CROSSRAIL'S DRILLING RIG

Crossrail is using a bespoke automated drilling rig for boring service connection holes, and fit out contractor ATC says that the investment has already paid off

Below: The rig was designed and built by Rowa

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WHEN CROSSRAIL COMPLETED ITS epic tunnel boring efforts in June 2015 it took the project from one major stage of construction to another. With the two 21km, twin tube, 6.2m diameter tunnels in place the Alstom, TSO and Costain (ATC) joint venture could push ahead with its challenging GBP 300M (USD 376M)

Designing the rig

One piece of work, explains Rowa's Alberto Belloli, was to bring everyone together within the joint venture and the design team of Crossrail and eventually freeze their needs to be able to say "this is the final position of those fixing and this is the number of combinations that you could be confronted with".

The second big topic was then to ensure the data flow starting from the digital model of the finished tunnel lining. "You leave the comfort zone where you have an ideal model and can assume at any point that you will be at the right point to drill now you get confronted with reality and have to fit that into your model." The team are matching their needs with the digital model of the tunnel and coming up with updated drilling files.

Defining the syntax was the third area. This is the formal aspect of that information so that the machine could handle that and also took a number of weeks. The software is quite complex and the original concept was to have a global station with an operator following the machine on site telling the machine how to align itself. A decision was taken jointly with ATC and Rowa to reject the idea to have that global station and operator on site every day for 10 hours a day and have something based on the input data, with the rig aligning itself automatically after every repositioning.

"Fourth we had to consider the dual mode of operation. Enabling the machine to run on rails and road and cope with inclines of 4 per cent." Finally a key challenge was finding a way to have a fairly sophisticated piece of equipment that can cope with all of the requirements, provide all that information for example track back whether a hole has been drilled or not. At the same time we are still in a tunnelling environment and need simple intuitive way of operation and clear instruction. This makes it a big challenge to find a machine that is a true innovation, which pushes the boundary of what is feasible further. At the same time it has to be robust and suitable for the harsh environment in tunnels.

fit out contract. But in order to fit the services including overhead power lines, the cable management system, emergency walkways, firefighting system and electrical cables, ATC needed to drill a lot of holes - more than 250,000 to be precise. And in typical Crossrail style the contractor looked for new, more efficient technologies to accelerate the process, resulting in the creation of a bespoke automated tunnel drilling machine.

"When you do this manually you need two teams. One that goes ahead and marks out where the holes go and another actually drilling them and putting the brackets in, so with this we have eliminated a whole team of people," explains Tim Kelly, lead engineer at ATC for the automated tunnel drilling machine. "And it is not just about the people. This is a much more streamlined process. It consolidates the surveying activity into the drilling activity and from a health and safety perspective the risk is as low as reasonably practicable."

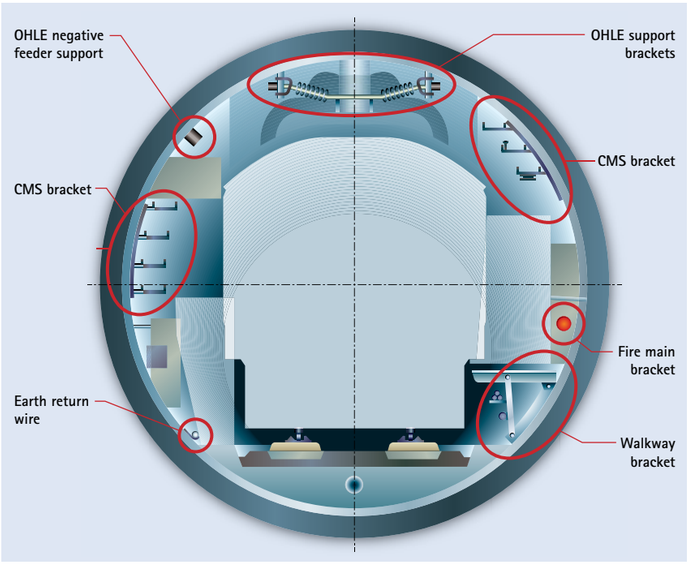
Manufactured by Switzerland's Rowa with drills from Hilti, the automated drilling rig has sophisticated software that allows it to read the data that tells its hydraulically operated arms where to place the drill holes. Operators can check this on the control panel. This data originates from a 3D scan of the tunnel taken a couple of weeks before the rig is scheduled to drill each section. "From that scan they take out key locations on the tunnel in a coordinate system and we take that data and convert that with a computer programme into the drilling locations. That data is then collated and checked before it is inputted into the machine so that it knows where it needs to go," explains Kelly.

When the machine is ready to start drilling, targets are placed onto the reference points on the tunnel and the rig uses laser guidance to determine its position, using the tunnels centre line and a guide roller either side of the rig as equalisation points. "Once you have done that the system is automated, it sets the arms, it rotates up or down to the correct angle, it sets a reference point for the drill and it drills 135mm or 150mm whatever it is set to on every hole," he says.

Each rig, and there are two on the project, has four operators and a traffic light system is in use to ensure that drilling takes place exactly where it is supposed to. A red light indicates that the drill is more than 250mm away from the target and amber and green indicate that it is closer or on target.

"In the best case scenario for rig one, which drills more holes, we target at 250m/d and we generally achieve 200-250," says Jonathan Cox, M&E tunnels team leader for ATC. "The factors that stop it achieving that might be how far the guys have to walk to get to it and if they are coming in on a train and there

Below: ***Cross section of the tunnel showing various brackets***



Above: ***Two Rowa rigs were used to drill the array of more than 250,000 holes required for services on the project***

are knock on effects from other activities or if it is on a steep cant where the inclination and curvature of the tunnel are at a maximum then it is harder for the machine to find its alignment – it finds it but it takes more time," he says.

Rig one is responsible for installing holes along the sides of the tunnel, typically around 16. A second rig is responsible for drilling the holes for installation of overhead lines, which sit vertically above the tunnel along the crown.

DUAL MODE

For most of the project the rigs have run along the rails of the Crossrail tunnels but it also has another operating mode giving it more flexibility. "The machine can run on tyres and rail. It is a very clever piece of kit," says Gregg Purcell, railway systems construction manager for Crossrail. "It is totally flexible. It is a lot easier on the track, on the rubbers it is a slightly harder configuration to work with."

Slightly harder because driving it along the road makes it more difficult in terms of maintaining alignment meaning that average progress here was around 200m/d rather than 250m/d. But the team maintain that this option was vital in terms of maintaining productivity. "It was a big benefit to the programme because we were able to get in and put brackets on before the concrete train and all the sleepers and everything came in so we did some quite good acceleration of the programme by coming in from the Pudding Mill Lane branch down to Stepney in the eastbound [tunnel] with the drilling rig," says Cox.

For manufacturer Rowa these operational requirements were not easy to accomplish. To be dual mode the axles had to be much wider than those of a track mounted machine and the underlying steel structure had to be analysed to ensure that it could withstand the induced stresses.

At the same time the tunnels are not perfectly flat. "The difficult part is that Crossrail has a critical inclination of 4 per cent that we had to take into account for dimensioning," explains Alberto Belloli, managing director of Rowa. "In the end it was a matter of selecting the proper drive solution. We ended up with hydraulic drives and we had both axles equipped with a drive and brakes.

"You could say that we doubled the installation or installed breaking power and drive compared to the requirements so that if one of those systems breaks down you still have the other one and you can work in a reduced mode or at least safely shut down the machine without losing control."

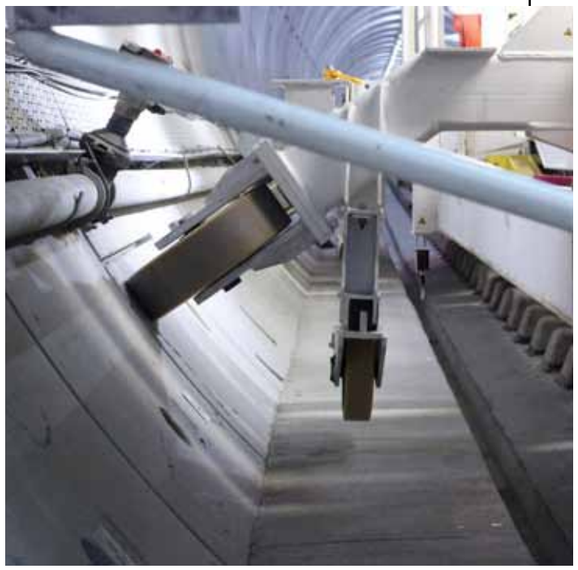
DUST STRATEGY

Another key challenge for the contractor has been related to the drill bits and dust removal strategy. "Hilti came up with a really innovative solution, which was represented by hollow drill bits and then a vacuum connected to the drill bit with an adaptor sucking out the dust directly within the hole, which is of course the optimum solution for leaving a clean hole behind and reducing wear," says Belloli.

However as drilling got underway it became apparent that a change of strategy was required. "The segments had steel fibres in them so what was happening was they were wearing the hollow drill bits down very quickly and it didn't become cost effective to go ahead with this solution," says Rick Flora, manager for Hilti UK. "So what we did was provide them with high end drill bits [the TE-CX carbide bits] and then designed a new bespoke dust extraction system for them to go with the equipment that they already had."

This was carried out in just four weeks at Hilti's Kaufering facility at a cost of around EUR 100,000 (108,000). "Priority number one was to come up with another bespoke solution for the dust. This was the first time that we have ever made something outside of our portfolio and to turn it around in four weeks was pretty good going," says Flora. "We had a good relationship with ATC and Rowa so that helped a lot. We swallowed 100 per cent of the cost, we didn't cross charge anyone for this. It was very important to do, because of the nature of the project."

Below: ***The machine was bespoke for the Crossrail project***



team, which is something that Cox would do differently on future projects.

"I'd make sure that the guy writing the programming would be onsite all the time and there would be more responsibility on them. You could still have supply of the machine separately but the operation and supply of the data I'd try to tie those contracts together so that there weren't people waiting for someone else who isn't part of the same cycle."

Another issue that the team must contend with is a clash between placement of platform screen doors and the rig. Once the doors are installed the rig cannot be moved past them as they reduce the tunnel diameter. "We'd like to do the rest of the tunnels with the rig but as more of the screen doors go in we get limited in our exit points and it is likely that we will do another 8 or 9km with the rigs," says Kelly.

FUTURE POTENTIAL

With this being the first time a rig like this has been used in the UK there are naturally some operational lessons that the team has learned from the experience. "When we specified the machine there was a lot more space in the programme, where there wasn't something trying to work in front of the drill rig, but now the programme is more congested," says Cox. This means that other work vehicles such as the concrete train might need to pass the drill rig on a daily basis and so the drill team have to move the rig in and out losing valuable time. "Wherever we can we leave it parked in the tunnel and the next crew come and start exactly where it left off."

By leaving the arms folded down in the deployed configuration the drill team ensure there is no loss of start-up time. But this became compromised by the need for other rail operations meaning that the machine had to be closed down and driven in and out. "We did look at trying to make the braking system compatible with a loco [motive] so that it could be towed in and out but it was too late as the brakes were not compatible. That would be a change we would recommend for future drilling machines – to be sure you can move it quickly in and out," says Cox.

The solution was successful and by December the team had drilled 25km of tunnels and according to ATC justified its worth as an investment. The progress record so far sits at 800m achieved over a weekend. "I'd say as a start-up machine developed for this purpose it has gone very successfully.

"We don't have major issues with the procedure or how it operates, it is just little issues and bugs that we are trying to iron out occasionally as the operation moves forward," says Kelly.

One of the "little bugs" is the occasional need to double check the data files or ask for software support from Rowa in Switzerland.

"The guys on the rig are very capable operators who come from a plant background but quite often it is to do with the dataset that is prepared. That data is prepared by a programmer who is a sub-contractor to ATC," says Cox, noting that this means that the sub-contractor is not always working according to the same cycles as the drill

Above: ***Crews rated the performance of the machine very highly***

Right: ***Record progress was 800m over a single weekend***

Belloli says that this is something that could be changed for future rigs. "If we were to develop the equipment once again, there certainly are a number of features we could design in a slightly different manner. Among these, the capability of folding and unfolding the machine in shorter time and a higher travel speed for the self-propelled mode. This would respond even better to the changed requirements of the contractor, and address aspects regarded as marginal while specifying the requirements, which however turned out to be relevant during operation."

BIG MOVE

By far the biggest move that the machine has had to undertake is moving it from the factory in Switzerland to the Crossrail project in London. Despite the well-planned operation there were a few challenges to overcome. "Originally we planned to disassemble the rigs in parts, which had to be as big as possible so that you didn't have a lot of time to reassemble," says Belloli. But due to time constraints and the limitations on site in terms of facilities, lifting devices and expertise it was decided to transport it in one piece. With a total weight of just under 40t, that one piece was heavier than the initial estimate.

"If you are heavier than expected you need to integrate your trailer with additional axles and this is the easy part," says Belloli. "There is then the bureaucratic part. A heavier truck needs new permissions and the paperwork can be quite time consuming."

At the same time Paris was hit by a series of terror attacks in mid-November 2015 meaning that border forces had other priorities to deal with. Despite this Crossrail had its rig within 10 days. "I think it paid off because everything we considered and fixed at the workshop was still intact when it came onsite. I would adopt the same approach again, fixing everything at the workshop and moving it in one piece and then organise the transportation the same way as Crossrail."

But Belloli points out that this might not be possible depending on the dimensions of the tunnel using the rig.

Looking ahead all parties see the potential for automated drilling on future projects. "For productivity, health and safety,

Both: ***Work to fit brackets to the tunnel lining***

the quality of the work, quality control, whenever the size of the project allows it should be the method of choice," says Belloli. "Within the metro size works we could even image a piece of equipment which is reusable."

"We have expectations that it will be used again in the future," agrees Flora pointing to projects in France, Dubai and Denmark. And Rowa too says it has had requests from continental Europe, Australia and Hong Kong.

However the ATC team point out that prefabricating the segments with the drilled holes included would be a more efficient option once on site if challenges around positional issues and the cost of doing this can be mitigated.

"I think that in the situation that we were in where there was nothing cast in to the segments then it is the way to go," says Cox. "But if you look at a project holistically casting some dowels or receiver sockets or something of that nature into the sockets means that you don't need to drill any holes"