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A LIGHT TOUCH

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A second-generation robotic inspection unit that only weighs 83kg (opposite) was successfully deployed on the Akashi-Kaikyo Bridge last summer *(Shutterstock)*

RISE OF THE ROBOTS

Engineers carrying out close-up inspection of the world's longest suspension bridge in Japan have trialled a new robotic inspection unit which is considerably smaller and lighter than the prototype. Helena Russell reports

Autonomous and remotely controlled maintenance equipment may be the latest trend in the wider bridge engineering world, but Japanese bridge owners put their first robotic inspection unit to the test in the mid-90s. Now they have developed a second-generation inspection unit that makes operation and handling much more practicable and makes it possible to view critical structures at close quarters safely and reliably.

The Honshu-Shikoku Bridge Expressway Company is responsible for maintenance of the 17 long-span bridges on the three fixed links connecting the islands of Honshu and Shikoku over the Seto Inland Sea, so improving the way the company inspects and maintains its bridges is an ongoing challenge. This challenge was preempted, and the need to carry out regular inspections of these massive structures was considered before the bridges were built, prompting development of the first robotic inspection prototype.

The three fixed links include the Akashi-Kaikyo suspension bridge, which opened to traffic in 1998, has a main span of 1,991m and still holds the world record for suspension bridges; the Kurushima-Kaikyo crossing, which has three suspension bridges back-to-back, with main spans of up to 1,030m; and the Tatara Bridge, a cable-stayed bridge with a total length of 1,480m and a main span of 890m – the world-record holder when it opened in 1999.

The Akashi-Kaikyo Bridge's main towers, which are constructed of steel and rise to a height of 300m, were the main motivating factor behind the development of the initial prototype inspection unit. This work started in 1989, when the bridge was under construction. The structural steel in the tower is protected by specialist coatings, but to manage deterioration of the coatings over time, inspection and local repair work must be carried out in the intervals between the main recoating work.

The traditional method for carrying out this work on a suspension bridge tower would be to use a gondola or other specialist access equipment capable of getting personnel and equipment up close to the surface of the tower, from top to bottom. But this type of access equipment is not only susceptible to weather conditions – wind in particular – which makes it unreliable, its use also requires extensive safety precautions and specialist equipment and training for staff.

The limitations of traditional equipment and the need to put a reliable and safe maintenance regime into place led the engineering team to start investigating other options that would enable them to carry out remote inspection of the bridge surface. The initial prototype, which was developed in 1996, was capable of close inspection of the structure by camera, as well as basic surface preparation and touch-up of coatings. It carries a camera for close inspection work, a steel brush for surface treatment and painting tools for surface repair.

The robot has magnetic wheels, which allow it to stick to the vertical surface of main tower, and it is capable of traversing the bolted splice plates which occur at 10m intervals, where the main tower elements are connected. It has a scraping tool attached to a multi-joint manipulator with five degrees of freedom and coating equipment that is operated from the ground. Safer and easier inspection work are possible, as well as local repairs even up to 300m above the ground.

Although it was able to carry out these simple tasks, the prototype was large and heavy – weighing 200kg and measuring more than 1.3m long. Its maximum speed while in operation was around 5m/minute. Additionally, it was a single unit that could not be divided into smaller pieces for installation or transport, meaning it needed special lifting equipment to put it into use, and its handling ability was limited.

Plans to develop the inspection unit further were recently revived as a result of changes to the law on inspection of highway bridges in Japan. The 2014 revision of the ministerial order mandating that all road bridges must be inspected at close quarters made it necessary to have a robot capable of easily inspecting the tower's surface.

HSBEC started to develop a second generation of the inspection robot, looking to create one which was still able to carry out close inspection by use of a camera but was smaller and lighter to improve handling. The main challenges were how to reduce its size and weight while still enabling it to negotiate the joints on the outer surface of the steel towers, where the structural elements were connected by high-strength bolts. The maximum size of the obstruction is 43mm: 22mm thickness of

splice plate thickness plus 21mm of the bolt head.

The new inspection unit, which was developed by the organisation and its subsidiary Bridge Engineering Company, was first trialled on one of the towers of the Akashi-Kaikyo Bridge last summer. It is just 862mm long and the whole unit weighs 83kg, but it can be dismantled into six pieces, the largest of which weighs 32kg, meaning it can be handled manually without the need for a heavy machine or specialist installation equipment. The travelling speed of the new unit is 10m/minute, twice that of the original prototype.

The main change that allowed the robot to be made smaller and lighter was to eliminate the repair function and focus entirely on the inspection work. The design of the body and the magnetic wheels was optimised, which also reduced its size. Although the travelling speed of the robot is about the same as that of the gondola, its ability to move independently means that it can complete inspections more quickly.

During trials, the new robot successfully carried out manual hauling and was able to travel on vertical, horizontal and diagonal alignments. It is capable of negotiating sloping surfaces, although its ability to travel underneath the deck has not yet been tested. Clear images were received from the robot's cameras, enabling close inspection of the superstructure. Engineers believe that they may need to make further improvements to make handling better for the operator.

Operation is simple, and is carried out by a single person using just one joystick – the operator uses the image from the camera to guide them in directing the unit from the base of the tower. Compared with the traditional inspection procedure for this type of structure – a gondola, aerial work platform, or telephoto camera with high resolution – the robotic unit is easier, safer and more efficient to use, although no detailed calculations of time or cost savings have been made. The aim of the research work is to develop an alternative to the traditional inspection methods, particularly for areas that are difficult to access, and any savings in cost or time are considered an extra benefit.

Video clips are captured at a distance of a metre from the tower's surface using a visible light camera and an infrared camera. These images are used to inspect the tower surface, looking for anomalies in the coatings, such as bulges or cracks, which are indications of a problem with the structure or a need to repair the coating.

The new unit could potentially be used on any of the other 17 long-span bridges HSBEC maintains, all of which have steel towers; by developing it for use on the Akashi-Kaikyo Bridge, which has the highest towers and the biggest joint size, they have theoretically addressed the most severe conditions it will have to negotiate. However, the team acknowledges that further improvement will be needed if it is to be used on structures that are taller than 300m, have a larger joint, or are non-magnetic.

Two other types of robotic equipment have been developed by the HSBEC maintenance team – one of them for carrying out recoating work, and the other for cleaning substructure caisson walls.

Attempts to mechanise recoating works on steel bridges were considered a key aim because of the difficulty and cost of doing such work at height, and in severe conditions, using traditional methods. A number of technical issues had to be resolved to allow recoating work to be mechanised, including how to get the robot to the location where the work was to be carried out and developing a suitable coating application method.

Initially, HSBEC focussed on creating a robot to work on box girders, which mostly have flat surfaces and are suitable for mechanised recoating works. They developed a flexible coating roller which was able to deal with uneven painting surfaces; a rolling brush for cleaning, made of flexible nylon coated with abrasive particles; an arm with a joint giving five degrees of freedom, which supports the roller and brush; and a system for controlling its movement. After testing in the laboratory, a trial robot was manufactured to perform an empirical proof test on the Ohshima Bridge – a single-span suspension bridge with a main span of 560m and a steel box girder deck.

The robot incorporates the jointed arm, a compressor, dust chamber, paint pump and control system. The rolling brush for surface preparation is equipped with a cover and the dust chamber in order to prevent paint shavings from dispersing into the environment. A pair of flexible painting rollers at the front rotate in the opposite direction to a pair at the back to even out the paint thickness. The test covered an area of 3,000m^2 and enabled the engineers to make a series of observations. The rolling brush was able to follow the uneven surface well, and the results of surface preparation by this method were considered more uniform than with manual work.

Similarly the coating rollers were found to be capable of following the uneven surfaces closely; paint application using this method was considered to be just as uniform as when manual procedures are used. A coating rate of 150m^2/day was achieved, and it was believed that this would increase as workers became more proficient at operating the robot.

A second robotic unit was developed to carry out cleaning of the steel caisson walls, which must be done prior to installation of electrodeposition systems for steel protection, and was traditionally carried out by divers. However, using divers is not only inefficient, it can be difficult at depths of up to 40m below sea level. To address this, HSBEC developed a caisson wall surface cleaning device that is controlled remotely from above the caisson, and cleans the caisson wall using a high-pressure water jet.

As the device has magnetic wheels for travelling on the caisson wall, it remains stable even in tides with speeds of approximately 1m/s. Its use improved efficiency, safety and quality and reduced the cost of underwater cleaning work

The Sydney Harbour Bridge is a vital part of the city's infrastructure, carrying over 160,000 cars per day *(Shutterstock)*

A LIGHT TOUCH

Researchers in Australia have just begun a project to develop and test a new method for removing corrosion in confined spaces on the Sydney Harbour Bridge. Helena Russell finds out more

It is only in recent decades that facilities for access and maintenance have been given proper consideration in the design and construction of bridges. Hence many owners and operators of older bridges face serious challenges to maintain their assets safely and keep iconic structures open for public use. None more so than the world-famous Sydney Harbour Bridge in Australia – an international icon which opened to traffic in 1932 and has been in use ever since.

It carries more than 200 trains, 160,000 cars and about 2,000 bicycles a day, and as such it is not just a cultural icon, it is also a vital part of the city's transport infrastructure. The New South Wales Roads & Maritime Services is responsible for looking after the bridge, and a large proportion of the work involves cleaning the steel structure and the stone abutments, repainting where necessary.

The steel structure was originally coated with lead-based paint, which is now deteriorating and being replaced with modern, longer-lasting and more environmentally friendly paint. Removal of paint and corrosion is traditionally carried out using power tools and sandblasting, but these are physically demanding and put staff at risk of injury. Furthermore, some parts of the bridge are not accessible with such equipment – in fact many are barely accessible even by operatives. Now, however, a three-year project funded by the Australian Research Council is bringing together engineers at Roads & Maritime Services with researchers at the Australian National University to develop a special attachment that can be used for carrying out laser cleaning inside the structure. The team is going to start by testing the latest laser cleaning technology to find out whether it is suitable for use on a historic steel structure.

Paint stripping with continuous and nanosecond pulsed lasers has been around for many years, and industrial-scale systems are commercially available from a number of suppliers. But, nanosecond-pulsed lasers deposit a great deal of heat into the surfaces being cleaned and can raise the temperature so high that it can melt the surface of steel. Hence there are concerns that nanosecond laser pulses may cause fatigue cracks to propagate in ageing steel such as that on the Sydney Harbour Bridge. Additionally, workers are put at risk of burns from the high temperatures, and adjacent material can also be damaged. This latest project aims to exploit recent research at the Australian National University by professors Andrei Rode and Stephen Madden in which they developed a new process to take advantage of recently available powerful ultra-short pulse lasers. The team will investigate the use of cold lasers in the femtosecond range – a million times shorter than nanosecond pulses.

This process is capable of rapidly removing thick paint layers on an industrial scale with minimal damage to metal and stone surfaces. "Cold lasers in the femtosecond pulse range do not melt the surface and are like a woodpecker chipping away the paint without causing cracking," says RMS strategic infrastructure manager for Sydney, Peter Mann. "This is a promising attribute, along with the more textured finish that allows paint to bond with it."Mann continues, "Steel bridges work hard and suffer from corrosion and fatigue loading. Extra care needs to be taken so that the service life of bridges is not compromised by the lasering process. Our research project is about identifying the most cost-effective laser type currently available and to verify that it won't damage the steel."

The hollow structural steel elements forming the arches incorporate an estimated 7.2km of confined space where sand-blasting is impossible. These elements vary in grade and height from about 40º at the base of the lower arch; there are access holes every 6m but they are just 300mm wide and most workers cannot fit through them. The restricted operating space, changes in orientation, visibility, and removal of the debris and blasting grit are all serious challenges. Consequently, the arch interior has not been repainted since the bridge was built, and laser cleaning is seen as a possible solution.

The second challenge for the team will be to develop a way of carrying out the cleaning process in these steel members. While they plan to adapt a robot that has already been proven in terms of navigating the confined spaces (*see box*), they will still have to make the laser cleaning equipment small enough for the robot to carry.

But, as Mann explains, lasers have not yet become mainstream in infrastructure maintenance and some barriers still have to be overcome. "Enabling the lasers to become field deployable, which is especially difficult on bridges, is where the current logistical challenge is. Given that our bridge is so large and inaccessible, the lasers (and robots) need to be as small as possible to carry around the structure. Most off-the-shelf lasers of sufficient power use large support equipment that power the laser head, such as the laser scanner, chiller and vacuum," he says.

Separate dust extractors will filter the air, although the laser head has a small vacuum that will clean the air locally where the laser strikes the steel. The robot will vacuum larger particles that fall to the floor and will blow down the steel surfaces prior to painting.

The first task for the team at ANU is to develop the ultrafast laser cleaning process with optimal laser irradiation conditions and highest possible efficiency in terms of cleaning speed in m^2 per hour and m^2 per hour per watt of laser power, all with minimal residual stress and damage to the metal structure. The residual stress and fatigue strength properties will be tested by the Australian Nuclear Science & Technology Organisation and the University of Sydney, while Roads & Maritime Services will provide conditions for the fatigue testing, prepare samples of actual bridge steel and paint, and organise trials on the bridge. University of Canberra experts will assess the laser cleaning for use on the granite facing of the main bridge towers.

Once the laser cleaning process has been developed and tested, the next stage will be to develop a special attachment that can be mounted onto Waumbot, the bridge maintenance robot that RMS and the University of Technology, Sydney developed over the last decade, and which is already in use on the bridge. This will enable the laser cleaning process to be applied to the internal walls of the steel members. The same technology is planned to be applied on the external parts of the structure, using hand-held lasers.

Assuming that the research project is successful, the process of cleaning and repainting the inside of the bridge structure could still take up to five years to complete, depending on the number of lasers being used. Current estimates are that with ten, 1KW-range lasers working 24 hours a day, seven days a week it would take between three and five years to carry out the work.

Nonetheless, the huge potential market even within just the transportation sector is attractive, with hundreds of thousands of steel bridges around the world needing continual maintenance. Other asset maintenance applications, such as aircraft refurbishment, where the ability to eliminate any risk of damage to the base material is crucial, are future opportunities.

Anti-clockwise from top; Waumbot in vacuuming mode in the girder; laser cleaning equipment in action; results following laser cleaning test

The new technique also has the potential for use in the heritage sector – where some rise in temperature can be tolerated, cleaning with nanosecond pulsed lasers has already proved cost-effective for restoring sculptures, bronze statues, ornate terracotta and even entire building facades. However, delicate items, such as paintings, gilded surfaces, and fabrics, which cannot tolerate temperature rises, may benefit from the ultra-short pulse methods. Ultrafast laser cleaning has already been used to clean previously untreatable complex and fragile gilded surfaces, but, with the new high-power process, this technique could be scaled to large areas, used for objects with heavy soiling, and deliver faster cleaning times

CONFINED SPACE INVADER

The Centre for Autonomous Systems at the University of Technology, Sydney has been collaborating with the Roads & Maritime Service of NSW for the last decade to develop robots for inspection and maintenance work, including the autonomous climbing robot Croc, which has been in use on the bridge for some years *(Bd&e supplement: Smart Technology)*. The latest robotic helper is the Wallpushing Autonomous Maintenance Robot (Waumbot), which is designed to remove old paint and rust, and to vacuum and paint inside the confined spaces of the structure.

The machine has four expandable legs, which each have toes at the end, and a robotic arm with six degrees of freedom, enabling it to manoeuvre through the rivet-filled spaces in order to carry out maintenance work.

Advanced sensing technology is used to map and localise the robot within the space; using live 3D maps, it can autonomously identify features such as rivet patterns, manholes and other obstacles to intelligently plan its route to the maintenance location.

Once it reaches the right place, the operator authorises the robot to perform maintenance tasks, such as removing old paint and rust, and cleaning debris along with dust and spray paint.

The robot can be controlled using a simple user interface that allows the operator to monitor the operation and performance of the robot. The robot provides 3D data and high-definition geo-referenced images that can be viewed remotely by the bridge maintenance workers for condition assessment.

Waumbot has been used on the bridge numerous times and is capable of navigating through the manholes to collect data.

Grit blasting and vacuum cleaning have also been tested on site. The robot has the potential to be used on other complex steel structures with limited access and confined spaces

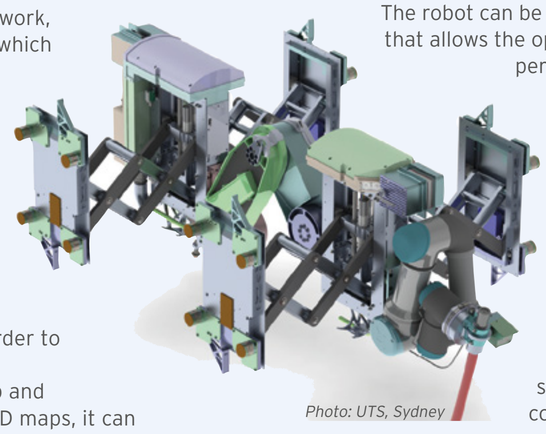


Photo: UTS, Sydney

BREATHING SPACE

New concrete jackets maintain the architectural theme of the original piers, which are visible in the background

The distinctive V-shaped piers of a bridge in England called for an unconventional approach when the time came to replace the bearings

The shape of the piers and the limited space available under the superstructure led to a new design for 12 pot bearings, as well as the construction of concrete jackets for the piers.

Nene Bridge in Peterborough, around 130km east of Birmingham, was constructed in 1984 and carries the A1139 highway over a railway line and the River Nene. It serves motorists travelling between the A1 and A47 highways and provides a key link for pedestrians and cyclists commuting between the north and south of the city.

Findings from earlier inspections and condition surveys had identified structural stress on the bridge piers and pier saddles as well as significant deterioration on the exposed bearings on the pier tops, to the extent that the bearings no longer functioned for the purpose for which they had been designed. For Nene Bridge to remain operationally safe, the bearings needed replacement.

Skanska Construction was tasked by Peterborough City Council to manage the US$6.3 million allocated for restoration works on the structure, contracting Ekspan to undertake the bearing replacement on six of its piers. A value-engineered solution was required that would accommodate the operation while maintaining the structure's unique architectural design.

The 155m-long bridge deck is supported on two abutments and four sets of V-shaped piers, two piers per set. Four piers sit in the River Nene and the remaining four are located on either side of a railway line. Each pier carries two bearings.

In 2016, preliminary visual surveys of the current bridge bearings and the internal bridge beam stiffeners were carried out by Ekspan in order for new mechanical bearings to be designed to modern standards. The measurements taken for the bearing positions and bearing stiffener details were also checked against as-built drawings to ensure there would be no conflict with a new temporary works system.

The early collaboration between the contractor and Ekspan established that a straightforward bearing replacement would not be viable on the original structure. The insufficient headroom and surface area on top of the bridge piers made conventional jacking – an essential process for bearing replacement – impossible. There was only around 160mm of space between the underside of the bridge superstructure and the pier top bearing shelf, and the top surface area was only around 2.7m^2: two factors that prevented the positioning of temporary jacking devices to lift the structure.

The solution proposed involved constructing reinforced concrete jackets around each of the piers, enabling the bearing replacement work to take place with an upgraded upper surface area of around 6.5m^2, while also strengthening them.

The design for the replacement pot bearings met a number of challenging requirements. Working to Skanska's existing bearing and temporary bearing schedule, new bespoke pot bearings had to be designed. These not only conformed to EN1337 but fitted in the same location on the structure – mirroring the same envelope as the original, smaller, BS5400 bearings – and acommodated loadings as high as 800t.

The temporary works design provided by Skanska featured temporary bearings positioned on jacks to constrain the structure in its temporary state. Unfortunately, as the loads were too large to be constrained through the hydraulic jacking cylinders alone, a new temporary system was developed with the additional use of temporary bearings. In addition, lifting accessories were designed, manufactured and supplied to fit a standard telehandler, necessary to enable pinpoint positioning accuracy for temporary supporting steelwork weighing over 1.7t on the underside of the structure.

In April this year the extensive design and installation of temporary works began. These enabled the bridge to be jacked by 3mm and the existing bearings to be replaced in stages using bespoke jacking frames bolted and welded through the main box girders.

The contract was completed in September 2019, with a total of 12 bearings replaced on six sets of piers. Four bearings on the remaining two river piers still require replacement, and the works for this are expected to be tendered in 2020 ■

The concrete jackets provided sufficient room for the installation of the temporary supporting steelwork and jacking systems

LOCALLY SOURCED

Cable saddles for a bridge nearing completion in Vietnam have been formed using high-performance mortar sourced regionally

The fifth and last cable saddle for the Cua Dai Bridge in Quang Ngai province in the South Central Coast region of Vietnam was successfully installed in September and the last set of cables is expected to be in place in December.

The 1.9km-long crossing comprises a main extradosed section consisting of two 75m-long side spans and four 120m-long main spans supported by six cable towers rising 20m above deck level. The crossing is flanked by 31 approach spans, each 40m in length.

The bridge is being built for the People's Committee of Quang Ngai by a joint venture formed by Trung Chinh, Tan Nam and 620.

Freyssinet has had a permanent team of 25-30 people on site since the beginning of the year, installing formwork, saddles and stay cables in time with the construction of the prestressed concrete superstructure, which is being built using the balanced cantilever method.

The structure's cable saddles each weigh around 800kg and contain eight saddle tubes made of ultra-high performance steel fibre mortar, with recesses for 19 cable strands. The strands are individually protected by sheaths, with no filler injected into the saddle recesses. Each strand contains seven hot-dip galvanised wires that are coated in a resin that ensures a full bond with the outer HDPE sheath.

The galvanised steel formwork for the cable saddles was made in Vietnam and delivered to site on steel framework using a design created by Freyssinet's team in France. Curvature radii for the saddle tubes vary between 2.5m and 6m. Ribbed elastomeric tubes were added on site to form the cable strand recesses for the pour.

In a first for Freyssinet, the saddle tubes were formed using specialist mortar sourced from Dura, a firm based in Malaysia. "We usually source high-strength fibre mortar from France, but we found a supplier that had a product with the same capacity and flowability and so on. We had to carry out our own tests to make sure it was suitable, which took place during the fabrication of the formwork," said Freyssinet Vietnam project manager Alain Granet.

The fifth and last cable saddle was installed in September by crane; the project is on course for completion in May 2020, well ahead of its target of August 2020 ■

The composite girder is made of fibres and resin

BREAKING THE MOLD

A newly developed girder promises improved durability, versatility and reduced carbon footprint. Khalifa Bokhammas reports

The Composite Tub (CT) Girder has been designed for use on highway, rail and pedestrian bridges, and was developed by AIT Bridges, a division of Advanced Infrastructure Technologies (AIT), in partnership with the University of Maine Advanced Structures and Composites Centre. According to AIT Bridges, the product is lighter than steel and concrete girders by 50% and 75%, respectively, and is made from fibre-reinforced polymer, a material the company has used as part of its Composite Arch Bridge System since 2010.

At the time of writing, five CT Girders were being prepared for use in their first ever structure: the replacement Grist Mill Bridge over Souadabscook Stream in Hampden, Maine in north-east USA. Construction of the new bridge forms part of a range of work being undertaken the Maine Department of Transportation on a 2.8km-long stretch of Route 1A. Speaking to local media about the CT Girder in August, Joyce Taylor, chief engineer at the MDOT said, "Our engineers are excited to use it and sought it out for this project. We are looking for other opportunities to use this technology on upcoming projects, and we'll be sharing it with other departments of transportation around the nation."

TY Lin International is the prime designer for the bridge and has designed it to have a conventional concrete deck and stainless steel reinforcement. Construction is scheduled to start in June 2020 and once complete the University of Maine will test and monitor the bridge to accumulate data for future applications of the girder.

Manufacturing the new girder involves layering sheets of composite fibres reinforced with a bonding resin in bathtub-shaped molds. The girder dimensions can be customised for each structure and for the Grist Mill Bridge they are being formed in a 24.4m-long mold to produce girders that are 23.2m long, 1.2m tall and 1.2m wide.

According to Ken Sweeney, president and chief engineer of AIT Bridges, there are numerous benefits to using FRP for girders over concrete and steel: "First and foremost is the durability of FRP members. FRP is a corrosion-free and fatigue-resistant material, which is a vital aspect in bridge design. Second is the ability to engineer the material to the specific demands of each structure. By altering fibre types and matrix materials we can engineer a more economical design with better efficiency," he says.

FRP has also been touted by the company as having much less of an environmental impact than concrete and steel. "The energy required to produce the carbon and glass fibres used in our products is in the order of two to three times less than that of steel and concrete. Our lightweight materials also reduce the emissions caused by transporting materials to site, and correspondingly the same reduction can be seen during installation," says Sweeney.

"Furthermore, both steel and concrete suffer in their long-term carbon dioxide emissions due to the fact that they require a lot of maintenance and only provide at best a 75-year design life," he explains. Adding to this the financial burden associated with the renovation and repair of the current bridge portfolio, and the company knew from the outset that a different material would be needed to reduce costs and workloads for the next generation of owners and bridge designers.

With this goal in mind, AIT Bridges teamed up with the University of Maine Advanced Structures and Composites Centre. Both organisations already have a history in the development of FRP materials for structural applications. Their working relationship goes back to the founding of AIT, which aimed to commercialise the Composite Arch Bridge System, for which the university conceived the main structural component in the early 2000s.

Since its commercial availability in 2010, the Composite Arch Bridge System has been used to build short to medium span bridges both at home in the USA and abroad. It consists of lightweight corrosion-resistant FRP composite arch tubes which act as reinforcement and formwork for cast-in-place concrete.

However, according to Sweeney, the company saw a gap in the market that the system was not able to fill. "With AIT's decade of industry presence and understanding of infrastructure market needs, we identified that our Composite Arch Bridge System product often fell short of providing a solution to some of the more geometrically constrained project sites in the short to medium span bridge market," he says.

"Noticing the need, we approached the University of Maine to assist in developing a beam type bridge structure that would complement our arch system by providing an alternate solution that didn't currently exist in the marketplace. Their key contributions to the research and development were to develop the analysis software, laminate architecture, and investigation of production methods."

From the start of the CT Girder's development path in summer 2016, the main aim was to provide a composite bridge structure in the 9.1m-30.5m span range that could reliably provide a 100-year low-maintenance service life.

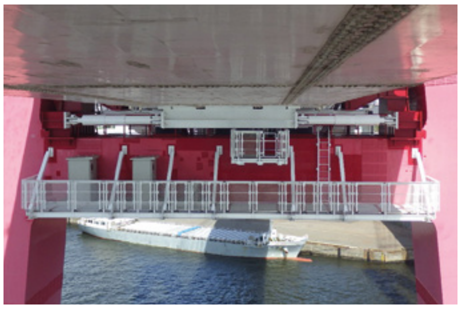
To this end, the team's first task in designing the product was to investigate all of the composite technologies used in bridge construction over the previous three decades.

"From that literature review, we could then begin to take parts and pieces of the successful projects and use that to formulate concepts and ideas. Those ideas combined with the expertise in composite materials, testing, and analysis from the Advanced Structures and Composites Centre and AIT's industry presence, market understanding and design acumen. We were able to create a system that is simple to understand from a design and installation perspective, while still taking advantage of complex, next-generation materials," Sweeney adds.

The CT Girder system will primarily be deployed on new bridge projects, and AIT Bridges believes it could be used for up to 80% of new bridges in the USA. Although doubtful that it will be deployed for bridge rehabilitation projects, Sweeney comments that it "might be an area the company adds its design engineering and fabrication services to in the future, if the market is amenable" ■

NEW ERA, NEW CHALLENGE

The ongoing seismic retrofit of the Meiko Triton Bridges involves the installation of the largest viscous dampers ever built in Japan, write Javier Lopez Gimenez, Hiroshi Shimmyo, and Takehiko Himeno



Retrofit of transversal (*above and centre*) and longitudinal (*right*) viscous dampers on the Meiko West Bridge

Collectively known as the Meiko Triton Bridges are the Meiko West, Meiko Central, and Meiko East bridges, three key links between major land transportation arteries and the Port of Nagoya, Japan's biggest and busiest seaport. At their time of completion in 1998, they were among the world's longest span cable-stayed bridges.

The bridges were designed with the latest engineering knowledge and the seismic design requirements of the time, but following the severe damage caused by the 1995 Kobe Earthquake, the seismic design standards in Japan were revised and the design seismic demands greatly increased. Due to their role as critical infrastructure and emergency routes, the seismic retrofit of the Meiko Triton Bridges became an important issue.

Each of these is currently at a different stage of a retrofit: The concept design of the Meiko East Bridge retrofit is ongoing. The retrofit works of the Meiko West Bridge have been completed, involving the installation of the largest viscous dampers ever manufactured in Japan. The contractor for the seismic retrofit of the Meiko Central Bridge was selected only a few weeks ago, but a detailed design with even larger viscous dampers than those in the Meiko West Bridge is expected.

The Meiko West Bridge was opened in 1985. It is a three-span cable-stayed bridge with a total length of 758m. The seismic evaluation of the bridge in its original configuration was carried out using the large earthquake ground motions described in the post-Kobe earthquake seismic design specifications, as well as site-specific earthquake inputs that highlighted the susceptibility of the structure to seismic damage. Among other issues, the results showed that in a strong seismic event, the girder displacements in the longitudinal direction were excessive and could cause girder pounding with the adjacent viaducts. In addition, the strains of the steel members of the girder, as well as the shear forces of the end piers, greatly exceeded the capacity limits. Based on these results, it was clear that the seismic retrofit was necessary, but since the location of the bridge is a major constraint, it was important to find a cost-effective solution that allowed minimum reinforcement of the girder and towers.

The installation of seismic isolation bearings and viscous dampers to reduce the demands at the structural elements by absorbing seismic energy was found to be the most effective solution. They allow the control of bridge response to strong earthquakes, the reduction of stresses of the towers below yield point, the minimising of stiffening works at the girder, and a drastic reduction in the displacements of the girder, avoiding pounding adjacent structures. Seismic isolation bearings were installed in the Meiko West Bridge to replace the existing bearings in the towers, and viscous dampers connect the deck and the substructure in both longitudinal and transverse directions to distribute horizontal inertial forces among the piers and to absorb seismic energy.

Viscous dampers are hydraulic devices that dissipate seismic energy by pushing a viscous fluid through an orifice. The requirements for the viscous dampers installed in the Meiko West Bridge in the longitudinal direction included a maximum stroke of ±650mm and maximum response velocities of 3.2m/s. In Japan, where maximum damper strokes are generally ±350mm and the performance of the dampers is evaluated under maximum velocities of 1.5 m/s, the design, testing, and manufacture of these large-scale dampers was a major challenge. The dampers, manufactured by Kawakin Core-Tech, were subjected to an extensive testing program in order to confirm the effect that the large strokes and velocities would have on their performance.

The first test was carried out with a damper specimen in which the size of the orifice through which the fluid flows had been reduced. The reduction was performed to reproduce the flow conditions when the response velocity is 3.2 m/s, since it is not possible to test the damper at such high velocities due to the restrictions of the testing equipment available in Japan. The test results confirmed that the obtained damping force at the velocity range that has influence in the seismic design did not differ more than ±10% from the design value. Another test specimen in which the internal structure around the cylinder matches the structure of a damper with ±650mm stroke was manufactured. The dynamic test results confirmed that the increase in dimensions around the chamber, which could induce deflection in the rod or affect the pressure of the fluid, did not modify the response of the damper.

The seismic retrofit of Meiko West Bridge was a major engineering challenge that required the collaboration of outstanding Japanese engineering, construction, and manufacturing companies and the use of cutting-edge seismic devices never-before built in Japan.

The seismic retrofit of the bridges that complete the Meiko Triton is ongoing, and it is expected to bring challenges that match – or even surpass – those overcome for Meiko West Bridge. An exciting and necessary task to ensure the safety of this critical infrastructure for Reiwa, the new era that has just begun in Japan

Javier Lopez Gimenez is technical business development manager, Hiroshi Shimmyo is director of business planning, and Takehiko Himeno is director of engineering at Kawakin Core-Tech

Meiko West Bridge

Owner: Central Nippon Expressway
Contractor: Takigami Steel Construction
Bridge design and planning: Nippon Engineering Consultants
Damper manufacturer: Kawakin Core-Tech