LAI CHI KOK – a slurry drive through rock

Contractors on Hong Kong's Lai Chi Kok flood relief tunnel have just completed a slurry TBM drive entirely through hard rock. TJ editor, Tris Thomas visited the site to see how the team and the machine coped

Lai Chi Kok Fact File

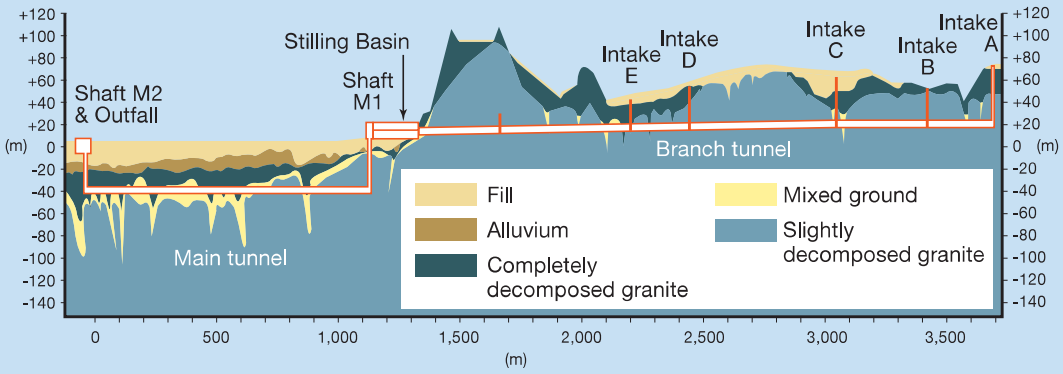
Project Title: Lai Chi Kok Drainage Tunnel
Client: Drainage Services Department
Contractor: Leighton – John Holland JV
Consultant: AECOM Asia
Original Cost Estimate: HK$1.7bn
Contract: Design and Build
Geology: Granite, Mixed Ground of Soil and Rock
Scope: 2.3km TBM driven tunnel (Branch Tunnel in Granite: 2.4km, Main Tunnel through Mixed Ground: 1.1km); 6 x Intakes
TBM: Herrenknecht Mixshield (Diameter: 5.65m)
Lining: Five piece pre-cast segmental ring plus key
Contract Commences: November 2008
Contract Completion: 2012

ALTHOUGH REFERRED TO in the 'singular' as the Lai Chi Kok Drainage Tunnel, the US$220M, 3.7km long, 4.9m i.d flood relief project currently being built for Hong Kong's Drainage Services Department, consists of two very different tunnels – the 2.4km long Branch Tunnel, a rock drive through slightly decomposed very strong granites, and the 1.2km Main Tunnel, a highly complex mixed ground drive through rock and soil under pressures of up to 4.2bar.

What is of real interest though, is the fact that the design and build contractor, the Leighton-John Holland JV, is using a single 5.71m diameter Herrenknecht Mixshield to construct both, with the machine boring the mixed ground and the hard rock drive entirely in closed face slurry mode.

Although the option was given in the tender documents to use two machines, with the rock Branch Tunnel allowed to be constructed in open or closed mode – as long as there was a concrete lining - the JV proposed, and had accepted the single machine solution. The use of an open shield TBM on the Branch Tunnel would have

Figure 1: Longitudinal section of the Lai Chi Kok Drainage Tunnel



Left: Project Manager Piers Verman displays two of the blocks that entered the pump

Far left: The Herrenknecht Mixshield about to be launched at Shaft M1 on the hard rock Branch Tunnel drive in March 2010

Bottom left: Partial view of the cutterhead from inside the shield

Above: View of the cutterface during a free air intervention

required continuous probing and pre-excavation grouting along the full alignment.

Although using a single TBM placed both tunnels on the critical path, DSD accepted the financial benefits of doing so, and the contractor's reassurance that a suitably configured machine would more than cope with the vastly differing ground conditions on the two bores, separated by the surface Stilling Basin and TBM launch shaft at M1.

"We had looked at using a dual mode machine for the Branch and closed for the Main Tunnel which would have driven us towards a dual mode EPB for the first drive and full EPB for the second, but a medium sized diameter machine like this would have been hard and time consuming to convert within the Branch Tunnel drive. We wanted to use slurry on the second drive so that was the option we took for both drives," explains Piers Verman, Project Manager for Leighton Contractors (Asia) Limited.

Although plenty of slurry drives have encountered rock for say, 250m along a 4km long soft ground drive, Verman noted there is a lack of information available on TBMs set up purely in slurry mode for drives predominately through hard rock, in Lai Chi Kok's case with strengths over 200MPa.

"It is very unusual," he says, "when we talked to the Client's consultant, AECOM, about the machine design, they asked Herrenknecht for a list of references where it has been done before, but we didn't get a lot of response. There just doesn't seem to be the information out there."

With the recent Branch Tunnel breakthrough on the 18th January after just over 10 months boring, the decision looks to have more than paid off - although there have been one or two problems along the way.

The Branch Tunnel Drive

The machine was launched in early March last year, with the shield fully assembled and four of the eight backup gantries connected providing essential services for tunnelling. The remaining four gantries, including the slurry pipe telescopes and 2 x 10 man refuge chambers were added after 70m of tunnelling.

A 37m launch chamber excavated with canopy tubes, steel sets and shotcrete through completely decomposed granite and mixed ground allowed the TBM to start in full face rock. The teams built some 22 rings in the launch chamber without the cutterhead actually on the face, relying on the friction of the shield and back-up force, and the initial use of chocks in front to build up more resistance. "The actual ring build in the launch chamber was good," reports Verman, "that was the bit I was always concerned about. With lower ring build pressures you don't always compress your gaskets, but it worked out well."

With the'learning curve' flattening out, the JV found itself making good headway as the teams got used to the TBM.

"We didn't have too many dramas, sometimes you can build the machine and you're always chasing something, but it was good from the start," says Verman.

Unfortunately, within some 70m, a basalt dyke, extremely strong and blocky, was to cause some serious issues. "We had very little thrust load, and if we pushed too hard it would all just come in and block the stone crusher," he says. The fractured nature of the ground was to result in blocks, each some 200mm across, coming through the crusher – all at the same time – and into the pump, blocking the inlet.

"Our crusher has a 150x150mm grid on it, so it's about 212mm across the diagonal.

Noise and vibration

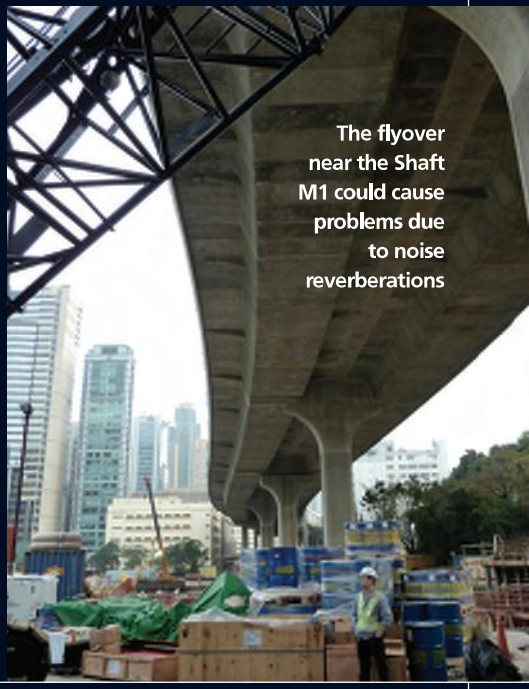
As with anywhere in Hong Kong, noise and vibration is a serious concern for any tunnelling project. And this has proved the case at Lai Chi Kok.

The project couldn't get a construction noise permit from the Environmental Protection Department for the whole drive in one go, these have been issued step by step and required the team to carry out near constant monitoring in each section. Airborne Noise is allowable to 70db until 11pm, and then from 11pm to 7am this reduces to 55db, with the ground bourne noise 10db less for each period.

"Early on we had to do a lot of checks to show we weren't exceeding the limits. We did these from 10.45pm to 11pm, and then from 11pm to 11.15pm."

The results have required the teams to switch off some plant at 11pm, the calculations show they can't operate an excavator so handling muck was out of the question.

"We didn't get a noise or vibration complaints until 1,430m into the Branch Tunnel drive when we got a call from a tower block resident saying they could hear our TBM. They said they could hear something for about 30 seconds, which stopped for a few minutes and then started again. If it had been us it would have been constant for an hour, so we sent a couple of guys up there to investigate and it turned out to be their elevator!"



The flyover near the Shaft M1 could cause problems due to noise reverberations

These (blocks) must have gone through on an angle, it's bad luck," he says philosophically. "The wear adds up, but it's the downtime getting these rocks out that's the real problem. You have to pull the rock box off the front, take off the small section of pipe that goes on the front of the pump, pull the blocks out, and then put it all back together, and it's happened more times than I can count on one hand."

After the basalt, some 300m into the drive, the decision was taken with Herrenknecht to close up the cutterhead a little due to the exceptional quantity of blocky ground, by adding 50mm packers behind the soft ground tools to bring the openings down to 150mm. This would keep more of the blocky material in front of the cutterhead, in a bid to grind it up more substantially.

"We certainly had fewer blockages after that, and we didn't suffer any accelerated wear on the cutterhead, which was my concern. I was also worried that holding the muck out front could have smashed up some of the discs and the like, but it didn't happen," explains Verman.

Progress accelerated encouragingly, with advance rates of up to 98m per week, but just past the one-third mark, some 800m into the drive, ground conditions were to force the JVs hand once again.

Three joint sets, closely spaced (60-200mm) in the bedrock were to bring in huge amounts of small to large cobble sized blocks that, in large enough quantities, would block the slurry pump, in some cases resulting in water-hammer within the slurry circuit.

The JV has made a couple of modifications for the next drive, all of the crusher inside the pressure chamber has been removed, and a new one put in. "But it's been through 2.4km of hard granite, so it's done a tough old job," Verman says.

The final push

The last 300m of the Branch Tunnel was to exhibit a frustrating combination of wide to very widely spaced (1 to 3m), and 200-250MPa granite, making for hard driving. "Our power consumption went through the roof. On a linear meter of tunnel, instead of taking an hour to an hour and a half for a push, we were taking 3-4 hours."

And Verman believes this had a psychological effect on the crews as the ring build times began to take longer and longer. "The guys weren't in the mindset of a ring build every 1-1.5 hours. They went from a 20-minute cycle to a 30-minute build. Nothing else had changed, it's just mentally they'd slowed down."

"It was hard at the end, and hard on the machine. It wasn't a problem of power, the machine had more to give, but we were at the maximum 27 tonnes per cutter. But it has to be said, the head at the end of the drive was in great shape," he says. "Looking at the cutterhead now, having the slurry has

The STP

All mucking out on the rock drive has been through the TBM's slurry circuit and then on to the Piggot Shaft & Drilling (PSD) supplied Slurry Treatment Plant (STP) and finally into the spoil bin. Generally the quality of the spoil has been high. In good ground bigger chips have been common, but the team has also produced good quality crushed rock which has been recycled, says Verman. "The biggest problem in that section has been the large quantities of really fine granite flour, it's totally crushed," he says. "We had little problem with density increase, but if you turn off the circuit without giving it a good flush you get a lot of settlement of this very fine stuff that takes a lot of work to get back into suspension."

"But the centrifuges dealt with it admirably, with no significant downtime experienced on the STP at all, either due to breakdown or material processing."

The STP has one primary screen and two secondary screens, with 18 number 5" hydrocyclones feeding each secondary screen. "We did consume a lot of the bottom taper sections of the hydrocyclone which we chewed out quite heavily on one of the two banks feeding each secondary screen. One got worn much more heavily than the other," explains Verman.

Talks with PSD showed that this variation in wear is common on a lot of projects. As the material passes through the primary screen into the tank it swirls in a particular way so as to deposit more material on one side that the other. From that one tank, under the primary screen, there are two big pumps that feed up into the 660mm hydrocyclone above each secondary screen, so one pump gets more wear than the other - it's simply got more material on its side. Likewise when the material goes down into the secondary tanks the same process occurs so one of the banks of 5" hydrocyclones was getting more solids that the other one.

The STP is designed to handle the large proportion of material that is sand size and larger, hence the primary and secondary screens. Experience from the KSL project has been incorporated into the LCK plant.

"They spent a fair bit of time before and after award going through with us the size of the centrifuges etc, I get a call every couple of weeks asking how it's going," says Verman.

The JV has one PSD operator on site during day shift, and an operator on the night shift who worked on the Kai Tak Transfer Tunnel, and KSL, which were both PSD STP rigs. "As long as you keep maintaining everything it's super reliable," Verman points out.

For the second drive something of an upgrade is required. "Early on we identified the second half of the Main Tunnel would be harder on the centrifuges. PSD had a bigger S5 centrifuge from their STP plant used on the Adelaide desalination project. We had two S4's but the S5 is double the capacity so we're installing that now."

The Piggot Shaft & Drilling Slurry Treatment Plant

provided a lot of lubrication. If we'd try to do this as a closed machine but in compressed air the wear on the cutterhead would have been massive."

In fact, the only place that exhibited any significant wear was a wear bar on the outer diameter of the cutterhead that had been exposed to material continuously flowing around it, and a little wear on a couple of protection blocks that had the corners taken off them. The buckets had also taken a bit of a chewing, whilst one double cutter housing was replaced and some single cutter housings were rebuilt.

"We had a rigorous inspection routine, initially every day if only to take a look. Being rock it was pretty easy. You drop the pressure, turn the air off, and pump out the slurry. We did all the interventions in free air."

"We got good trends on cutter wear so we started going in every second day. Towards the last third of the tunnel though we went in every day again to tighten up the cutter disc bolts because some of the disc's C pieces were cracking and breaking, or the bolts were snapping, and we would change discs every second day."

Interestingly, the machine rarely lost a disc due to failure, although there were a few that came out flattened, looking something like a hexagonal nut says Verman. "You look at it and wonder how the hell it kept turning," he says. "It depends a lot on the joints, the cutter's not always in contact, once it goes round it breaks a joint and leaves a gap. The next cutter passes this without actually touching anything, and then suddenly grabs the next bit of ground. It must have been brutal in there."

"The TBMs main drive is also in great condition," he adds. "It's just been inspected by Herrenknecht for the next drive and it got a good pass so it's ready to go."

For the next drive the JV has replaced all of the slurry circuit as there will be 4 bar pressure in the front at all times - not a situation to be stuck with thin pipes.

"We expected the slurry pipe to last a bit longer on the first drive. We certainly knew the pumps would take a beating so we had spare bowls and impellors on site. With the slurry being pumped 2.4km on the return line we need one pump on the TBM and two booster pumps in the tunnel.

Verman is also happy with the quality of the 4.9m i.d universal ring, made up of five 1.25m long pre-cast concrete segments plus a key. The segments, he says, are excellent having been cast by Nippon Hume in Shenzhen. There was no carousel used, just six sets of static moulds supplied by Korean Moulds.

"We had a bit of a problem in the first right hand curve and had a little cracking in the middle one of the three bolt holes on the leading edge of the segments on the outside of the curve," he explains, "so we looked at the detail of the reinforcement and thought it needed improving. We made a few bars continuous and changed some of the detailing around the bolt pockets, after that it was greatly improved."

By this stage Nippon Hume had obviously cast a lot of segments, so the team painted a different colour dot on the newly cast segments and used the old reinforcement design segments on the straight sections and the new ones on the curves. All of the segments, and in fact all deliverables and removables, are brought to the ring build area using Mining Equipment supplied 9 Tonne Clayton Locos, and flatcars, "which have worked great, it's been a good system so far," remarks Verman.

The machine breakthrough on the 18th January heralded the completion of something of an unusual drive - a slurry TBM entirely in hard rock - but the choice has been vindicated. Wear has been manageable; the TBM by all accounts is in good condition, with solid advance rates in good ground, and vitally there has been no settlement measured of any noticeable magnitude.

Above: The segmental lining on a finished stretch of the Branch Tunnel

Left: Celebrations at the Branch Tunnel breakthrough in January this year

The Main Tunnel

Currently the machine is being reassembled at Shaft M1 in a 60m long launch chamber set in bedrock. Initially the TBM will be assembled up to gantry 4, launched, and then gantries 5-8 subsequently dropped in, similar to the Branch Tunnel launch

"Our first challenge will be the dip in the rock-head 180m into the drive. After that we've got to pass under the existing MTR Tsuen Wan line and the MTR's future XRL Tunnels will pass over us with 2m seperation."

"Then we're into the mixed ground at chainage 340m where the rock head comes up and down into the tunnel profile," explains Verman.

There will be a lot of monitoring to be done during the work, as the alignment passes close to any number of obstacles, including piles for a six lane viaduct some 5m away.

From there on the drive should be mostly through CDG, "but there are a lot of corestones which should be fun," jokes Verman, "so we're talking with Herrenknecht about different options for dressing the face."

"On the Kowloon Southern Link (KSL) they had some corestones the size of cars, it's not like you can just have a bit of a rip at them and get through, you need to cut through them."

On KSL, problems occurred because the ground was quite loose in one section allowing the corestones to move around with the cutterhead, causing massive damage says Verman. "Given that we're 40m down there's a fair bit of ground pressure holding them in place, so hopefully we can cut through them," he explains.

One potential headache that has thankfully been cleared up for the JV has been the matter of working in Compressed Air above the statutory pressure allowed in Hong Kong.

"It's the first time the Labour Department has given permission to work over the 3.45bar (50psi) pressure limit. There were a number of additional conditions over what's already in the Regulations and they will be keen to see how it may be used in the future," he explains. "We've got a specialist doctor and approval to use the French oxygen tables for decompression. It's also the first time a non government or university has been approved by the Hong Kong Medical Council to employ an overseas doctor to practice in Hong Kong."

And so, having taken the slurry machine successfully through the 2.4km hard rock tunnel, the JV now switches its attentions to a drive supposedly far more suited to the machine's slurry configuration. But it won't be easy, in fact most in the know on the Hong Kong scene will tell you the biggest challenges for the project lie ahead, in the mixed ground drive which officially launches in May. But with that breakthrough not scheduled until November, it will have to be a story told another day.