THE CONSTRUCTION WEEKLY

ENR

Engineering News-Record

April 25, 2005 ■ enr.com

The McGraw-Hill Companies

Global Projects

Double Duty

Smart thinking fits Malaysian highway into stormwater tunnel

McGraw-Hill CONSTRUCTION

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Dual Purpose Tunnel Becomes a

Very Smart Solution

Putting road into Malaysia water tunnel is key to affordability

Periodic flooding of Kuala Lumpur's commercial center has dampened Malaysia's ambitions for its capital to become a major international city. But by building a 9.7-kilometer-long water diversion tunnel, and putting a two-deck highway inside, local contractors are working to alleviate monsoon floods while showing a talent for novel engineering and smart financing.

Included as an afterthought, the unprecedented 3-km-long contractor-financed highway component is subsidizing the $525-million Stormwater Management and Road Tunnel (SMART) project, bringing it within the government's means. On two levels, the road portion will run through roughly the central third of the tunnel.

▲ **Tough Cut.** Tricky ground conditions required slurry-pressure TBMs.

Having sold the dual-purpose concept, the local joint venture, Syarikat Mengurus Air Banjir & Terowong Sdn. Bhd (SMART JV), had to garner missing skills to drive the 13.2-meter-dia bore through difficult karstic limestone. With $200 million of tunneling reportedly going well, SMART JV's technical gamble seems to have paid off. Whether it profits from its cash investment remains to be seen.

A radical cure for Kuala Lumpur's flooding became increasingly necessary as traditional mitigation measures became overwhelmed in recent years. As the city grew, river channels no longer could contain the water. Serious flash floods hit central Kuala Lumpur three times in 2001 and once two years later.

A key constraint to continuing channel enlarging is at the confluence of the Gombak and Klang rivers in the city center, where a profusion of buildings limit mitigation work. Further downstream, a low mass-transit bridge over the Klang poses a further obstacle.

Aware of the pressing need to deal with floods, SMART JV proposed building a water diversion tunnel from the Klang River, starting above the city center, and discharging in the south. The team drew on technical support from a joint venture of local design firm Sepakat Setia Perunding (Sdn) Bhd. with the U.K.'s Mott MacDonald Group, London, the subsequent project's joint designers.

"When we put forward our tunnel concept, the government was not in favor of spending $525 million and requested a cheaper solution," says Param Sivalingam, SMART JV's general manager. The joint venture's solution in 2002 was to reduce the government's outlay by incorporating a road tunnel, which the contractor would finance.

PHOTO COURTESY OF SMART JV

▲ **Junction.** Contractor had to haul TBM through huge open pit excavated to accommodate highway connection.

PHOTO COURTESY OF SMART JV

Attracted by the idea, the Dept. of Irrigation and Drainage invited rival concepts. But the mixed-use tunnel option won "on the basis of technical strength and the financial proposals," says Sivalingam. There was no formal bidding for the contract, but "it was a matter of competing solutions," he says. After about six months of negotiations, the contract was signed in summer 2004. Flooding during that period "helped crystallize the thinking," he adds.

Under the innovative deal, SMART JV raised about $155 million, including its own equity, to finance the highway element, says Sivalingam. It will recover that investment through car tolls during the contract's 40-year duration. The joint venture also raised state-guaranteed loans for the government's contribution.

Most of the time the 11.8-m-internal-dia tunnel will be entirely dry. But several times a year, during moderate storms, water will be diverted into the lowest gallery, while traffic continues running in the two levels above. In worse conditions, perhaps annually, traffic will be excluded and water gates in shafts sealing the road's ends will be opened to move water. After about two days to clean up and deal with any damage, the road will reopen.

In full floods, water will be diverted at up to 290 cu m per sec from the Klang River and fed via a holding pond in the Gombak district into the tunnel. It will flow down the tunnel's general 1:800 slope for storage at an upgraded old mining pond in Taman Desa, at the south end. From there, it will be released through a 500-m-long twin box culvert into the Kerayong River. Apart from diverting floods, the system can store 3 million cu m of water.

Conventionally, the tunnel will have galleries linking the two decks as emergency exits. But novel features are needed for the tunnel's flood relief function. Ventilation equipment, for example, will be above water level at four ventilation shafts, with air flowing through nozzles in the tunnel sides.

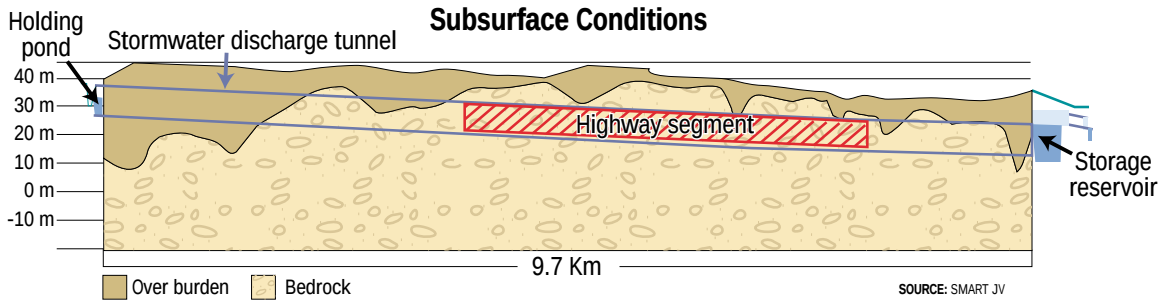
In addition to water barriers at the vent shaft and escape galleries, there will be major gates at the tunnel ends. Normally, vertical gates in the highway tunnel upstream and downstream of the ramps will be closed. A third, standby gate also will be fitted at each end. Flap gates rising from the road deck will stop traffic at the tunnel entrances.

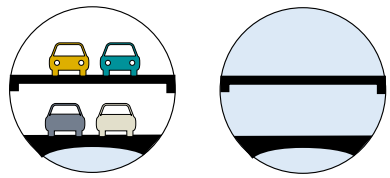
The roadway's structure also is unusual "in that it is subjected to upwards and downward loads," says Arthur Darby, Mott MacDonald's divisional director. The road structure consists of two reinforced concrete decks cast integrally with side walls. Fixed to the tunnel by shear connectors, the box applies only vertical load on the bolted segmental lining. But because of the upward water pressure from the filling tunnel, the box itself will undergo bending moments in slab and walls.

When the gates open, water will enter from both ends, creating a transient upward pressure on decks, says Darby. To establish optimal balance between gate opening rates and structural loadings, BHR Group Ltd., Cranfield, U.K., ran surge analyses for the de-

signers, he adds.

To keep the boring machines supplied along the tunnel base while the roadway is being built, the lower deck was raised, allowing for a 2.8-m invert, but limiting headroom above. Because the construction program is very tight, "they need to construct the lower deck while the TBM is still driving," says Darby. The resulting increased water flow capacity below the road cuts the frequency of total tunnel closures, he adds.





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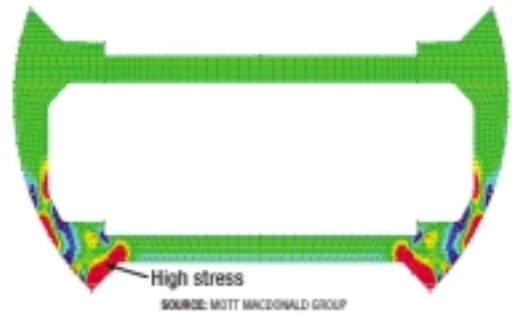

▲ **Unique.** Water puts stress on highway box (right) when tunnel pulls double duty.

Organizing

In winning the contract, SMART JV secured the overall task of designing, financing and procuring the entire project and operating the highway portion. The government will manage its flood control functions. But the joint venture's equal partners, Malaysia Mining Corp. (MMC) Berhad and Gamuda Berhad, lacked the technical experience for such a project, says Sivalingam. With annual sales of about $400 million, Gamuda, for example, has built drill-and-blast tunnels, but this is its first machine-driven project.

KLADOS

For construction, MMC and Gamuda set up a separate joint venture (MMCG) and awarded it a turnkey contract in 2002. When Gus Klados came in June 2002 as senior tunnel specialist, the design was partly done but the tunneling method was undecided, he says.

By then, Mott MacDonald already had recommended using slurry-faced TBM's, but vendors also had proposed earth-pressure-balance technology. Having struggled in a previous Singapore job with an earth-pressure TBM in difficult rock with high water pressure, "I brought confirmation that we needed a slurry shield," says Klados.

Klados also brought enough experience and contacts to create a tunneling organization almost from nothing. He started in the business at home, on the Budapest metro in the early 1970s. From there he moved to the Calcutta subway job, before joining the Channel Tunnel team in England. He then took in the Lesotho highlands water project and the Athens metro before heading for a decade in East Asia.

"I had to set up a company within the joint venture but I didn't have experienced people," says Klados. "Gamuda had done the best it could in the circumstances.... They [let] me do the job. It was [for them] a big leap of faith."

For essential "back office engineering and work preparation," Klados relied on Paris-based Vinci Group. Former colleagues helped to specify and procure the segment molds in France and the TBMs in Germany. Altogether, he recruited 13 expatriate tunnel specialists.

The team built up by Klados wins plaudits from Peter Chiappa, project manager with Germany's Wayss & Freytag Ingenieurbau A.G., Frankfurt, which now is driving the tunnel's north 5.3 km. "I was very surprised from the very beginning how professionally they handled this," he says. W&F in early 2003 won the contract to drive the northern tunnel section, with an option for the southern 4 km that never materialized.

SIVALINGAM

"We had to decide whether to outsource the whole thing or do one half ourselves," explains Sivalingam. Without any bored tunnel experience, the Malaysians took on the southern drive aiming "to become a serious tunneling company," he adds. As a result, Klados took direct control of the southern drive, while overseeing all tunnel work.

Early Changes

MMCG first chose to procure tunneling equipment for the north drive and hand it to a contractor, when appointed, to save time. Because of its limited TBM experience, the team decided to buy the TBMs with all associated equipment from a single supplier. But W&F had other ideas.

"As discussion went on, the whole concept changed," says Chiappa. Apart from having its own bentonite separation plant, "we offered a TBM with second hand components, which had a much shorter delivery time," he adds. The move saved the contractor several million dollars and got the machine on site three

▲ **Double Deck.** Highway decks are attached to lining segments with shear connectors.

months ahead of the unit destined for MMCJV's south drive, he says.

Germany's Herrenknecht A.G, Schwanau, won orders for both machines in 2003. The 13.2-m-dia mixshield TBMs use compressed air to balance ground pressure in the face. Bentonite is pumped through a pressure wall and then via a compressed air chamber, which ensures the slurry pressure matches that in the soil and water ahead.

The advantage of this arrangement over conventional slurry machines is "if you come out of rock and hit an area of soft ground, the compressed air expands [quickly] and the slurry flows in to fill the partial void. You can maintain pressure to support the face," says Darby.

The feature seems well suited to Kuala Lumpur's tricky ground. Under superficial loose alluvium, the tunnel route cuts through complicated limestone with a variable profile and containing dissolved cavities filled with peat-like soil. Most of the south drive and over half the north bore is in this karstic rock, while the rest is in soft material.

Tunnelers know when they hit a cavity because cutting resistance drops, slurry changes color and the volume of grout needed behind the segments doubles or triples. "We have to watch it like an eagle," Klados says. Solution caverns can be warren-like, consuming huge amounts of bentonite.

With about 13 m of cover in places, "it is a very shallow drive, especially in areas in the south drive where we are driving in soft rock...the bottom part of the face might be in limestone with alluvium at the top," says Klados. With such treacherous conditions, the contractor has not stinted with soil investigations.

▲ **Curves.** Tunnel has tighter bends than normal for a large TBM.

TBM Track

Both TBMs' cutterheads are mounted on a spherical main bearing to steer a 250-m radius, says Klados. Because the tunnel follows roads as much as possible, its bends are much tighter than would be normal for such a large machine, he adds.

The first machine, W&F's, arrived in Kuala Lumpur a month after the 150-m-long, 25-m-deep launch pit was completed in January of last year. The second machine followed a few months later.

W&F's machine set off on its 5.3-km drive last May, with Chiappa's team "fine tuning" all the processes to the difficult ground, he says. Chiappa knows of no other bentonite machine to have worked in such karstic rock. Having built up a rhythm of work, W&F was interrupted after some 700 m by the huge open pit of the north highway ramp.

Having hauled the machine some 200 m through the pit, W&F restarted work in February, aiming to finish by May 2006. The average advance in the first 700 m was just over 5 m in 24 hours, exceeding that by 50% toward the end, says Chiappa. He hopes to do better than 10 m a day once his team regains its beat.

MMCG's southern TBM, took off last August, for completion in March 2006. Working around the clock, the TBM has achieved 100 m in a week, a "good performance with such a large diameter slurry shield," says Klados. In following the W&F machine by a few months, MMCG will have gained vicariously, believes Chiappa. "When mistakes were made, they didn't need to repeat them," he says. ■

PHOTOS COURTESY OF SMART JV