The machines are designed without internal obstructions to allow reinforcement cages to be fixed off site and handled in by the gantry crane

STRETCHING THE LIMIT

Contractors building a new high-speed rail link in Turkey are using movable scaffold systems to make light work of a series of viaducts near Ankara. **Helena Russell** reports from the site

Four viaducts with a total length of more than 6km are being built across the valleys on the outskirts of Ankara as part of a high-speed rail link that is intended to connect the Turkish capital with the city of Sivas. The line is being built in seven different sections, and these four structures, which are under construction by contractor Doğus, form part of the 74km-long section between Ankara and Kirikkale.

The Ankara-Sivas route is one of three high-speed rail links currently being built in Turkey; when these are all completed, the country will have a total of five high-speed rail routes. The first high-speed route to start construction was the one linking Istanbul and Ankara, and this came into operation in 2014, although trains still only run to Pendik, with the final connection into Istanbul city centre not expected to be completed until 2018 at the earliest. The line from Ankara to Konya started operation in 2011, cutting travel time between the two cities from more than ten hours to just 90 minutes. The three lines that are currently under construction will eventually connect the Turkish capital to the cities of Sivas, Izmir and Bursa. This programme of expansion is the responsibility of TCDD, the Turkish railway authority,

In total, the high-speed railway link between Ankara and Sivas is a substantial undertaking, demanding the construction of 460km of new line. The Ankara-Kirikkale section alone has 13 viaducts, of which the four that are being built with the movable scaffolding systems are the tallest and longest. The structures are designed to carry trains travelling at 250km/h, with 300km/h as the ultimate design speed, and there will be two railway tracks, one for each direction.

When bids were invited for the construction of the four concrete viaducts the designers anticipated that balanced-cantilever construction would be used to build them. But main bridge contractor Doğus and its deck subcontractor Kappa proposed an alternative construction method, using Berd's MSS with organic prestressing system, which they demonstrated would cut the amount of concrete and reinforcement almost by half over the four structures. Savings not only come from the ability to make the deck construction more slender, but also from the consequent reduction in the pier dimensions, piles and foundations needed to support the superstructure and the machine itself.

There are also other benefits – in a region such as this, which is prone to earthquakes, a structure with lighter spans will have a less severe response to seismic loading. The increased safety of working within an enclosed machine, especially at heights of 80m, and the improvements in quality and accuracy of construction are also worth mentioning.

After some discussion the proposed alternative was accepted by the client, and the contract was awarded to Doğus, although the subsequent step of redesigning the viaduct to optimise use of the new construction method and enable it to be even more efficient was not taken on board by TCDD. Optimisation of span lengths might have increased the material savings and reduced the construction programme but the client opted to retain the span layout that had already been established.

While similar in some respects, the four structures differ in span configuration, height and length; three of them are located very close together on the longitudinal alignment, while the fourth is somewhat distant, with a 4km-long tunnel on the line between it and the others. All four viaducts have maximum spans of 90m, some as many as 13 of this length, while the remaining spans are between 37m and 50m long.

The longest of the four viaducts is the closest to Ankara on the line; dubbed V7 it is 1.8km long and almost 54m high with spans ranging from 42m to 90m. The next of the group, V9, is almost as long but higher, reaching 65m in height and with a similar span range. V10 is just over 1.5km in length but the highest of the four, at 88.6m, and the one that features 13 of the 90m-long spans. Viaduct V15 sits some way distant, and is just 1.4km long and approximately 65m high.

Two machines designed and manufactured by Berd are being used to build the four viaducts, with the logistics of four separate construction sites demanding some careful programming.

Added to this, the main contractor is responsible for the foundation and concrete substructure construction, with Kappa coming along afterwards to build the concrete box girder deck.

The machines that Berd has designed and manufactured specifically for this job are the M55-S and the M1-90-S; both are movable scaffold systems with overhead equipment, and with gantry cranes inside for ease of operation. They have Berd's patented Organic Prestressing System integrated in the machine, which is a form of active prestressing which comes into operation during the concrete pouring, and enables construction of more slender spans than can be built using traditional launching gantries or similar construction methods.

The spans of 49.5m and longer have a deeper box girder cross-section of 5m compared to the shallower section of the shorter ones which is just 2.6m deep. The typical span construction for the M55-S is 45m, but the M1-90-S has been designed to stretch Berd's system beyond anything it has previously built; it is capable of constructing spans ranging between 50m and a full 90m.

Before work started on this project, the longest span built using Berd's MSS was considerably shorter than this record, at 70m, and it was achieved on projects in Spain and Slovakia. However, the company has always been confident that the system could be adapted to even longer spans, and was keen to demonstrate it on this project. In the right conditions, the machine is designed to achieve a 14-day construction cycle per 90m span, with certain procedures and operations being optimised especially to achieve this. For example the formwork is opened using an electrically-driven system rather than the traditional hydraulic operation, opening horizontally like a set of drawers instead of opening out below the deck; the electric system is faster and speeds up the work.

At the moment, at its current location at V15, the cycle time of the machine is much longer than the optimum, admits Kappa civil engineer Murat Kutay, but they hope to improve within the next couple of months and are keen to achieve faster cycle times.

Not all of the options for speeding up the process are being fully exploited at the moment – the M1-90-S equipment is designed to straddle the deck fully, leaving the inside clear of all obstructions to enable reinforcement cages to be fixed offline, brought in ready-assembled and lowered straight into the formwork. Two gantry cranes are provided within the MSS framework for this purpose, and to assist with other parts of the process, such as during the launching to the next span. At the moment the contractor has opted to fix the reinforcement in situ, which lengthens the overall cycle.

Viaduct V15 crosses the Red River, named so because of the colour of the clay that is naturally present here. The 1.5m-diameter concrete piles that Doğus installs below the piers vary from 20m to 40m in length, with ground conditions being similarly variable between soft clay and hard rock. Construction of the concrete piers, which is achieved using climbing formwork in 3m steps, started on this viaduct in 2015. The assembly of the machines was originally scheduled to begin in July the same year, but the extended period of discussion that was needed to agree the change in construction method meant that this was delayed by some months.

In the construction method originally proposed in the tender documents, the pier top segment would have been built by the superstructure contractor, but with the move to the MSS construction method, main contractor Doğus has to build the pier top segment as well, ahead of the arrival of the MSS equipment. This is slow and complex construction, reveals Doğus project manager Erkan Hanefi Hakan, and each one takes around a month to complete.

The big machine is scheduled to build the full length of viaduct V15 before being dismantled, packed up and transported to the next viaduct where it will be used to build the larger spans. Initial assembly after delivery to the V15 site took three

The contractors' alternative proposal was to use movable scaffolding systems

The construction of each pier top segment takes around a month


It is the first time Berd's MSS has been used on 90m-long spans

months so the relocation is expected to be a lengthy process, although Kutay believes it can be achieved within two months as the machine does not have to be dismantled right back down to its smallest components before it can be moved.

The concreting of the box girder is done as a single span, but in two stages. First the U-shaped lower section is poured, with the slab being poured in the subsequent stage after placing of the upper formwork and reinforcement. The biggest pour on the structure is the U-section of the 90m span, which requires some 700m^3 of C60 concrete. The slab of the same span requires an additional 500m^3 of concrete, so a total of around 1,200m^3. Three pumps and three distributor systems are used for the concreting procedure, the largest of which takes about 18 hours to complete.

Kutay explains that concrete supply can be an issue due to the remote nature of the site. The main site compound and concrete batching plant is about 40km away by road, so the contractors have to rely on a combination of local suppliers and deliveries from the main compound.

Even once the concrete reaches the site, the logistics of delivery to the work front are complicated. At less than 13m wide, the bridge deck affords limited space for multiple concrete wagons to reach the work front, not to mention manoeuvring and exiting the span once the material has been delivered. "It's narrow and it already has lots of stuff stored on it," admits Kutay, "so it's not ideal. We do want to try and get to a delivery rate of 50m^3 per hour, which would enable us to complete the deck slab pour in about 14 hours."

The site also suffers a wide range of temperature variation, going as low as -25°C in the winter and as high as 40°C in the summer. Concreting continues in all weathers, with a steam-curing system in use to ensure that the curing is fully controlled. Post-tensioning, which takes the form of 14 tendons on the longest spans, takes around 12 hours to complete, after which the machine is readied for launching to the next span.

Both machines being used on the site are overhead rather than underslung versions of the movable scaffolding system. Having the equipment overhead offers specific advantages for contractors depending on the type of structure and the local terrain of the bridge under construction. When the viaduct to be built has a tight curve on plan, taking the equipment overhead rather than underslung prevents it from clashing with the piers as it navigates the corners. Likewise if the assembly location and initial spans are low to the ground, there may well not be any space to accommodate underslung equipment. In terms of cost the underslung option may be cheaper, but this depends on many variables, not just on the position of the equipment.

While the big machine is scheduled for use on all four viaducts, the smaller M55-S will only be required on two of them. When *Bd&e* visited the site at the beginning of April, the M55-S was hard at work on the longest of the four viaducts, V7, where it was building 45m-long spans in cycle times of around ten days. This represents a considerable improvement from the first span, which took 20 days to build, with nine or ten days being the optimum cycle time this equipment can achieve on this size of span. With this equipment, the largest concrete pour is 450m^3 for the deck slab on the 45m span. The larger machine, which is currently at work on V15 and had just started construction of its eighth span when *Bd&e* visited, is due to arrive at the V7 viaduct by the end of the year where it will build about ten of the longer and deeper spans.

Construction progress varies across the four sites, with foundation work still under way on V10 viaduct, but by the end of this year, Hakan is confident that all the pier construction will be completed and the work remaining to be done will be the deck construction. Currently the plan is to complete the US$85 million contract for the four viaducts by the end of 2018


Berd's huge M1-90-S has been designed to cast 90m spans in situ and can achieve a cycle time of 14 days per span in the right conditions