Forming a new route for drainage

High-density polyethylene void formers have proved effective in providing drainage and pressure relief at the Black Hill Tunnels for Hong Kong's Mass Transit Railway Corporation. N G Swannell, associate director, Halcrow Group; T R M Greig, tunnel design team leader, Halcrow Group; F Belhomme, technical manager, Dumez GTM-Chun Wo JV; and A Bamforth, managing director, ABG, explain how the project was carried out.

Design and build contracts provide the opportunity and motivation to reconsider conventional details to optimise construction and to improve cost effectiveness. A recent example can be found in Hong Kong, where the design and construction of new railway tunnels gave rise to the optimisation of the invert drainage and pressure relief system, and produced a cost effective solution.

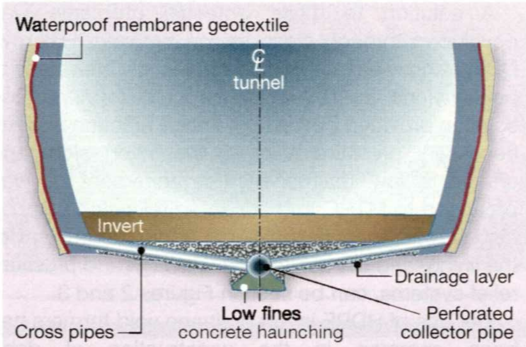

Fig 1. Typical previous invert detail

Black Hill Tunnels

In Hong Kong, the Mass Transit Railway Corporation (MTRC) is undertaking the Tseung Kwan O Extension Project to extend its rail system to new towns east of the Kowloon peninsular. Contract 603, Black Hill Tunnels, is one of the major rock tunnelling sections. The tunnels are being constructed at a maximum depth of 180m in granite and volcanic rocks and will connect Yau Tong with the new town at Tiu Keng Leng to the east.

The contract covers multiple running tunnels, approximately 6m in diameter and 1.8km long, including a centre siding tunnel and two turnout tunnels and associated shafts and adits. The contract was awarded to the Dumez GTM-Chun Wo Joint Venture (DCJV) in November 1998. DCJV appointed Halcrow China (Halcrow) as its detailed design consultant. Commissioning is scheduled for mid-2002.

As with all recent MTRC driven tunnels in Hong Kong, the Black Hill Tunnels were specified to be concrete lined, waterproofed around the arch, and generally pressure relieved. The requirements for assured waterproofing, high quality concrete and low maintenance for the design life of 120 years are fundamental to the continued successful operation of this high capacity transport system.

To achieve the required waterproofing of the arch concrete and pressure relief, groundwater is first collected in a geotextile layer behind a conventional welded waterproofing membrane on the concrete lining extrados. From there the groundwater is normally fed to a longitudinal collector drain in the tunnel invert, leading to pump sumps at tunnel low points. In addition to achieving the required level of waterproofing, this arrangement also generally results in a very high quality of concrete finish.

A common detail in such tunnels is for cross pipes to be welded to the waterproof membrane close to the base of the arch. These cross pipes are designed to carry the water from the geotextile to the perforated collector drain. The cross pipes and drains are set in a layer of drainage stone below the invert slab, which provides the necessary pressure relief of this slab. Figure 1 shows a typical detail.

Optimisation

As part of the optimisation of the design for Black Hill Tunnels, every effort was made initially to minimise the excavated cross sectional area of the tunnel and the lining thickness. This led to a modified structural form of lining, replacing the horseshoe arch and invert slab shown in the client's reference design, with a composite lining structure (Figure 3). Advantage was taken of this modified shape, as an initial concept, to connect the arch geotextile directly to a layer of drainage stone below the invert, from where the water would find its way to the central perforated collector drain. This detail thus eliminated the need for cross pipes and the associated maintenance.

However, sections of the tunnel in and near to the central siding were required to be at very low gradients for parking trains. To maintain acceptable hydraulic gradients it would therefore be necessary for the longitudinal collector drains to be installed in trenches more than 800mm deep in parts. The

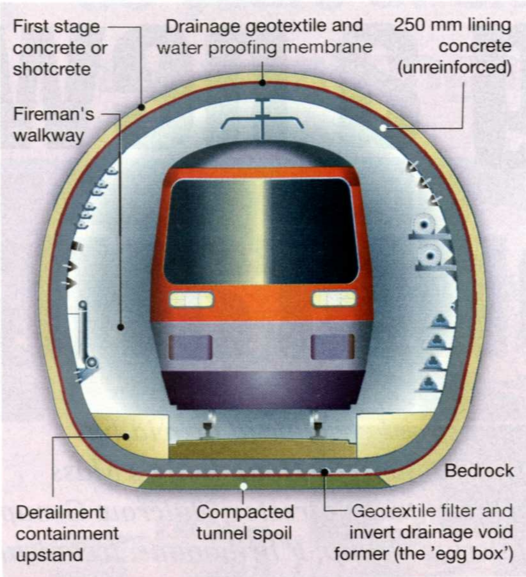

Fig 2. Adopted cross section of running tunnel

construction of such trenches could have presented major difficulties and have significant programme implications.

A solution to these potential problems was developed through close liaison between Halcrow, DCJV and ABG, a manufacturer of high-density polyethylene (HDPE) drainage void formers. The solution provided both the drainage function and the necessary pressure relief of the invert slab, and offered a low maintenance arrangement. It was proposed to MTRC and accepted following detailed discussions and site trials. The final arrangement of the lining, and the associated drainage and pressure relief systems, can be seen in Figures 2 and 3.

The use of HDPE invert drainage void formers has been common in the construction of deep foundation structures and similar works for many years. However, their use to optimise the drainage and pressure relief of lined rock tunnels, as at the Black Hill Tunnels, has not previously been recorded, as far as the authors are aware.

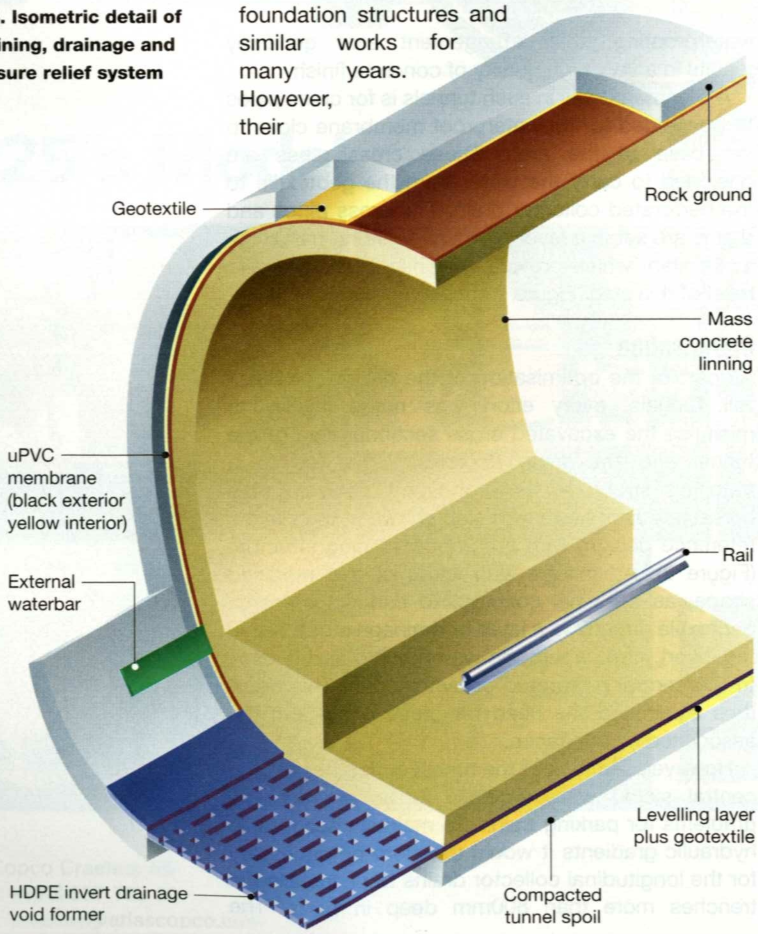

Fig 3. Isometric detail of the lining, drainage and pressure relief system

Material properties

HDPE is one of the most resistant materials to chemical and biological degradation, although in this application it is not required to provide a long-term function once the invert concrete is cast. Polyethylene is difficult to ignite, resists flame spread and does not produce toxic fumes when burned. It therefore presents low risk as a construction material in tunnelling works. When formed into dimpled sheets HDPE provides a robust structure, which has been found to stand up well to the rigours of tunnel construction (Figure 4).

Design and construction

The main design issues at Black Hill were:

- bearing capacity
- concrete stress in the 'cups' of the void former
- flow capacity for the predicted groundwater inflow rates.

The most critical load case, in terms of bearing capacity, came from the railway loading on the central flat section of the invert slab. Loading from construction traffic was found to be less severe. When cast, the voided invert slab bears onto a geotextile sheet, placed over a crushed stone levelling layer, spread on compacted tunnel spoil (Figures 2 and 3). (The purpose of the geotextile is to allow drainage into the voids, while preventing the migration of fines from below). It was calculated that a 50% bearing area of concrete through the void former would be required; this was controlled by the bearing capacity of the compacted tunnel spoil rather than concrete stress.

This requirement was found to be far in excess of available standard void formers. In addition, edge flanges of the void former sheets were required to overlap with the waterproofing membrane at the base of the tunnel arch. A system was also required which would allow sheets to overlap and to be installed around horizontal curves (minimum radius 300m) in the tunnel.

Customisation

It was therefore necessary to develop a custom-made product to meet these requirements, and to provide sufficient flow capacity for the section of tunnel with the maximum predicted cumulative inflow. The requirement for a large bearing area and relatively high maximum flow capacity at low hydraulic gradient was achieved by making the 'cups' rectangular and aligned in the direction of flow (Figure 4). The ability to follow the horizontal curves of the tunnel was achieved at the overlaps of the void former sheets, the male side of a sheet being made smaller than the female side to give the required flexibility in alignment.

The manufacture of customised sheets did not present any major difficulties, and had only a minor impact on cost. Sheets were delivered to site in containers, and were dimensioned and colour coded for particular applications in the various tunnels.

To prevent cement paste from penetrating to the drainage voids during construction, the overlaps of adjoining sheets were sealed with parcel tape. Details were developed on site to prevent the ingress of dirty run-off into exposed ends of the drainage voids during construction.

Maintenance provision

Because the final solution provides a sealed and filtered groundwater drainage system, it was felt initially that the void formers did not need to be accessible in the long term, and that there were many advantages in ensuring a permanently sealed system. However, following discussion with MTRC, it was agreed that access trenches (with sealed covers) should be left in the invert slab at around 50m centres to provide for routine maintenance inspection. Nevertheless, it was agreed that the void former would not be cut more than absolutely necessary where it was exposed in the base of the inspection trenches. This would minimise the risk of dirt and debris entering the system. It was also seen as a useful feature during final construction cleaning works. In the event that cleaning of the system should become necessary, trials showed this could be done very effectively using a conventional high-pressure water drain flushing tool.

Conclusion

In summary, the advantages of the adopted system to the contractor were:

- elimination of the need to blast narrow invert trenches for pipework, with attendant overbreak, making good, and restrictions placed on tunnel access and other operations
- earlier demobilisation of drilling and blasting plant (by some months)
- much increased flexibility in construction operations and reduced programme risk, with the invert drainage works forming part of a systematic train of lining construction comprising drainage, waterproofing, invert and arch concrete operations.

The major advantages to the client are:

- a drainage system with a large amount of redundancy – the flow path network is such that, should one of the channel voids become blocked, the water can find an alternative path
- a groundwater system that is fully filtered and which can remain largely sealed from outside contamination during the life of the project
- a system that is robust and readily maintainable should the need arise. T&T

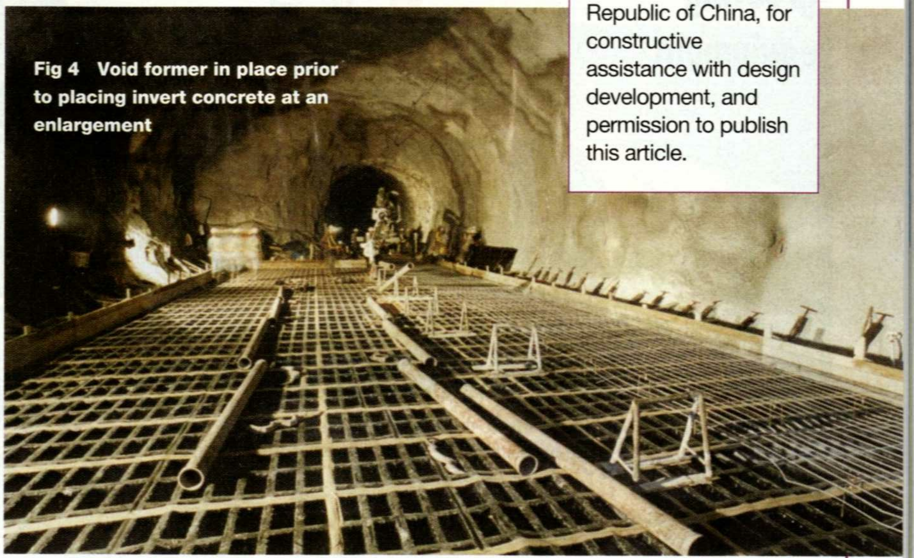

Fig 4 Void former in place prior to placing invert concrete at an enlargement

Acknowledgements

The authors gratefully acknowledge the extensive help and support of colleagues in the development and implementation of the system. Thanks are extended to the Mass Transit Railway Corporation of the Hong Kong Special Administrative Region of the Peoples Republic of China, for constructive assistance with design development, and permission to publish this article.