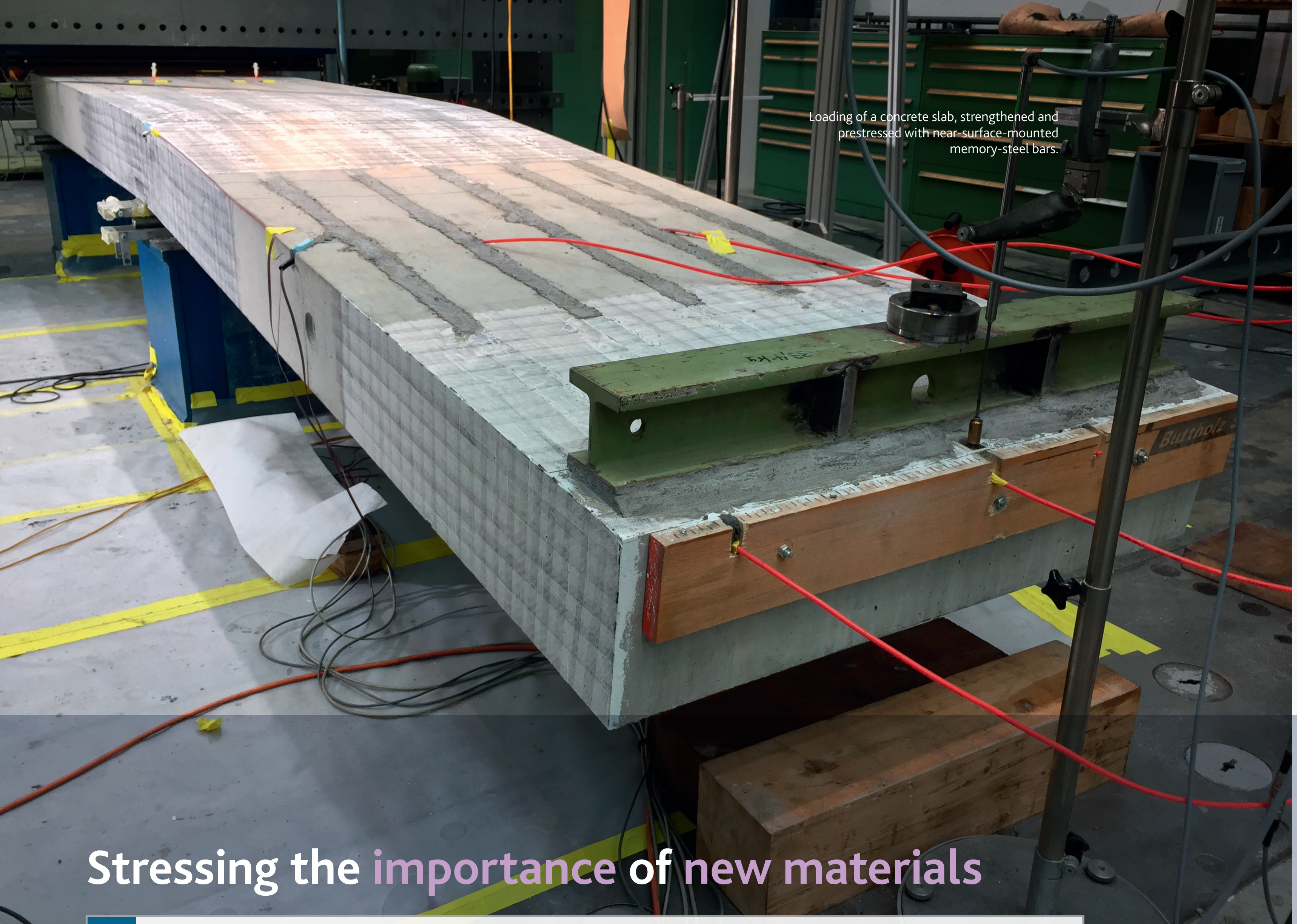


Loading of a concrete slab, strengthened and prestressed with near-surface-mounted memory-steel bars.

Stressing the importance of new materials

Shape memory alloys can regain their original shape after they have been deformed. They are applied in several different areas of industry, including in construction and civil engineering projects. We spoke to Dr. Christoph Czaderski about his and Prof. Dr. Moslem Shahverdi's groups' work at Empa in developing these materials, optimising their properties, and exploring their applications.

A Shape Memory Alloy (SMA) regains its original shape after it has been deformed, which is an important attribute in civil engineering. However, these materials are today rarely applied in buildings, bridges, and other structures across the world. One of the most commonly used SMAs today is nickel-titanium (NiTi). Yet, researchers are also exploring the potential of other alloys, a topic at the heart of Dr. Christoph Czaderski's and Dr. Moslem Shahverdi's research at the Empa Institute in Switzerland. "NiTi is an excellent alloy, but it's also very expensive, and so it's not really feasible to use it widely in construction. Thus, a new iron-based shape memory alloy has been developed," outlines Dr. Czaderski. This material has its roots in research at Empa dating back around 20 years. Now scientists are looking to fashion effective, reliable and high-performing new products out of it for use in engineering projects, including strips, ribbed bars, and wires. "The alloy has been developed and improved over time, and there is a lot of interest in using it in different products," says Dr. Czaderski.

As a Senior Researcher at Empa, Dr. Czaderski's primary interest is in investigating emerging topics around materials science and technology, yet this work also holds commercial interest to the construction sector. Together with his colleagues, Dr. Czaderski is working to develop and enhance new materials, and also to explore their possible commercial applications. "Many engineering and construction companies are interested in the development of innovative, new products which give them a wider range of business opportunities," he says. The specific iron-based (Fe) SMA that was developed at Empa has already been applied in a number of projects, for example in strengthening some buildings and bridges, yet research also continues into how it can be combined more effectively with concrete in construction applications. "An iron-based SMA has slightly different properties to other alloys; compared to NiTi, the shape recovery is not perfect," says Dr. Czaderski. "However, we are using recovery stress – a type of mechanical stress – which is a novel approach. When we heat this material, we pre-stress it."

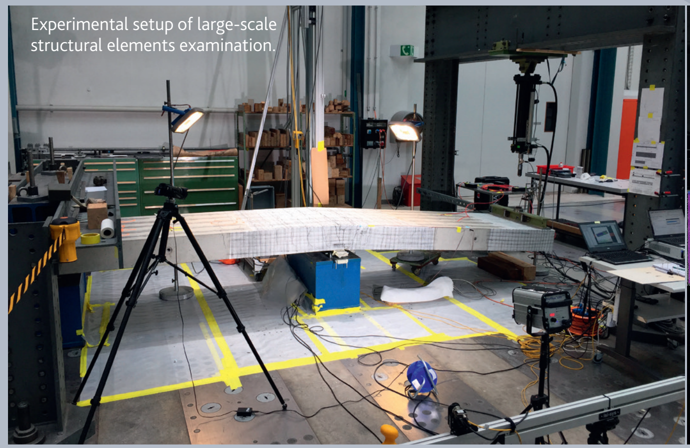
Recovery stress

The concept of recovery stress relates to the recovery of a material following heat treatment. When the SMA is heated with electricity, it develops a pre-stress capacity, which researchers are now looking to explore and harness. "We are using this approach to pre-stress structures," explains Dr. Czaderski. This represents a significant departure from the conventional approach to pre-stressing structures. "Across the world, bridges and other big structures are often pre-stressed internally, with conventional tendons. These tendons are typically in a duct inside the bridge, so that they can be effectively pulled. For example, if you pull a rope on both ends, then the whole rope is pre-stressed. Also, with pre-stressed steel, you need an anchorage on both sides," says Dr. Czaderski. "We are following a different approach as the shape memory effect relates to a change of the crystal structure, which is recoverable. We deform the material at room temperature – the crystal structure is then heated so that it reverts back to the original crystal structure, which has the advantage that anchorages and ducts are not necessary anymore!"

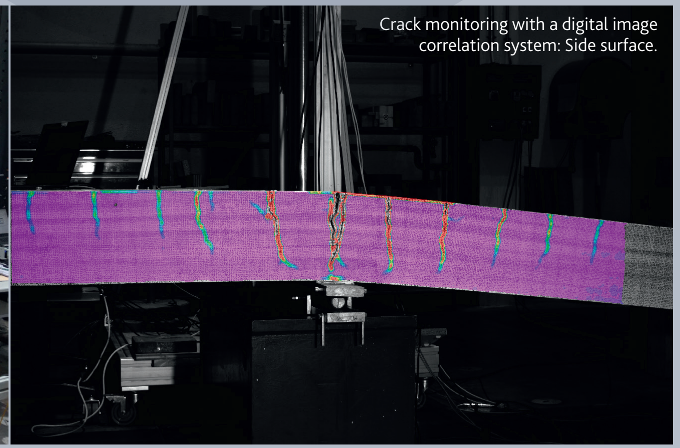
The material is now the subject of a deep and rigorous investigation within a framework of a PhD project by Dr. Czaderski's and Prof. Shahverdi's student Bernhard Schranz, with a specific focus on how such material works together with concrete. In this specific case, the iron-based SMA (Fe-SMA) itself is formed into highly novel ribbed memory-steel reinforcement bars. The researchers are looking to assess the effectiveness of Fe-SMA reinforcements in terms of strengthening concrete structures. "We cut some grooves in the surface, then we put the bars inside and fill this groove with cement-based mortar," explains Dr. Czaderski. The main focus of the research was then the nature of the bond between these ribbed bars and the concrete, with Schranz studying several different aspects. "How is the bond between these ribbed bars and the concrete? How does it transform under pre-stressing? What are its characteristics?" continues Dr. Czaderski. "We measured the characteristic of the bond behaviour, and presented respective analytical models. This research is a combination of experiments and models, and then we can draw comparisons between the models and the experiments and at the end present design proposals for practical engineers."

The evidence gathered so far suggests that this iron-based SMA can act as an effective pre-stressing material for strengthening purposes, while it also has some significant advantages over other materials. Beside the advantages explained before, there are also no frictional losses. "If you wrap a material around a column, which is the conventional approach, then you can imagine that there is a lot of friction. But with this new material we don't have any friction, because there is no movement," explains Dr. Czaderski.

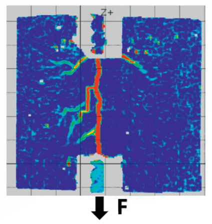
> How is the **bond between Fe-SMA ribbed bars and the concrete?** How does it **transform under pre-stressing?** What are its **characteristics?**

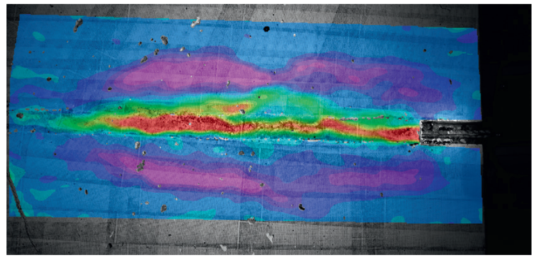


Experimental setup of large-scale structural elements examination.

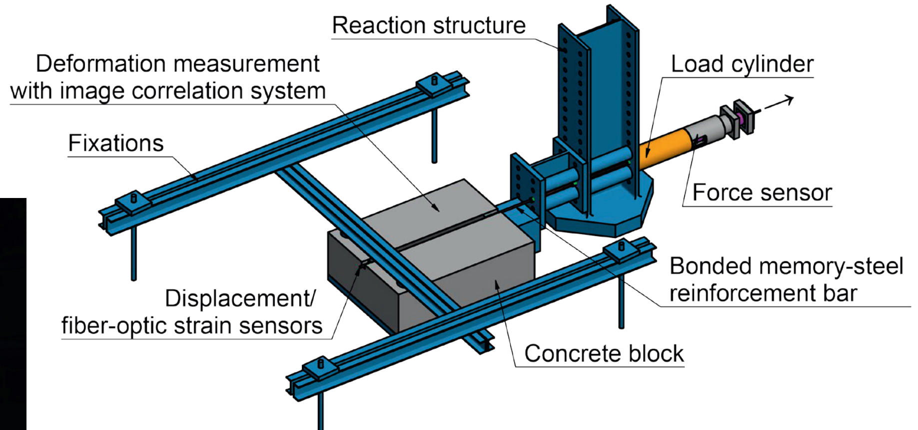


Crack monitoring with a digital image correlation system: Side surface.





Crack monitoring with a digital image correlation system: two different pull-out experiments to study the bond behavior of memory-steel.



Experimental setup of pull-out experiments.

MODELING OF RC MEMBERS

Modeling of RC members strengthened and prestressed by a novel iron-based shape memory alloy reinforcement

Project Objectives

A new material was developed for construction and civil engineering projects at Empa in Switzerland. The new material is a new iron-based shape memory alloy, which is produces in the shape of strips, ribbed bars and wires. Dr. Christoph Czaderski and Prof. Dr. Moslem Shahverdi's groups work at Empa are developing these materials, optimising their properties, and their applications.

Project Funding

The project is funded by the Swiss National Science Foundation, SNF grant 200021_175998: Modeling of RC members strengthened and prestressed by a novel iron-based shape memory alloy reinforcement.

Project Partners

• Company re-fer, Switzerland (www.re-fer.eu)

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Christoph Czaderski (left)
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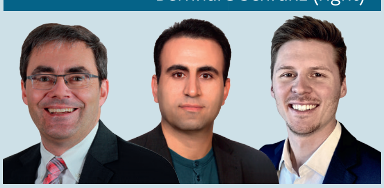
Bernhard Schranz (right)



Dr. Christoph Czaderski, leader of the "Strengthening Concrete Structures" research topic at Empa, senior researcher and developer for the civil industry.

Prof. Dr. Moslem Shahverdi, leader of the "Advanced Structural Material" group at Empa, researches on Shape Memory Alloys, RC Structures, and Digital Fabrications.

Bernhard Schranz, PhD candidate at Empa and ETH Zürich, investigates novel strengthening methods for concrete structures using memory-steel bars.

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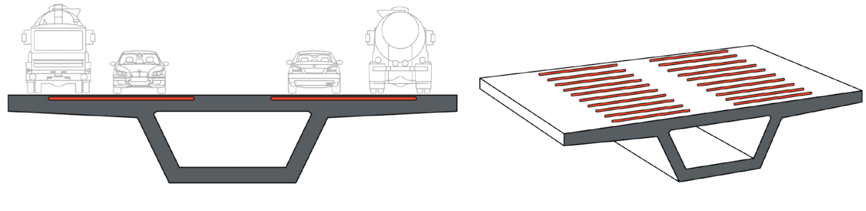


Hollow box girder bridge strengthened with memory-steel.

Commercial interest

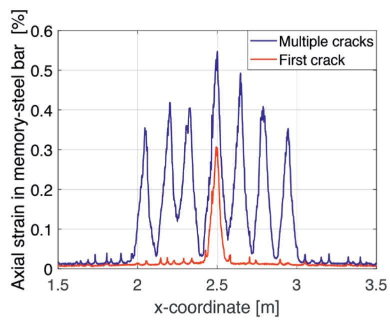
This work holds wider interest to commercial construction companies, who may be interested in using this material in strengthening a bridge for example, or in other types of civil engineering projects. A spin-off company called re-fer was established in 2012 to build on the research advances that have been achieved at Empa; it has since grown to become a prominent supplier of Fe-SMAs, and Dr. Czaderski says there are still strong links between Empa and the company, from which both parties benefit. "As academics we are interested in conducting research, but we also benefit from collaborating with commercial companies involved in selling materials. The company is still involved in a number of ongoing research projects," he outlines. The main focus in terms of Schranz's research is in using this material in buildings and bridges, but Dr. Czaderski believes it could also be applied in other areas. "We see potential uses for this material in many more applications - one could be in 3D printing for example," he says. Investigations and feasibility studies on the application of Fe-SMA reinforcement for 3D printed concrete structural elements are a core topic in Prof. Shahverdi's group.

A number of other projects are ongoing within Empa's Structural Engineering Laboratory to explore these wider possibilities. "We have several different strands of research and are investigating topics in several different fields," outlines Dr. Czaderski.

Prof. Shaverdi's group continues to optimize the alloy through the use of certain types of material technology, which could open up further possibilities in terms of applications. Furthermore, he studies the application of Fe-SMA reinforcements for self-centering concrete bridge columns if an earthquake is ongoing. "Another colleague in our group at Empa is a specialist in the strengthening of steel bridges, and he is conducting research on how to strengthen steel bridges with this material," says Dr. Czaderski.

The material could also be applied to help make structures more resistant to the effects of earthquakes through an approach called damping, which is used to reduce vibrations. Further treatment and research will be required before this iron-based SMA can be used in this way, one of the different areas that Dr. Czaderski and his colleagues plan to investigate further in the future.

"Many buildings have been strengthened using this material, while it has also been applied on bridges in Switzerland, and we hope it will be used more widely in the future," he says.



Measured strain in memory-steel.

Onsite application of memory-steel in a building.

Onsite application of memory-steel in a tunnel.