# Titanium Finds a Home in Civil Engineering

## Unique properties create cost, safety, and durability advantages for rehabilitation projects

*by Jill Adkins and Warren George*

Most people associate titanium with aerospace technology, or perhaps with medical implants, but research that began at Oregon State University's (OSU) structural engineering lab is proving titanium's usefulness in ground-based civil engineering applications. This has led the Oregon Department of Transportation (ODOT) to complete the world's first titanium-based bridge restoration project in Mosier, OR, pioneering the way for many new applications that take advantage of titanium's properties and cost advantages.

### Aging Concrete Bridges

Many cast-in-place concrete bridges built in the construction boom of the 1950s and 1960s had inadequate reinforcement detailing. To ensure public safety, those bridges are now facing potential replacement, imposition of restrictive load limits, or rehabilitation. The challenges are compounded by today's higher legal truck weights and comprehensive understanding of rating requirements.

### Consideration of Titanium

The titanium rehabilitation solution proposed by Christopher Higgins, OSU Professor of Structural Engineering, was a titanium near-surface-mounted (NSM) "staple." In NSM strengthening applications, grooves are cut in the outer concrete surface at a shallow enough depth to avoid cutting into the original steel reinforcing bars. While Higgins was experimenting with NSM strengthening using fiber-reinforced polymer (FRP) bars, he saw an opportunity to improve the technique by using a ductile material not subject to brittle fracture and that could be field bent at the ends to form 90-degree anchorage hooks. Titanium's near-ideal elasto-plastic properties (Fig. 1), combined with the necessary corrosion resistance to survive with little or no concrete cover, made it an obvious candidate for NSM testing.

### Research and testing

In cooperation with titanium bar producer Perryman Company of Houston, PA, a round titanium bar with a unique surface pattern was specially developed for testing at OSU. The selected bar material is the same quality titanium used in aircraft applications, and the surface pattern was chosen for its bond performance with epoxy adhesive. Tests at OSU, in cooperation with ODOT, began in 2012. Testing was first performed on lab-scale beams, and then moved quickly to full-size concrete beams. Full-size beams with titanium NSM

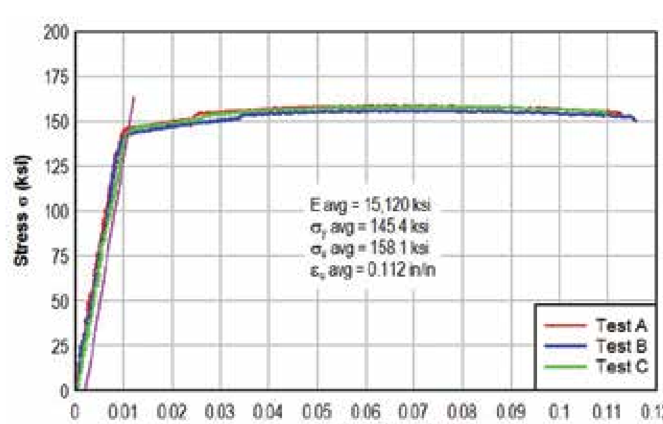


**Fig. 1: Titanium alloy has a high yield strength and exhibits elasto-plastic behavior (Note: 1 ksi = 6.9 MPa; 1 in. = 25 mm)** *(graph courtesy of Christopher Higgins, OSU)*

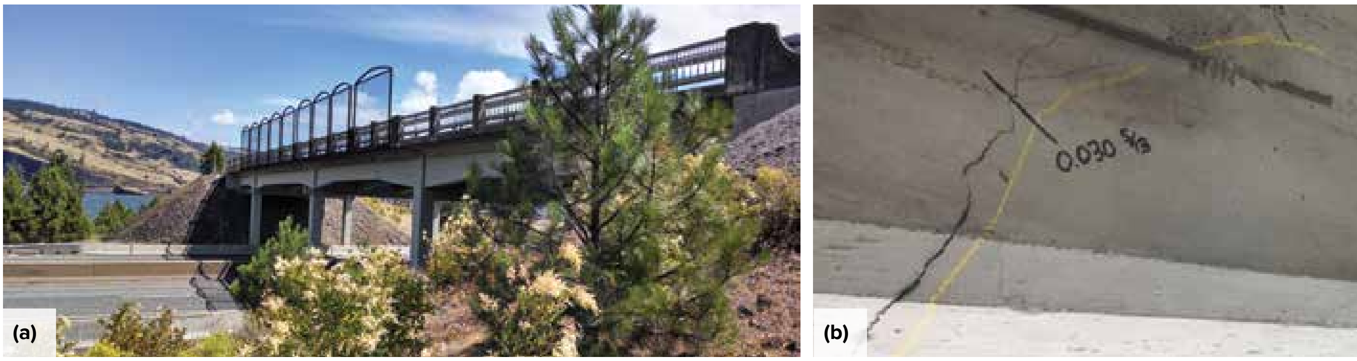

Fig. 2: The Mosier bridge is an overpass for a secondary road crossing I-84 in Oregon: (a) overall view of structure; and (b) cracks were observed near cutoff points for flexural reinforcement *(photos courtesy of ODOT)*

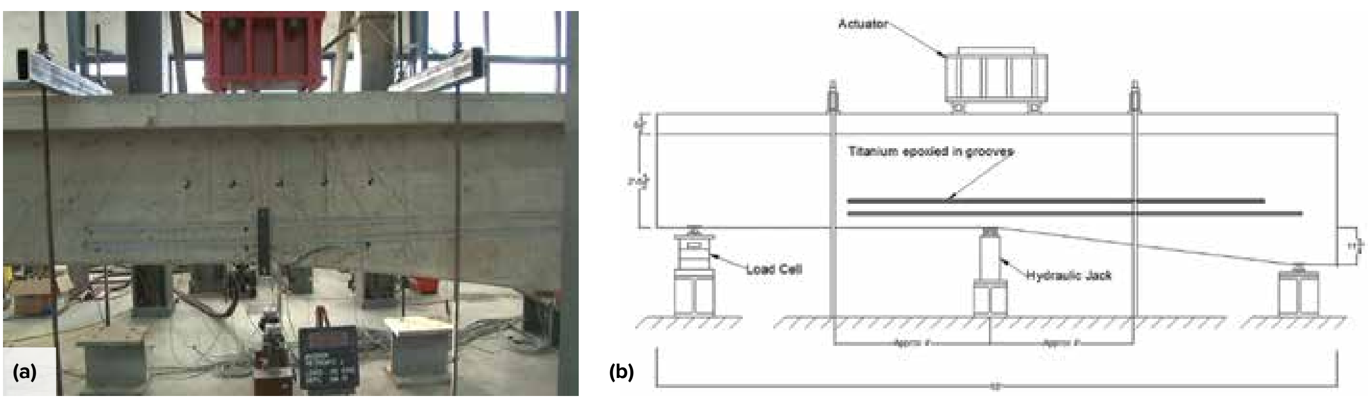


Fig. 3: Full-scale beam testing was used to verify the adequacy of the proposed repairs for the Mosier bridge: (a) photo of a strengthened beam prior to testing; and (b) schematic of test apparatus (Note: 1 ft = 0.30 m; 1 in. = 25 mm) *(photo and schematic courtesy of Christopher Higgins, OSU)*

flexural strengthening were tested for both positive- and negative-moment regions. The titanium-reinforced beams exhibited a significant improvement in load capacity as compared to the nonreinforced beams. The beams were also subjected to 50 years of environmental and cyclic loading in a lab setting. The fatigue tests of the bars in combination with the epoxy showed no degradation.

The initial studies also included beams strengthened with stainless steel bars. To match the strength of beams retrofitted with titanium bars, twice as many stainless steel bars were required. Because the highest costs of NSM strengthening are labor and epoxy and not the bars themselves, OSU and ODOT saw that titanium could provide a significant cost advantage over stainless steel.

## Titanium provides the answer

The research conducted at OSU showed that titanium provides other advantages over other corrosion-resistant materials—benefits that go well beyond project cost savings. In addition to high tensile strength, ductility, and environmental durability, titanium offers high shear strength and resistance to mechanical damage, high maximum service temperature, and thermal expansion compatibility with concrete. Coupled with these features, titanium also provides contractors the ability to custom bend mechanical anchorages at the ends of NSM bars. Mechanical anchorage provides an extra strengthening reserve that can't be achieved with a material that depends solely on bond strength.

## Case Study – Mosier Bridge

As the tests at OSU were still in progress in mid-2013, an opportunity accelerated the urgency of the research. An overpass on Oregon's main East-West Route I-84 was deemed critically deficient when inspectors found significant cracks—some with vertical displacement—that originated at the cutoff points for flexural reinforcing steel in the bridge girders (Fig. 2). ODOT officials detoured traffic 15 miles (24 km) to the next overpass as their crews moved in quickly to place steel shoring to keep the span from collapsing onto the freeway.

After estimating that replacing the structure would cost about $4.6 million USD and would take over a year to restore regular traffic, ODOT engineers looked to the titanium NSM techniques being proven at OSU. At ODOT's direction, OSU quickly constructed and tested a series of full-size replicas of the as-built girders on the Mosier overpass (Fig. 3). The tests verified that just four No. 5 (about 16 mm diameter) hooked titanium bars embedded in the outer inch (25 mm) of the girders could double the flexural strength. Tests also showed that girders repaired using titanium bars anchored only with embedded hook extensions had 50% more strength than the girders were originally designed and built to carry. This test verified that the beams would be safe even if there was an adhesive failure.

## Installation of the titanium NSM bars

With the test results in hand, ODOT awarded a contract to rehabilitate and strengthen the girders on three of the four bridge spans using a total of 70 titanium NSM bars (Fig. 4). The installation did not require specialized equipment or a specialized workforce. The first steps involved cutting shallow grooves into the concrete and drilling holes at the ends of the grooves for the bar hook extensions. After thorough cleaning, epoxy was added to the grooves and the titanium "staples" were inserted into the holes and grooves. The last step was the application of a second layer of epoxy flush with the concrete so the bars were no longer visible. The work was completed in just a matter of weeks—on time and within budget—and the bridge was reopened to full service.

## Total cost advantage

ODOT calculated that the overall cost for the titanium strengthening for the Mosier bridge was less than 3% of the estimated cost for bridge replacement and 30% lower than rehabilitation completed using alternative materials. Contrary to the widespread belief that titanium is too expensive to be used in structural applications, the research


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at OSU and the Mosier bridge repair proved that titanium is a viable alternative for rehabilitation projects. Titanium's high strength allows NSM repairs to be completed with fewer bars than alternative materials, minimizing labor and epoxy adhesive costs as well as traffic disruption.

## Future Applications for Titanium

Due to the success of the Mosier bridge project, NSM titanium bars are now being used in another project—the comprehensive restoration of the iconic Rogue River Bridge in Grants Pass, OR. Other bridges in Oregon are also scheduled to be retrofitted with NSM titanium bars.

While titanium has now gained a foothold in bridge restoration applications, there is growing interest in using titanium in other civil infrastructure and building retrofit applications, including confinement reinforcement for seismic strengthening of bridge piers and tendons for external unbonded post-tensioning systems. With increased awareness of its properties and project cost savings, there is a strong potential for increased use of titanium in civil engineering applications.

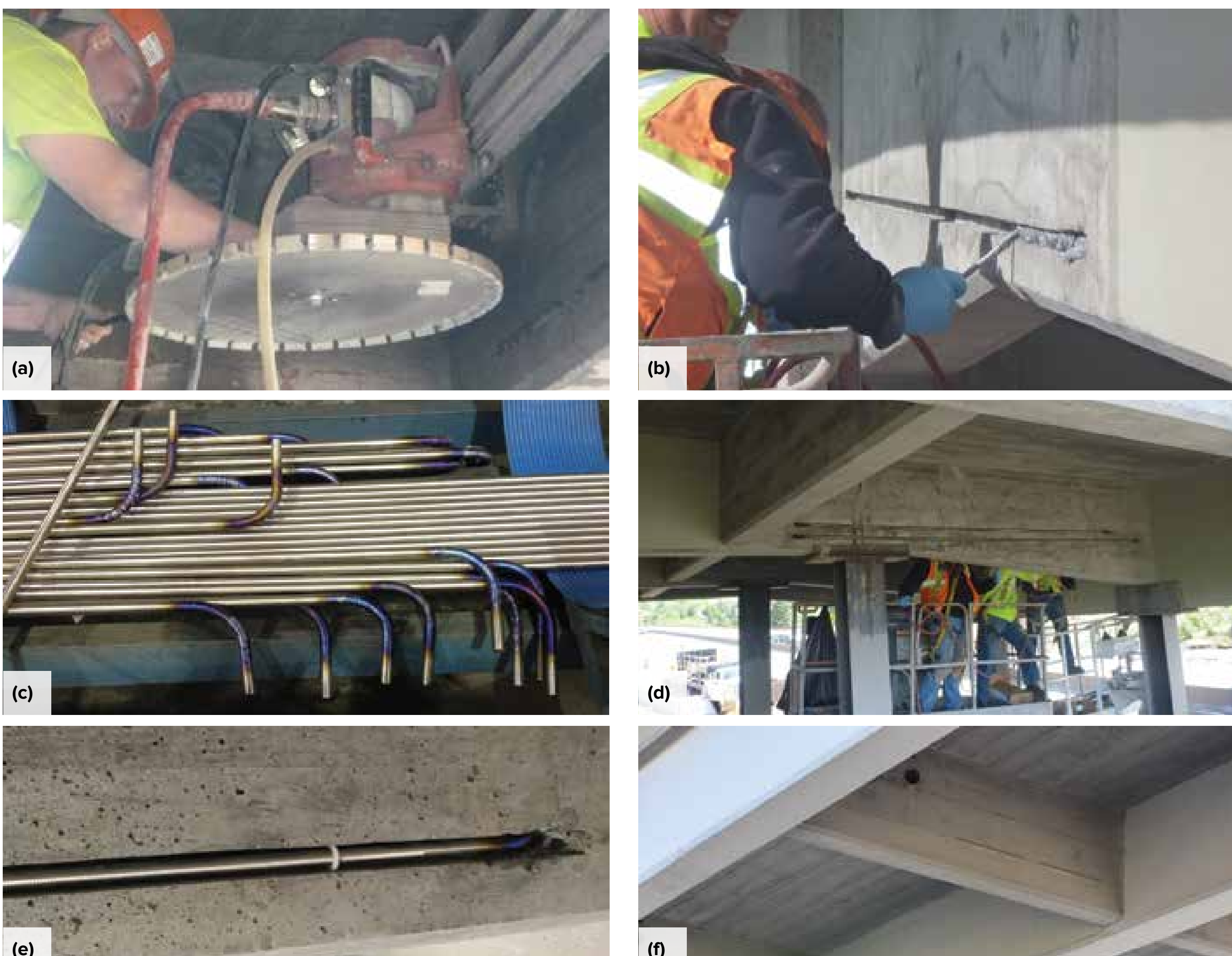


**Fig. 4: Installation of titanium bars on the Mosier bridge: (a) grooves were cut using a diamond blade; (b) after holes were drilled and cut surfaces cleaned, epoxy was placed in the groove; (c) titanium "staples" were produced by bending hooks, shown here with a characteristic blue color where they had been heated for bending; (d) staples were inserted in the prepared grooves and holes; (e) close-up of the installation; and (f) after another layer of epoxy was applied to cover the staples, the girders were painted to complete the installation** *(photos courtesy of ODOT and Perryman Company)*

## Acknowledgments

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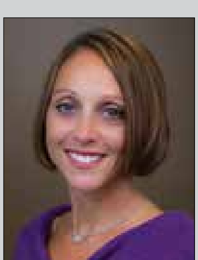

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