ON THE RISE

Erection of the deck for a new landmark bridge over the Sava River is under way

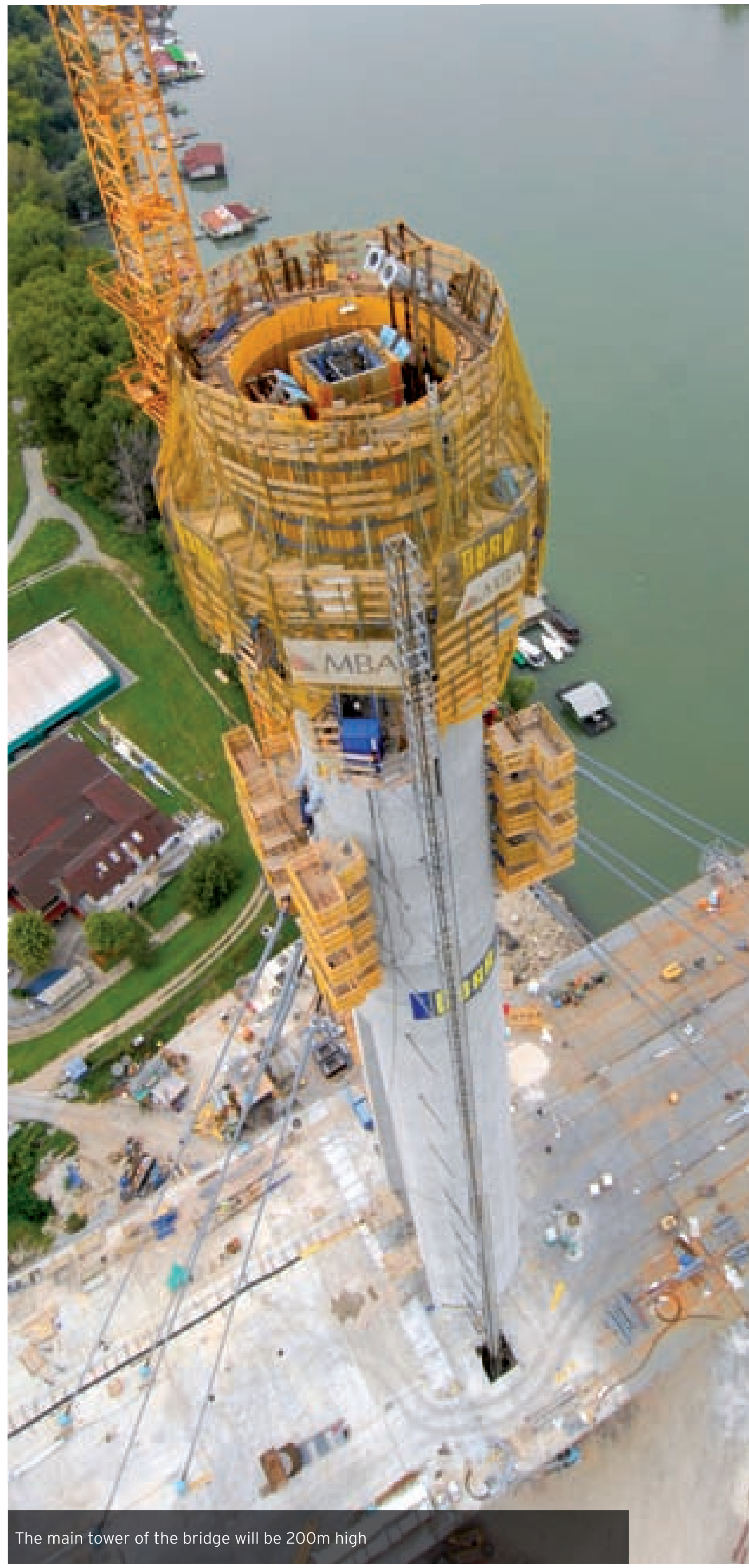
Serbia's capital city, Belgrade, sits at the confluence of the rivers Danube and Sava. The continuing expansion of the city northwards has been significantly constrained by the limited capacity of the existing bridges over the river Sava, creating a bottleneck which has increased traffic congestion in the centre of the city. The new Sava Bridge will form part of a new inner city ring road and crosses the river 4km upstream of the point where it meets the River Danube.

The crossing is intended to create a landmark structure for Serbia, incorporating a needle-shaped tower which rises to a height of 200m. The steel main span is 376m long and is supported by 80 stay cables connected to the tower and counter-balanced by a post-tensioned, reinforced concrete back span of 200m. Meanwhile the approach to New Belgrade is carried on a 338m-long post-tensioned, reinforced concrete side span which has a continuous beam box girder with a deck that is similar to the back span.

The bridge is designed to carry a future two-track LRT metro system as well as six lanes of highway traffic of the Belgrade semi-ring road. According to project consultant Louis Berger senior resident engineer Ray Hawes, a two-tier deck, with highway on the upper and metro on the lower deck was not a viable option.

The vertical clearance required would have resulted in an elevation of the highway deck of more than 24m at the southern abutment, Hawes explains. There is restricted space for connecting ramps on the south bank and such an elevation would have significantly increased construction costs of the approach structures. Instead, the highway and metro system are accommodated on a single deck. This arrangement dictated a minimum trafficked width of 41.2m when considering the addition of cycle paths and walkways, but excluding any additional width required for stay cable anchorages or width of a supporting structure. The final deck width of 44.5m between outer parapets was achieved allowing for the structural elements. This width has resulted in a deck area of more than 16,700m^2, believed to be the largest on the main span of a single mast, asymmetric, cable-stayed bridge. By comparison a standard six lane highway bridge would generally have a deck width of approximately 28m to 29m.

The deck superstructure consists of a central box girder that supports the LRT track and stay cable anchorages. The highway, cycle paths and walkways are supported by cantilevers, propped back by struts to the central box section. The width of 15.7m



The main tower of the bridge will be 200m high for each cantilever has resulted in a 4.75m-deep central box girder in order to limit the angle of the struts that prop the cantilever to 18°. Although this arrangement creates a deeper box section than on bridges of similar width, if required it can be assembled in three sections, says Hawes.

The original concept was that the main and back spans of the main bridge would both be built in structural steel to reduce the loading transmitted to the stay cables, mast and foundations and reduce material and construction costs. However the successful designer/contractor demonstrated that the asymmetric design favoured a back span of post-tensioned, reinforced concrete – the weight of the concrete creates a more balanced structural system and reduces the uplift forces on the southern abutment.

The overall length of the seven-span continuous bridge deck is 964m. The deck of the main span has been designed as a structural steel box girder of 4.75m overall depth, built using the free cantilever method across the River Sava, 20m above water level. The back span and side span prestressed concrete decks are installed using the incremental launching method.

The seven piers are founded on deep bored piles of 1.5m diameter, approximately 30m long. The tower is supported by a foundation designed as a composite deep pile footing, within a cylindrical diaphragm wall 36m diameter and 37m deep with a central core consisting of a grid consisting of 113 concrete piles of similar depth. This design offers optimum economy whilst ensuring the stability of the supported structure.

The preliminary design was carried out in 2006 by consultants Ponting, DDC and CPV, whose team won the international competition to design the bridge. The load of the 376m-long main span is transferred via 40 twin cables to the tower and then down to the 200m-long back span. The main span is structural steel in order to minimise its weight and this in turn is balanced by the shorter concrete back span. On the south side one end span extends the bridge to the connection to the approach ramps. On the north side the side span consists of four spans of 70m, 108m, 80m, 80m and construction is similar to that of the back span, being post-tensioned, reinforced concrete. The deck is fixed at the tower pier table.

The external dimensions of the deck superstructure are carried through the full length of the bridge despite the use of two different construction materials. The deck slab is supported by a hollow box girder 14.5m wide and 4.8m high and the outer 15.3m-wide cantilever slabs are supported every 4m by inclined struts. To distribute the stay cable forces a triple-cell hollow box is used. This 45m-wide deck will carry six traffic lanes and a double track light rail line, as well as two paths for pedestrians and cyclists.

In April 2008 the design-build contract was awarded to Ogranak Sava Most, a consortium of contractors Porr, DSD und SCT. Porr is technical and commercial coordinator of the consortium, being responsible for the construction of all piled foundation works, substructure and superstructure of the back span, tower and installation of the bridge stay cables. DSD is responsible for the supply and erection of the structural steel for the main span while SCT will build the side span and supply reinforcing steel for the tower concrete and all ancillary works. The detailed design of the superstructure of the bridge and side span is being carried out by Leonhardt, Andrä & Partners, while design of foundations is the responsibility of Porr's geotechnical division.

"The critical path incorporated those milestones which affected the start of the free cantilever."

The design and construction project is being administered by Louis Berger Group, appointed as project manager and engineer in association with Serbian consultant Eurogardi Group. Site inspections are being carried out by Institute Kirilo Savic of Belgrade.

The post-tensioned concrete structure of the back span, over Cukaricki Bay

Site work began in April 2009, following a period of extensive geotechnical investigations of subsoil conditions and testing and approvals of materials. One particular stipulation for the construction of the bridge is that the main span across the Sava River must be built without any temporary supports in the river. This constraint led to the use of the free cantilever method for construction of the deck, using the stay cables for support and keeping the navigation channel unobstructed.

Hence the critical path work incorporates milestones which affect the start of the free cantilever; the tower must reach a minimum height of 130m and the back span must be connected to the tower through the pier table together with the completion of the construction of the composite transition segment of the deck that creates the interface between the different forms of deck construction.

The side span is being built independently of the main bridge and at the same time as the main span. Following the completion of the link between the two structures, pavement and finishing works can be completed. The post-tensioned concrete structure of the back span crosses Cukaricki Bay, a former channel of the River Sava. It is being constructed on an elevated casting yard at a height of approximately 20m behind pier 7 in segments with length of 18m. From there it is launched towards the tower using three temporary braced piers over a distance of 50m - launching began in late 2009.

Due to the exceptional size of the deck the fabrication area was divided in three sections. In the rear section the bottom plate is cast, while in middle section the 4.75m-deep triple box is poured with the stay cable anchorages already installed. The cross-section of the superstructure consists of a 45m-wide transverse post-tensioned cantilever deck with a central triple-cell concrete box girder with cantilevers supported by steel struts. This arrangement of segments on the launching platform allows construction to proceed simultaneously on three sections of deck segments, reducing construction time.

In the final operation, which took place in July, 20,000t of deck 200m long had to be launched. Two sets of hydraulic jacks located underneath the four webs were used to raise and push the structure.

Bridge closure was carried out on the scaffolding at the pier table to achieve the required fixed connection to the tower and further structure. The auxiliary piers will be dismantled once the main span has been completed and the stay cables are installed.

The 200m-tall conical concrete tower is intended to create a dramatic landmark for the Serbian capital – and it was intended to enhance the elegance of the viaduct.


Deck erection on the main span of the bridge

The lower part bisects, forming two legs which penetrate the deck between the highway lanes and the light rail track. These legs meet at a height of 98m above which they continue in a single circular shaft in which the stays are anchored. The formwork has been designed to deal with the continuously-changing radius of the cone which reduces from 16m at the foundation pier cap to 4m radius at a height of 175m. The upper 25m of the tower will be structural steel with a stainless steel cladding. One tower leg is equipped with a service elevator located in a shaft; the other leg houses emergency stairs.

Construction of the tower is being carried out using self-climbing formwork; five lifts of 4.4m complete each leg up to the bridge deck level, after which a further 34 lifts of 4.6m bring the legs up to a height of 175m.

The designers of the travelling formwork had to accommodate the continually-reducing outer radius of the circular or partial circular cross-section of the structure from 30m at the base to 4.5m at the junction of the concrete and steel finial, 175m above. The formwork had to be self-climbing with anchors to support the structural frame embedded in previously-cast sections. The forms have been designed such that panels can be cut after each casting to create a regular and uniform surface across the full height of the mast.

The tapering cross-section of the upper section of the mast also presented a challenge to the design engineers due to the higher stay cable forces and longer stays it created. The mast is therefore constructed with three different strength grades of concrete; the lower section with grade 55, the central section with grade 60 and the upper section with grade 67. The use of the highest grade concrete challenged the mix designers and possibly reached the limiting strength of the locally-available materials including river gravels, whose limiting factor is the bond between the aggregates and cement matrix due to the polished nature of their smooth surfaces.

To reduce construction time the two tower legs were built through the pier table section following the cross-section of the tower. The pier table was built on heavy falsework and connected to the tower legs by reinforcing couplers and post-tensioning tendons. At a height of 98m the two sets of formwork were merged into a single unit, this took place at the end of June – three compression struts support the legs up to this point.

The upper 25m of the tower has a stainless steel tip supported by a structural steel frame, terminating at a height of 200m with a diameter of 1.5m. The cone end has no structural function but is designed to increase the height and elegance of the tower. It will also be the highest structure in Belgrade and needs to have appropriate earthing to protect it from lightning strikes. The concrete section of the tower is expected to be finished by the end of 2010, and erection of the steel tip is scheduled for summer 2011.

A total of 8,600t of high quality steel grade S355J2+N is required for the main span of the bridge; components are fabricated in China and delivered in transportable units of maximum length 17m, height 2.6m, width 4.1m and weight 41.4t. They are brought from China by sea to Rotterdam, then by river barge via the Rhine-Main-Danube route to the assembly yard close to the bridge site in Belgrade.

One of the challenges for the project was deciding what size of structural steel deck segments was appropriate in order to build the main span in the shortest possible time. Considering this, as well as the fact that the stay cables are anchored at 8m centres, led the contractor to choose a segment 16m wide and with a maximum weight approaching 400t. Originally the contractor had proposed transporting and lifting units weighing a maximum of 40t, but due to high risks and general time constraints finally opted to assemble full 44.5m by 16m segments at the yard on the north bank of the main river channel and transport them to the leading edge of the deck cantilever.

This decision created another challenge – the transportation of such large objects from the assembly yard to the barge, which itself had to be large enough to carry the segments. Constant and unpredictable fluctuations in river levels of more than 5m also had to be considered and influenced the contractor's selection of transport.

Special heavy-load transport devices are used to move the deck sections on to pontoons to take them 500m up the Sava River. A derrick crane is used to lift up the four sections which form each 16m-long segment – this dimension is determined by the separation of the stay cable anchors. After lifting, adjusting and welding to the cantilevered deck the weight of the new deck section is transferred to the back span via the tower by two pairs of stays before work continue on the next section. Predicted cycle time for each of the 19 segments in the main span is approximately 21 days and closure of the deck is currently scheduled to take place in September 2011.

Final transition of reaction forces from steel main span to concrete pier table is achieved by a transition segment of composite design, using post-tensioned tendons and shear studs.

The stay cables are formed from compacted bundles of parallel seven-wire strand steel cables. The outer diameter of the covering HDPE pipes finished in a silver grey colour will vary from 200mm to 280mm depending on the number of strands enclosed. In total 1,280t of high grade steel is used for the 80 cables which have up to 91 strands and are up to 372m long. Installation of the stay cables began in August.

Once the launch of the back span is complete, the hydraulic equipment and steel launching nose were relocated for use on the side span and the first launch took place at the end of September. The casting yard is positioned between the first two spans; to reduce the span during the 36 launches, temporary piers have been built between the permanent piers. The bridge deck is designed as a single-cell hollow box girder with primary post-tensioned tendons for launching and secondary draped tendons within the web to achieve final spans of 70m, 108m, 80m and 80m. They are stressed after launching in order to allow the removal of the temporary piers. The camber of the largest span provides a particular challenge, and specially designed camber beams have been developed for this launch.

At pier five the steel nose will be dismantled and a steel connection element will be attached to the leading edge. During this operation the last span will be poured at the following edge with an extended cantilever slab to connect the approach roads.

The bridge is intended to be open to traffic by the end of 2011

> "Three temporary compression struts support the tower legs up to the point where they join."