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Construction of the concrete legs

Deck elements being raised onto the span

MAKING MOZAMBIQUE

Africa's longest suspension bridge is set to open to traffic by the end of the year. Jörn Seitz and Cao Changwei look at some of the key features of Mozambique's new landmark

Africa's longest suspension bridge — the Maputo-Katembe Bridge in Mozambique — is due to be opened by the end of this year. The bridge has a main span of 680m and with the north and south approach bridges, a combined length of more than 3.1km extending both sides of Maputo Bay *(Bd&e issue no 85)*.

The crossing is considered to be the most important infrastructure project built in the country since Mozambique achieved independence in 1975. It will carry the national highway EN1 across the bay and beyond to the city of Ponta Do Ouro in the extreme south of Mozambique, some 130km away. Construction of the bridge and approximately 184km of link roads, which started in 2014, has cost an estimated US$725 million.

The design and construction of the bridge is being carried out by China Road & Bridge Corporation and is based on the *FIDIC Silverbook Engineering, Procurement & Construction* contract. German consultant Gauff Engineering was appointed to oversee quality control, to carry out the complete site supervision and to verify the design against Eurocodes. This was considered very important by the owner Empresa de Desenvolvimento Maputo Sul, a development corporation set up by the Mozambique government to oversee the project and future management of the infrastructure.

The Maputo-Katembe Bridge is comprised of three different bridge types. A reinforced concrete, post-tensioned T-beam is used for the south approach structure, a balanced-cantilever reinforced concrete box girder for the north approach bridge, and a suspended steel box girder main span across Maputo Bay which is 60m above sea level.

The design speed for this highway project was defined as 80km/h and different construction methods had to be chosen due to localised constraints. On the north, the approach bridge is a balanced-cantilever reinforced concrete box girder construction with a length of 853m with another connecting 240m-long prefabricated post-tensioned T-beam section to the abutment, rising up towards the suspension bridge with a gentle S-curve in plan.

The southern approach bridge was built using prefabricated post-tensioned T-beams of 30m-long and 45m-long spans to create a total length of 1.2km of the approach bridge from ground level to the southern tower.

The approach bridges connect on each side to the single-span double-hinged suspension bridge made up of 57 steel box elements. The steel box girders were manufactured in China and were delivered to the site in September 2017, being immediately erected and their provisional installation on the hangers completed at the end of October 2017. The main cables are 1.3km long and have a diameter of 509mm - each is formed of 91 galvanised strands. The steel box girders were connected to them by hangers, which are parallel wire tendons with pin-connections. The upper connection to the cable clamp and the lower to the steel girder are achieved with Y-shaped lugs.

A double sheath of 8mm-thick PE is used to wrap the tendons for protection and the hangers are at a standard interval of 12m. The interval from the tower centreline to the nearest hanging point is 16m. Each hanger consists of 61 lengths of parallel steel wires — 73 pieces for the hangers at each extreme of the bridge. These are 5mm-diameter galvanised high-strength steel wires of grade 1,670MPa.

Each of the 57 steel box girders is 12m long, 3m high and 25.6m wide including the wind fairings. All the box girders were shipped across the Indian Ocean from China to Mozambique, and the ship docked at the international harbour of Maputo, very close to the site.

The bridge has a combined length of 3.1km including approach bridges

A special lifting gantry was installed to erect the deck elements, which weigh up to 137t. To keep the main cable in uniform shape, erection started from the centre of the main span and continued symmetrically in both directions towards the towers. As a result of the continuously increasing weight on the cable, the angle between the steel box girders changed until the last element was in place. Therefore the elements were temporarily bolted together as they were erected, and the permanent welding work did not start until the last box girder had been raised onto the cables. In addition to the main circumference weld, the u-ribs on the bottom were welded and the u-ribs on top were connected using prestressed bolts.

During installation of the stiffening beam, the load in the main cables increased and resulted in bending in both of the towers; to bring them back to a vertical position, a horizontal movement of up to 1.6m of the two main saddles was necessary.

The main cables are guided over splay-saddle buttresses which are anchored into two massive anchor blocks, one on each side of the bay. These structures had to be built to a substantial size due to the poor geological conditions and high water table at this location. Each has a diameter of 50m and the shaft depth during excavation was up to 37.5m. making them among the largest anchor blocks in the world. They contain chambers of sand and concrete for mass, with the south anchor block being particularly large, weighing an impressive 170,000t in its final form.

The cables extend from anchor block to anchor block and are placed over the top of the two portal-frame towers which are positioned on each side of the bay. On the Katembe side on the south bank, the tower has a final height above ground of 137m, and the Maputo tower is 138m high. One interesting aspect of the tower design is the fact that each leg is inclined at 2° towards the centre line of the bridge for added stability; in addition to this, each tower is founded on 24 piles with a diameter of 2.2m which extend to depths of 110m on the south side and 95m on the north. Again this is due to the poor geological conditions, which dictated the need to design substantial foundations. In total 331 piles were constructed for the main bridge and its approaches, with an average depth of 50m.

Keeping the goal of the highest quality of the concrete in mind, compressive strength concrete cubes were manufactured for testing at 7, 28, 90 and even 365 days.

View of the bridge and its substantial approach viaducts

Altogether more than 51,600 cubes were tested for the nearly 350,000m^3 of concrete that was used during the construction period.

Mandated durability testing was done continuously, according to South Africa National Standard specifications. Another very specific aspect of the concrete on this project was the substitution of up to 40% of cement by fly ash; this not only offers immediate cost savings but also long term benefits.

The subsitution was proposed by the contract due to the fact that the environment at the site is considered severe, requiring a very durable concrete that could only be obtained with such substitutions. Durability indices are now standard requirements for concrete, as well as compressive strength.

Despite the fact that the fly ash had to be imported, this substitution still resulted in a cost saving of 7% and an estimated reduction in carbon emissions of 30%. Such substitutions have no drawbacks, although they do depend on the presence of coal-fired power stations for supply of the material.

The fly ash was supplied to the site from South Africa and has resulted in concrete with an extremely high durability, a fact which was confirmed by the University of Cape Town's Concrete Materials & Structural Integrity Unit which tested samples cored from the bottom slab of the north anchorage. The high quality concrete received a commendation at the Fulton Awards 2017 for its sustainability.

Mastic asphalt was used for the first time in Africa for a suspension bridge with an orthotropic steel deck. The bridge carriageway is 18.6m wide with a pavement area of 12,648m^2 and the deck carries a dual carriageway with a total of four lanes, two in each direction. The steel deck pavement consists of a sand-blasted corrosion protection treatment, waterproof bonding layer, 35mm-thick Gussasphalt GA-10 and 38mm-thick modified asphalt SMA-10. The requirements of the surface after the sand-blasting was specified in both Chinese and European codes in terms of cleanness and roughness. The asphalt mixing plant was 120km away, so the laying of the Gussaphalt and SMA-10 asphalt had to be carried out with specialist equipment from Europe to guarantee the highest quality and accuracy of the layers and their compaction.

It took 14 days to complete the process of sandblasting, applying the anti-rust primer, waterproofing layer and high strength adhesive. A further 20 days was necessary to apply the Gussasphalt, followed by six days for the SMA layer.

The cable anchors are substantial structures in their own right

A specialist subcontractor from China was commissioned to do the Gussasphalt paving, and the SMA layer was done by the Chinese in-house team; all pavement works were completed in May 2018. Gussaphalt was chosen because it has a longer lifespan than regular asphalt; case-studies from Europe demonstrate that it can last up to 20 years with a minimum of maintenance work.

A dehumidification system was installed on the main cable, anchorage chambers, saddle rooms and steel box girder deck. This will inject hot air into the closed section of the main cables and also separately into the steel box girders to reduce the humidity and prevent corrosion — the system is designed to run 24 hours a day, seven days a week throughout the year. Humid air is extracted from the structure at a number of exhaust sleeves, and the circulation of the air is controlled via a data collection system, with measuring devices installed in a separate monitoring room. Its operation will be monitored for six months and then approved once it reaches a constant level of humidity. The wrapping of the main cable is a three-ply laminated construction with a thickness of 3.6mm.

The long-term dehumidification and online monitoring function includes two sets of main cable dehumidification systems, four sets of saddle room dehumidification systems, four sets of anchorage room dehumidification systems, four sets of steel box girder dehumidification systems. These are intended to create an internal relative humidity of the steel box girder, anchorage room, saddle room of less than 45%; the trigger level for the system to start running is 60% humidity.

Although the key technology of the main cable dehumidification system has been proven and in use for the last decade, this is the first time that a bridge dehumidification system has been used in Africa.

When the bridge reached structural completion, a bridge loading test was required by the client, due to the irregular geometry and form of the structure, and this was carried out at the beginning of June 2018.

For the main bridge the elements being controlled were the main cable deflection and force at the anchorage saddle, the force in the hangers, the deflection, displacement and strain in the stiffening beam, and the displacement and strain in the bridge towers. Only strains and deflections were controlled for the cast in situ box girder.

Different test scheduling plans were created for each bridge. For the suspension bridge, a total of 11 conditions were tested, with the number of trucks varying from 12 to 56 on four different test sections across the span. Because of the symmetry of bridge, static load was only tested on the southern part of the main bridge. For the north approach bridge, seven conditions were tested, with the number of trucks varying from 14 up to 20.

Dynamic testing was also performed by moving the trucks at different speeds, and braking in between the movements. The maximum elastic deformation under the static loading was approximately 1.14m and the elastic deformation of the towers was measured as 108.5mm towards the middle of the bridge — these values were in the predicted range.

Handover of the new bridge to the Mozambique Government is currently scheduled to take place before the end of this year, forever changing the skyline of Maputo ■

Jörn Seitz is project director at Gauff; Dr Cao Changwei is project general manager at CRBC

WOVEN STEEL

The main span over the Ring 3 highway was erected at the end of October

A new bridge in the northeast of Oslo aims to improve conditions for pedestrians and cyclists at a major junction. Andri Gunnarsson and Magnús Arason report

Replacement of an ageing and narrow footbridge in Norway will make it easier and more pleasant to cross the capital city's ring road at a busy intersection. When it is completed next autumn, the new Ullevaalskrysset footbridge will provide more space for cyclists and pedestrians to co-exist, and will make the journey safer and more pleasant for all.

The new crossing is a 400m-long and 7.2m-wide bridge structure which is served by four ramps feeding foot and cycle traffic into a central circulation area. It will provide a new elevated route across the Ring 3 highway, which carries 60,000 vehicles per day, as well as the smaller Sognsveien road which carries 12,000 vehicles per day. The bridge is designed to link and interweave separated cycle and pedestrian lanes from four directions at the elevated integration zone, resolving the current problem of insufficient capacity, and improving traffic safety in the area.

The site is next to Norway's national football stadium, Ullevaal Stadium, which also hosts concerts and other crowd-gathering events. The surrounding area is heavily used by motorists, pedestrians, and cyclists as they commute to and from the facilities in and around the district. The primary aim of this project is to improve the accessibility, safety and capacity for pedestrians and cyclists by replacing the narrow and ageing bridges at the site. It will also serve as an important link in the ongoing expansion of the city's cycling network, of which the cycle route along the Ring 3 highway is a vital component.

The existing bridges are narrow, at only 2.5m wide, and this not only restricts the capacity, it increases the risk of collisions between pedestrians and cyclists. Another issue is that the bridge ramps slope at 1:10 and have no landings, making them unsuitable for the disabled. When footfall is high due to events at Ullevaal Stadium, the bridges tend to oscillate, making users feel unsafe. The cycle route across the smaller street, Sognsveien, is currently via a zebra crossing which is very close to the Ring 3 slip road. This gives rise to a danger of collisions between motorists and cyclists crossing the road due to limited visibility and the high speeds involved. Using the existing bridge to cross Ring 3 on a bicycle is not much easier, which effectively creates a gap in cycling provision along Sognsveien at this point.

EFLA Consulting Engineers and Brownlie Ernst & Marks Architects were assigned the project design by the bridge owner, the Norwegian Road Administration, after the team had carried out a conceptual design phase in early 2015. This resulted in the definition of plan layout, elevation and bridge type. Tender design was completed in the spring of 2017. The total cost of the project is US$35 million.

The bridge site poses a series of technical challenges, and the chosen layout and

structural system very much reflect the site restrictions. The narrow boundaries of the available area led to a bespoke planar layout, made up of ramps from four directions connecting to the main spans of the bridge and an integration zone where the traffic streams weave between each other.

Another challenge is the large depth to bedrock, which ranges from 20m to 45m, with the soil mainly consisting of sensitive clay. To address this, drilled, concrete-filled steel tube piles were chosen for the bridge foundations, along with lightweight access ramps made of expanded polystyrene that connect the bridge superstructure to ground level. Furthermore, there is a large quantity of services in the ground at the site, some of which cannot be moved, and this directly affected the bridge alignment.

One of the main design criteria was to minimise traffic disruption during construction, particularly on the Ring 3 highway. Discussions with the bridge owner and road authorities at the early stages of the design process resulted in steel as the construction material of choice. The decision to use steel for the superstructure allowed the construction period for the whole bridge to be minimised, as the superstructure could be fabricated at the same time as foundation works were being carried out. With the exception of two road closures of one or two-day periods, necessary for the erection of the superstructure over the road, traffic disruption could be kept to a minimum.

The bridge layout, along with the client's stated requirement for an elegant aesthetic, led the EFLA/BEAM design team to the chosen bridge type; a steel box girder with cantilevered ribs stretching out from a curvaceous, flowing spine and supported by pairs of V-shaped steel columns. Tuned mass dampers are necessary at the two longest spans of 27.5m and 37.5m, to achieve a dynamic behaviour appropriate for pedestrian comfort. The use of mass dampers also allows for a relatively slender and lightweight construction of between 1.4t and 2.4t per metre and a transparent structural system.

The construction of the bridge is being carried out by the main contractor NRC Group Norge, supported by steel fabricator Western Constructions, Hallingdal Bergboring for the pile installations and Fastlane Technologies for on-site erection works. Construction site supervision is run by the project owner, the Norwegian Road Administration, with the support of Axess for steel inspection.

Construction work began last year, in November 2017, and the first phase included relocation of the local services along with site preparation. This was a substantial undertaking, as cables and pipes at each of the 19 bridge pier locations had to be diverted and relocated.

Installation of the steel tube piles started in February this year, when more than 2km of piles with diameters of 500mm or 600mm were installed. The longest piles were up to 50m, pushing the installation process to its limit with the casting of concrete into the steel tubes being the most challenging part. The piles were excavated using reverse-circulation drilling with the excavated soil being removed by suction up to the ground level. This method is particularly favourable for installing very deep piles in sensitive soil. In conjunction with the piling, construction of the pile caps and abutments started in spring, and all the bridge foundations were cast in place by September.

Fabrication of the steel superstructure started in Klaipeda in Lithuania also in spring this year – most of the bridge is being brought to Oslo by road, with just the four largest elements being shipped to the site. The structure is emerging from the fabrication plant in 19 main elements that range from 14m to 18m in length and between 20t and 36t in weight. Due to their substantial width, 15 of the main segments had to be divided in two to enable their transport by truck from Klaipeda to Oslo.

The largest challenge of the fabrication and erection process is the complex geometry of the bridge, since it has a range of different curvatures in plan and elevation, and the geometry is further complicated by the four adjacent ramps that come together with different cross-slopes at the integration zone. To make the bridge fabrication easier, a detailed 3D model of the bridge superstructure was created in Revit by EFLA to support the 2D tender drawings. The model not only defines the bridge geometry, but also the material type, plate thicknesses and various details; it formed the basis of the shop drawing modelling done by the steel fabricator.

Night-time photomontage of Ullevaalskrysset Bridge *(Brownlie Ernst & Marks)*

The first elements of the bridge arrived on site in August; most of the 19 segments arriving by road are being erected soon after arrival on site, due to the limited space available at the construction site for storage.

At the beginning of the process an integration zone was erected on rigid foundations to create a stable backbone for the bridge structure, followed by the mounting of the four ramps onto their hinged columns.

The two scheduled road closure periods are for the mounting of the bridge's main spans. The 37m, 62t Ring 3 span was erected on to its column and welded onto the adjoining section on 28 October, during a 48-hour weekend road closure. This involved strategically mounting two large cranes with a lifting capacity of 500t and 250t so that they would not conflict with the existing bridges, which remained open during the operation. A similar operation is scheduled for the Sognsveien bridge span next month *(December).*

By the end of last month *(October),* eight of the 19 bridge elements were in place and erection work was set to continue throughout the year. The bridge access ramps were under construction, and this phase will be followed by linking the bridge to the cycle and pedestrian networks in the area and associated landscaping. The whole project is scheduled to be completed in autumn 2019 ■

Andri Gunnarsson is structural engineer and Magnús Arason is project design manager at EFLA Consulting Engineers

On-site erection operations at the bridge integration zone

Composite bridge over a railway line in Luxembourg with hot-rolled sections in weathering steel grade *(Arcelor Mittal)*

COMBINED FORCES

Alternative corrosion protection systems, combined with hot-rolled sections, can make steel more economical for small and medium-span bridges, say **Dennis Rademacher** and **Wojciech Ochojski**

Both hot-dip galvanising and weathering steel can have advantages over traditional coating systems, in particular when the whole life cycle of the bridge is considered. They require no maintenance and hence any impact on traffic caused by maintenance works can be eliminated. When these systems are combined with hot-rolled sections, there are further advantages to be gained, by making composite bridges more economical and durable, particularly in short and medium spans.

Steel is often associated with very large spans due to its favourable relationship between strength and weight. But even with small and medium span lengths of up to 60m, steel combined with concrete as a composite bridge can lead to economically-justifiable construction.

Worldwide, the condition of bridge stock is poor, and the work that is needed to repair them is considerable. For example a recent detailed survey on the status of bridges in Germany revealed that 20-25% of the municipal road bridges in steel and composite construction require replacement — and the annual investment for replacement alone, not taking into account any that need partial repair, is estimated at US$630 million in Germany.

All bridge components must withstand corrosive influences for decades to ensure their long-term use. Thus, a key aspect of the permanent function of bridges is durable protection against corrosion over their intended 100 or 120-year service life.

Corrosion damage is often responsible for the poor condition of a bridge and this can be observed independently considering concrete, steel and composite bridges. A study of municipal road bridges in Germany concluded that in about 68% of all cases, corrosion is one of the reasons that a composite bridge would need replacing — and this figure is similar for concrete bridges. For steel bridges corrosion is one of the decisive causes. Hence, an improvement in the general condition of the bridges would be achievable using a more durable corrosion protection system in steel and composite bridges.

There are several technologies available for corrosion protection of steel members. Traditionally, multi-layer organic coating systems are applied, and the advantages of this method are the ease of use, high degree of experience and the option of colour. However, these systems have to be renewed after 25-30 years, and while current development efforts are pointing in the direction of 40 or even 50 years of protection, this would still not protect the bridge for its full lifetime. In addition, they are prone to being damaged during transport and assembly.

Against this background, the use of hot dip galvanising as the state-of-the-art corrosion protection method would have been an obvious approach. Recent research found that a coating thickness of only 200μm can be sufficient to provide corrosion protection over the entire life cycle without renewal, even in an environment of high corrosivity, such as classes C4/C5.

Another option is weathering steel, which requires no additional corrosion protection

systems because it is able to form a natural permanent protective layer; as yet, however, this is not widely used. But if a few rules are observed, weathering steel can outlast the design life of 100-120 years without any need for maintenance of the corrosion protection. This steel is only unsuitable in direct proximity to the sea and in areas of permanent humidity, where the surface cannot dry. Weathering steels are part of the harmonised European standard series *EN 10025 (Part 5)* and included in the design rules of Eurocode 3 as well. National and international guidelines such as *DASt guideline 007* or *ECCS publication no 81,* provide additional information on design and construction.

Common practice is to optimise the steel sections depending on the loads and construction phases, resulting in composite bridges with asymmetric steel sections with narrower and thinner upper flanges and wider, thicker, lower flanges. Occasionally, the cross-sectional height also changes due to variation of the web height, and this minimises the steel use. With rolled sections, variation of the cross-section along the longitudinal axis can generally only be achieved by adding reinforcing plates on the flanges or welding plates into the web. In general, however, the designer is bound by the geometric properties of rolled standard products.

In direct comparison, rolled sections may be a few percent heavier than optimised built-up sections, if the same steel grade is used. Nevertheless, it is beneficial to use rolled sections with a maximum height of up to 1.1m for bridges with span lengths of 40-45m, and slenderness ratio of L/30.

In Europe, welded beams for small and medium span bridges are usually made from standard plates in steel grade S355. The use of plates with higher strength is not common for small and medium span bridges; on the other hand, the use of hot-rolled sections in S460 is well established in European practice and is advantageous for road bridges, since the high strength can lead to weight savings often in the range of 20-30% over welded built-up sections in S355. Furthermore, when the higher strength profiles are thermo-mechanically rolled and optionally produced by the quenching and self-tempering process, the low carbon equivalent of the steel beams results in improved weldability of the material.

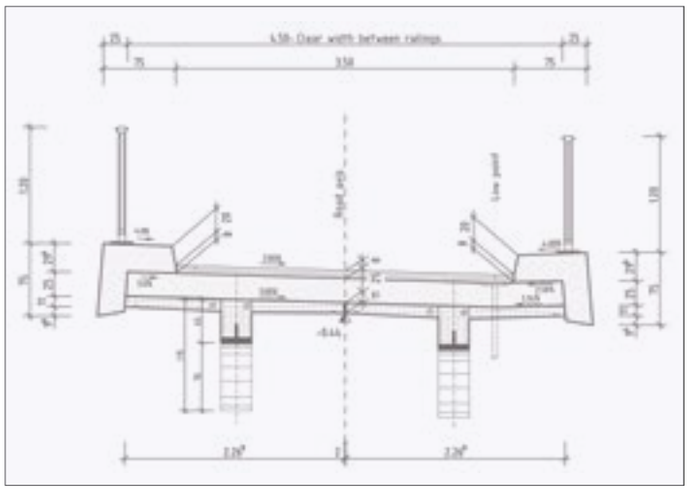

Cooling of galvanised beams

For welded built-up sections, in addition to the fillet welds between the flanges and the web, butt weld joints of the plates or plated beams are required every 12-18m, either in the workshop or on the construction site. For long products such as rolled sections, neither fillet welds nor butt weld joints are required up to a component length of 40m. In addition to the reduction in processing costs, any capacity bottlenecks in ▶


Precobeam in final position before adding in situ concrete for the slab *(SSF Ingenieure)*

steel fabricators' workshops can be circumvented and thereby delivery times can be shortened. Because of the weight savings and simple manufacturing, rolled sections in high strength steel grade are being used more and more frequently as the economical alternative to welded, built-up sections.

When combined with hot-dip galvanising, hot-rolled sections offer additional advantages that can enhance the benefits of both technologies. In terms of the process-sided handling, homogeneous hot-rolled profiles are a good fit with the galvanising process, where they are completely and uniformly coated with zinc by immersion into the liquid-hot zinc melt. Hot dip galvanised hot-rolled sections also look good due to uniform layer growth, since the chemical composition in the web and flanges is uniform.



Cross-section with two Precobeams and in situ concrete *(SSF)*

In the case of welded built-up sections, the unavoidable use of different materials can lead to differences in appearance and zinc layer thickness. In contrast to coatings that are sprayed or painted, this full shop application method offers a far higher quality of execution and safety, matching the corresponding quality of the profiles. In addition, since rolled beams are produced without welding work, there are no residual welding stresses and the risk of welding-induced distortion, both in steel construction production and galvanising, is excluded. Furthermore, thermally cut surfaces must be removed mechanically by at least 0.5mm, otherwise the zinc deposit on the cut surfaces is defective. This means that all cut surfaces in the longitudinal direction on the flanges of welded built-up sections must be ground; by contrast, rounding and grinding of edges and surfaces of rolled sections is not necessary.

While hot-dip galvanising as corrosion protection for load-bearing bridge components is neither included in the Eurocodes nor in the German specification standards such as ZTV-ING, the first successfully executed bridge projects demonstrate that it is feasible. The Elster-Bridge Osendorf is the world's first Precobeam bridge with a hot-dip galvanised steel structure. This bridge combines the economic advantages of prefabricated composite beams with composite dowel strips (Precobeams) with those of hot-dip galvanising. This single-span integral bridge with twin-girder cross-section and a span length of 21m replaces an old three-span structure that was damaged by a flood.

Rolled sections of HD320x300, in steel grade S355ML, cut in half with the typical modified clothoid dowel (MCL) shape, are used as external reinforcement of the T-beams. After flame cutting in the Arcelormittal beam finishing centre, the edges and surfaces of the steel teeth were ground. The halved beams were subsequently cambered by cold forming with a depth gauge of 1.08m, which could still be measured without changing after galvanisation. The construction depth is 0.7m in mid-span and 1.4m at the abutments of the bridge, resulting in slenderness ratios of L/30 and L/15 respectively.

The steel beams were hot-dip galvanised and had a layer of mean thickness of at least 350µm on the bottom flanges to ensure a theoretical corrosion protection period of more than 100 years. The bridge construction was opened to traffic in 2017.

For longer bridge components, hot-dip galvanising has the disadvantage that the zinc baths are limited in length and site joints are necessary — multiple joints over the length of a beam can be costly. In such cases it is appropriate to consider weathering steel, which is almost universally applicable. Weathering steel has similar mechanical properties as non-alloyed structural steel, but in addition, significantly better durability properties without the need for any additional coating.

Weathering steel is produced in accordance with the delivery standard EN 10025-5 with the addition of 'W' to its designation, for example S355J2W. Due to the addition of the alloying elements such as copper, chromium or nickel, weathering steel forms a barrier layer — or patina — which slows down the usual corrosion process. Some consider the rusty appearance as a disadvantage, but in architecture it is being used more and more commonly for facades and sculptures marking the start of a trend towards its acceptance.

Weathering steel is usually more expensive to procure, due to the additional alloying elements and the consideration of material loss over the lifetime, but in many cases the savings that come from eliminating protective coating systems are still greater. And over the 100-year life cycle of a bridge, the advantage of weathering steel is even greater, especially in circumstances where the repair of corrosion protection is difficult, time-consuming or expensive. The costs and inconvenience of traffic closures, for example on railway lines, can be avoided.

Unlike hot dip-galvanising, the use of longer components does not create any additional work, as rolled sections of weathering steel can be produced without splices up to a length of 40m. But even if a weld is needed, there is no need for repairs to the steel — the protective patina will form in the same way as on the other surfaces, assuming the right filler metal is used on the top layer.

The design and construction rules of the Eurocodes are completely valid for weathering steel without restrictions. Eurocodes provide slightly modified rules, for example with regard to the fatigue strength, furthermore, some rules for the design are specific, for example for spacings of bolts.

The protective effect is significantly influenced by the formation of a patina on the previously blasted surface, which develops in a period of about one to three years under the influence of atmospheric SO_2 and as long as the steel goes through alternating wet and dry periods — ideally in a 60% to 40% ratio respectively.

In subsequent weathering, the structure and colour of the patina changes from light brown to dark brown, and the patina inhibits contact between oxygen and water, and the base material, hence slowing down further corrosion. However, if a structure is to be built very close above a water body or in close contact with vegetation, weathering steel would be unsuitable. The patina would not be able to develop properly due to the lack of alternating wet and dry periods.

The exact development of weathering steel depends on many factors and is specific to each location. To facilitate the assessment of the material's removal behaviour, corrosivity categories which specify a minimum and maximum rate at which material is removed, can help. For weathering steel and non-alloyed steel, the expected removal rates can be calculated from references in literature for a use of 100 years in the corrosivity categories C2, C3 and C4. The maximum corrosion loss for unprotected weathering steel caused by exposure in corrosivity category C4, is 1.05mm over 100 years and is therefore significantly lower than the maximum calculated corrosion loss of 1.71mm for non-alloyed steel. Recent measurements, however, show a trend towards significantly lower removal rates due to the improvement in air quality, and a lower SO_2 content in recent years ■

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TRUSS TAKES ON TEMPORARY SUPPORTING ROLE

Renovation of the historic Félix-Gabriel-Marchand Bridge in Quebec, Canada is being carried out with the assistance of a temporary modular steel truss sytem supplied by Acrow Bridge.

The Marchand Bridge spans the Coulonge River in Mansfield et Pontefract, a municipality of Western Québec, and was built in 1898. At 152m long and with six spans, it is the world's longest covered bridge carrying road traffic, and one of the longest of all types of covered bridges. It is notable for its unique combination of Town Lattice and queen post trusses. A mainstay of the region's tourism industry, despite ongoing repairs, the bridge had to be closed for safety reasons in May 2014 after a structural evaluation found that it was sinking.

Rehabilitation work on the structure to strengthen it, replace the roof and deteriorated supports, and realign it both vertically and horizontally began in January. Six temporary structures 24.6m long were installed in the summer and are being used to lift the bridge and provide support during the renovation.

Because of the poor state of the covered bridge, installation posed a problem as launching rollers were prohibited for use on the existing floor of the structure. Instead, the floor was opened at the five piers and steel supports installed to receive the rollers. A cable was used to pull the complete assembly of six along the full length of 146.3m. Once the structure was completely launched, pins were removed to create the six spans. Acrow's DS structure is 2.7m wide, which is narrower than the existing bridge, to allow 915mm of space to provide access for workers on each side.

Acrow supplied the rental bridging components to contractor Eurovia Québec Inc working under the direction of the Ministère des Transports du Québec. The design engineer is Cima+.

The temporary support is expected to be in place until the completion of the job, now anticipated for early 2020.

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LIGHTWEIGHT DECK BRINGS NEW LIFE TO OLD CLASSIC

An historic wrought iron bowstring arch-truss bridge in the City of London, Ontario, Canada, has been rehabilitated in a US$8 million project. The 143-year-old Blackfriars Bridge is Ontario's oldest working crossing and its 67m-long bridge deck carries vehicles, cyclists and foot traffic across the north branch of the Thames River. The combination of a concrete deck and modern traffic loads proved too heavy for the historic structure. Dillon Consulting and the City of London selected Composite Advantage's fibre-reinforced polymer Fiberspan deck following research and study of the product's performance on two Ottawa vehicle bridges.

"FRP panels are 80% lighter than reinforced concrete panels," says Composite Advantage president Scott Reeve. "The goal was to preserve as many of the original components as possible such as the structure's arches, lattice work and pedestrian railing. The design flexibility of FRP allowed us to mesh advanced composite material with the original components of the bridge to retain the beauty of the architecture while giving it long-lasting performance."

Design requirements included a design vehicle loading of 75% of CL3-625-ONT with a 1.3 dynamic load allowance and a 0.9 environmental durability factor. Allowable stress design standards and limit state design determined safety factors which were compared to design strain requirements. Traditional beam bending equations were used to analyse Fiberspan deck panels constructed as a series of closely spaced I-beams. Panels met an L/500 deflection and bending strain/shear strain was less than 20% under the service load plus dead load. Minimum fatigue life was rated at 2,000,000 cycles. Panels were designed to a temperature differential of 60°C. The design allows the bridge deck to move independently of steel beams in the longitudinal direction.

The FRP deck was installed on Blackfriars' rehabilitated steel truss. Direct bolting of the 5.3m-wide panels was designed to handle braking loads while connection clips resist uplift and lateral movement of the bridge. Panel widths ranged from 18mm to 23mm thick with a moulded-in crown. Kerbs, integrally moulded into the FRP deck, were covered with 9.5mm-thick 304 stainless steel plates to protect them from wheel impacts and snow ploughs. The FRP deck was given a dark aluminium oxide wear surface. The large prefabricated FRP panels eliminate the labour hours associated with assembling multiple pieces or pouring concrete.

City of London director of roads & transportation, Doug MacRae, says: "We selected FRP decking for the Blackfriars Bridge rehabilitation project for its durability and corrosion-resistant qualities. We wanted a material that would reduce the amount of maintenance work needed once the bridge was reopened to pedestrians, cyclists and motorists."

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