durability issues are present, optimizing the maintenance project. If it's a specific component or element of the bridge, the engineer may choose NDT methods when there are visible cracks, and it's unclear whether they are due to corrosion, alkali-aggregate reaction, or other issues. NDT provides additional insights into the material's condition.

One of the major challenges for civil engineers is that we can't see inside the bridge. NDT helps bridge this gap by providing a glimpse inside the structure.

Johannes (08:17.813):

Mhm.

Johannes (08:21.315):

And I think potential field measurement is also popular, as it gives insight into a larger area of the structure. However, deciding where to test and which method to use is not always easy, as you mentioned, and analyzing the results can be challenging due to the heterogeneous nature of concrete.

Yves (08:56.332):

Exactly. I could point to the NTEC project, which addresses this issue. The NTEC project, initiated by ASTRA, provides an overview of all currently available NDT methods and SHM technologies, helping to understand which technology is suitable for which hazard or question. Economic considerations involve power, the risk for the bridge, the size of the bridge, and the level of hazard.

Johannes (09:33.149)
Okay, this is going to be published now, right? I'll make sure to mention it in the podcast description or link it on my homepage.

Yves (09:38.49)
It should be published by the end of the month.

Johannes (09:42.433)
I'm really looking forward to it. Because generally, these technologies, including Structural Health Monitoring, have been around for quite a while. Most measurement methods are not new. What's a bit lacking now is the implementation of a set of pilot projects, but also how to scale it up. That's why I find such research projects, where various technologies are analyzed, very useful.

Can you already say what the general conclusion is? Or have you been able to create a list depending on the component and type of damage, indicating the best technology? Or what can we expect from the report?

Yves (10:24.282)
Exactly, that's it. For each type of component, for example, on a bridge, it could be the deck, perhaps the cables, or the bearing system. For each component and hazard, because there aren't always the same sensors that can cover all types of hazards, especially in...

non-destructive testing. So the question or hazard might be corrosion, cracking, material fatigue, and so on. Based on the hazard and the component, there's an estimate of the cost and benefit of each measurement technology. And it also considers how severe the consequences would be if a particular component collapses. The greater the consequences, the more likely one is to choose a more expensive method.

Johannes (11:31.327)
And the impact on traffic is also considered when something needs to be repaired?

Yves (11:39.642)
Yes, I believe in the exact evaluation of NTEC, no, but generally, the side costs of traffic closures, safety measures, and so on are indirectly included but not specifically quantified.

Johannes (11:59.39)
Okay, very interesting. Let's move on to SHM, Structural Health Monitoring. Can you explain what the threshold is for these methods and what exactly SHM is?

Yves (12:16.442)
Yes, SHM, I would translate it as a kind of continuous monitoring of the structural condition. It fundamentally differs in two points from non-destructive testing. First, the monitoring is permanent; it's not just once or periodically; the sensors are on the bridge at all times and continuously measure.

And it provides a more global assessment of the structural condition. Not locally, indicating corrosion at one point, but rather overall, how the structure behaves. Does it behave the same as it did three weeks ago, or is there a change that might indicate damage? The goal is to detect damage early to reduce the risk of collapse or other problems.

and thus optimize maintenance management.

Johannes (13:14.776)
So, there are many sensors that measure continuously, often embedded in concrete to measure properties like concrete or corrosion. But they are not officially considered SHM because they make very local recordings.

that need to be combined versus technologies that provide global assessments, as you mentioned. Can you give us an overview of the technologies used?

Yves (13:50.926)
With SHM, we generally choose sensors that reflect global behavior. For example, phase-optic sensors measure strains over longer distances, strain gauges measure more local strains, and accelerometers measure the vibrations of the bridge.

Johannes (13:52.603)
... in SHM.

Johannes (14:19.235)
Can they be categorized in terms of their use?

Yves (14:28.922)
Yes, it's generally not wrong to combine different technologies. For example, the vibrations we measure provide insight into dynamic behavior. So when traffic rolls over the bridge, we know exactly how much it vibrates and at what frequency, to understand the condition of the bridge.

Vibration is actually measured with accelerometers.

Yves (14:53.818)
Exactly, yes. Vibration is the translation of vibrations. So what we measure with these dynamic sensors. For other technologies like phase-optic sensors, it might also be useful to conduct a load test, placing a known load on the bridge and seeing how it behaves.

Johannes (14:57.562)
People.

Yves (15:24.09)
also to understand how accurate our computational models are. I have experience with many measurements on bridges, and our models are generally very conservative. If we have a load of X, the model's result tends to be too large in terms of displacements and forces in the bridge.

So, these technologies, especially the phase-optic and strain gauges, can also be used to understand how the bridge behaves compared to a computational model, for example, to back-calculate the bridge's maximum load or remaining fatigue life.

Johannes (16:10.327)
And the computational models are usually finite element models, right? You also need to know the exact dimensions of a component for that.

Yves (16:14.778)
Exactly.

Yves (16:21.338)
Exactly, the more information you have about a bridge, the more realistic the model becomes. This includes the use of a digital twin, so to speak, knowing the geometry, material, etc. of the bridge. Unfortunately, with existing structures, the information is often quite limited, which can affect the model's quality.

Yves (16:46.618)
If you don't invest much effort in getting to know the bridge precisely, modeling it, then the model's quality might be questionable. That's one point where classic SHM, where you install a sensor and try to understand how behavior changes over time, makes more sense because it

depends less on a model and more on how behavior changes over time.

Johannes (17:17.31)
We can move on to the approaches. One is using a computational model, calibrated with sensors. For that, you need to know the dimensions exactly, but you only measure it once to calibrate.

And then, moving a step further, you have classic Structural Health Monitoring, where you measure continuously. In that case, is a computational model useful or not always used?

Yves (17:56.09)
It's not always used, no. It's not necessarily required. If the goal is simply to monitor a bridge, where you have a good idea of its condition, and to see if it deteriorates over time, you don't necessarily need a model. However, if you want to extract additional information from the measurements,

Johannes (17:57.141)
Okay.

Yves (18:18.202)
then having a model is beneficial. For example, with SHM sensors on a bridge, you can monitor the structure's condition and understand the impact of traffic. Nowadays, WIM (Weigh-In-Motion) stations are widely used to understand traffic loads.

But there is also a trend to use BWIM (Bridge Weigh-In-Motion), where you determine traffic loads indirectly through deformations or accelerations, which can be very important in fatigue issues. In this case, a model is very useful.

Johannes (19:07.572)
Okay, so BWIM sensors measure the load of trucks, cars, freight transport, etc., crossing the bridge or component.

Yves (19:21.594)
Exactly, and they provide information per axle, indicating how the load of a truck is distributed across different axles.

Johannes (19:26.451)
Axle load. Just to return to the categorization of Structural Health Monitoring: it measures continuously over time and provides a global assessment. But strain gauges are also very local measurement methods. So, with phase-optic sensors, you can distribute an

optical fiber over the entire component and measure strains through optical signals. Accelerometers are distributed on the structure to gather information. But strain gauges are very small, local sensors applied, for example, to cracks.

How are they used to get global assessments? Is it similar to accelerometers?

Yves (20:24.506)
Yes, you wouldn't use just one strain gauge but a series of them. It's therefore more global because the strains result from the overall stiffness of the bridge. For example, whether the supports are fixed or not affects the strains at other points on the bridge. So, it provides global information about the bridge. As you correctly said, it's somewhat more local because it can

measure something very local that might not be desired. For example, if you apply strain gauges directly to the reinforcement, just exposing the reinforcement by scraping the concrete might cause it to behave differently locally than the rest of the bridge. So, strain gauges remain local sensors, and one must be careful in interpreting the data. The advantage with accelerometers is that the information they provide, such as natural frequencies and mode shapes, truly reflects the global condition of the bridge or structure.

Johannes (21:32.154)
Okay. Yes. And strain gauges measure the electrical charge of the metal plates or cables applied in a zigzag or raster form, very locally, right? And further, accelerometers measure the charge, for example, the

change in capacitance between two electrodes, right?

Yves (22:17.818)
Exactly, all these technologies are rather indirect. All your information is correct. Strain gauges measure electrical resistance that changes with strain. Accelerometers can have different types, but in MEMS sensors, it's about changing electrical capacitance. And with phase-optic sensors

, the way the light passes through an optical fiber changes with strain or temperature, so all

technologies measure indirectly. This makes the signal interpretation and data analysis more challenging, but it also enables us to gain a lot of insight into the structural behavior and changes.

Johannes (23:03.746)
The term MEMS sensor is already known, a micro-electro-mechanical system. Many accelerometers work with this principle, changing the capacitance.

Yves (23:17.466)
Yes, it's very typical. MEMS sensors are extremely small and can therefore be used in many different applications. It's very standard technology.

Johannes (23:27.987)
Okay. Just returning to the combination of technologies, are all SHM methods used in practice already, or is some in the testing phase, or is it known which methods are actually combined? Or are all combinations possible, depending on the project?

Yves (23:52.094)
Yes, all combinations are possible. The choice of method depends on the specific project and its requirements. In terms of practicality, some methods might be more advanced and proven than others.

Johannes (24:12.882)
I understand. Finally, can you give us an outlook on future developments in this field? What new technologies or approaches can we expect to see in the near future?

Yves (24:24.657)
In the near future, we can expect advancements in sensor technology, data analysis, and the integration of artificial intelligence in Structural Health Monitoring. The use of drones and robotics for inspection and

monitoring is also increasing. Additionally, there will be more emphasis on creating digital twins of structures to simulate and predict their behavior more accurately.

Johannes (24:47.774)
That sounds exciting. Thank you, Yves, for your insights and for taking the time to discuss this with us. I look forward to reading the final report on NTEC.

Yves (24:56.012)
Thank you, Johannes. It was a pleasure to be here.

Johannes (24:59.109)
Thank you.