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Planning and design of the A3 Hindhead tunnel, Surrey, UK

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ABSTRACT: The A3 Hindhead project includes a 1.8 km long twin bore tunnel that is planned to commence construction in 2007. This paper describes the development of the tunnel design through the planning and design phases including the design for maintenance, and the innovative approach to tunnel support in the sand and ‘soft rock’ sandstone.

During the preliminary design period, the UK Health and Safety Executive (HSE) issued three Chemical Hazard Alert Notices (CHAN’s) relating to a reduction in the allowable exposure levels of respirable silica and NO_x during construction. This caused us to compare SCL and TBM design and construction strategies and compare the risk profiles.

1 INTRODUCTION

The A3 Hindhead project located in Surrey, UK is a 6.7 km dual carriageway truck road that includes a 1.8 km tunnel being delivered under a Highways Agency Early Contractor Involvement (ECI) contract. This paper describes the development of the tunnel design through the planning and design phases including vertical and horizontal alignment, tunnel cross section, ground support measures, and the design of the tunnel structure to resist fire loading.

During the preliminary design phases both TBM and Sprayed Concrete Lining (SCL) methods were considered for construction, and a comparison between the designs is included. The differences in construction methodology including planning, and program are also discussed, and the different risk profiles outlined.

2 PROJECT DESCRIPTION

The A3 Hindhead project is one of the schemes in the UK Government’s Targeted Programme of Trunk Road Improvements. The project will complete the dual carriageway link between London and Portsmouth and remove a major source of congestion, particularly around the A3/A287 traffic signal controlled crossroads. Refer to Figure 1 for location details.

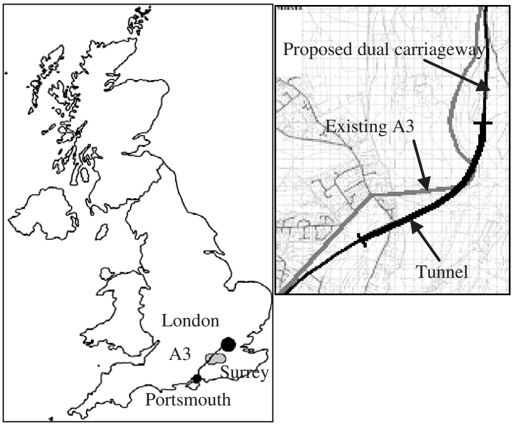

Figure 1. Project location.

The project will deliver quicker, more reliable journeys on a safer road, and remove much of the present peak time “rat-running” traffic from unsuitable country roads around Hindhead. The centre of Hindhead will be freed from the daily gridlock that blights the area, with the result that the project will bring benefits to road users, local residents, and the highly prized environment.

2.1 *Planning phase*

The A3 Hindhead project has been planned since 1983 when it was included in the Government’s Trunk Road program. The challenge for this project was balancing environmental impact with user economic benefits. Striking the right balance between these competing

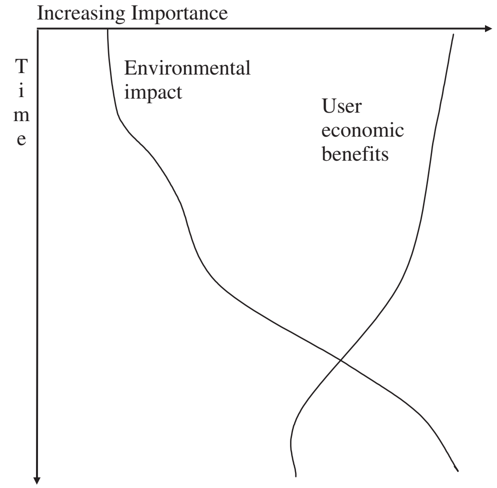

Figure 2. Change in approach to development of A3 Hindhead Scheme.

Table 1. Project development time-line.

Date	Activity
1983	Enters Trunk Route Program
1987	Single Route Consultation
1988	Red Route confirmed as preferred
1992	Second public consultation
1993	Modified yellow route with bored tunnel announced as preferred route
1995	Work suspended
1998	Roads review – Road Based Study into tolling announced
1999–2000	Tolling Study
2001	Enters TPI
10/2002	ECI contract awarded
9/2004–2/2005	Public Inquiry
8/2005	Inspectors Report received
9/2006	Secretary of State decision
1/2007	Commence construction
7/2011	Open Tunnel
3/2012	Complete Scheme

issues has taken over 20 years to resolve. Almost all the scheme lies within an 'Area of Outstanding Natural Beauty' (ANOB) with Site of Special Scientific Interest (SSSI) that are part of the Wealden Heaths SPA – an EU Designation that prohibits development except for "no choice" and national economic or safety considerations. The route passes through National Trust owned land which is classified as "in-alienable". It can only be compulsorily purchased against their wishes with the approval of the UK Parliament.

In the 19 years since the project was first mooted, and the commencement of the current phase of project development in October 2002 there has been a sea change in planning and approval thinking where economic benefits originally had primary importance and now environment damage mitigation is uppermost. This change in planning approach with time is shown on Figure 2. The key to a successful planning process in this case was to provide a tunnel under the environmentally sensitive areas, and to close the old A3 thereby reuniting sections of the SSSI/SPA. Other environmental benefits included the removal of intrusion and severance within the AONB, and the removal of air, noise and light pollution.

Part of the change in approach was the adoption by the Highways Agency of partnerships for scheme development. This was manifested on the A3 Hindhead project by the establishment of a Project Advisory Group (PAG) incorporating all the key stakeholders including the protectors of the environment such as National Trust, English Nature, Countryside Agency and English Heritage. The objective of the PAG was "*To assist in developing the tunnel scheme to minimize its impact on the built and highly prized natural environment, and one that is broadly acceptable to the local community, while ensuring that all impacts have been addressed*". Table 1 below outlines the project development timetable since inception in 1983.

2.2 *Early Contractor Involvement (ECI) contract*

The Highways Agency introduced the principle of "Early Contractor Involvement" in 2001. This new form of procurement is about bringing suppliers and designers together much earlier in scheme conception than previously occurred, allowing them to work together more closely. This allows more scope for innovation, improved risk management, better forward planning of resource requirements and minimization of long term environmental impacts, improved consideration of buildability and health and safety, shorter construction periods and reduced environmental impacts during construction. Overall, the early creation of delivery teams clearly offers the opportunity for better value and improved performance.

3 GEOLOGY

3.1 *Overview*

The geology of the Hindhead area comprises a sequence of fine grained sedimentary deposits laid down during the Lower Cretaceous period in near shore transgressive marine conditions on the margins of the subsiding Weald Basin. The tunnel is within the Hythe Beds – a 90 m thick sequence within the Lower Greensand Series formation.

The Hythe beds are variably sorted, highly glauconitic, variably bioturbated and cross-bedded sands and sandstones.

The Hythe bed unit is divided into 6 lithostratigraphic subdivisions, 4 of which the tunnel passes through.

3.2 *Tunneling conditions*

The tunnel at the southern end passes through units Upper Hythe A and B which are similar units with an increasing number of sandstone bands with depth, described as '*medium dense thinly bedded and thinly laminated, clean to silty and clayey fine and medium SAND with subordinate weak to strong sandstone, cherty sandstone and chert*'.

The majority of the tunnel passes through the more competent Upper Hythe C and D, and Lower Hythe A units, described as '*Weak, locally very weak to moderately strong, slightly clayey fine to medium SANDSTONE with occasional thin beds of clayey/silty fine sand*'.

The remaining unit is Lower Hythe B which has been avoided by the tunnel as clays and sand become dominant in the lower half of the unit.

The sandstone within Upper Hythe C/D and Lower Hythe A has typical UCS values of between 2 and 5 MPa and is heavily fractured with 6 joint sets including the sub-horizontal bedding with mean fracture centers varying between 190 and 815 mm.

The tunnel is above the historically observed water table, with the maximum predicted water table exceeding the invert level in only 1 location. Refer to Figure 3 for geological longsection.

3.3 *Ground behavior model*

A challenge for this project was to define a ground behavior model in an unusual material that has not been tunneled previously. The difficulties in interpretation stem from the weak to very weak nature of the sandstone material in combination with the content of up to 20% interbedded soil layers. A recurring challenge in tunneling is to determine the rock mass strength and stiffness, with empirical methods such as GSI, RMR or the Q-method (Bieniawski, 1984) often used. The strength and stiffness relationships that are the cornerstone of these methods are generally determined from data from significantly stronger rocks than the 2–5 MPa sandstone and do not take account of the influence from the soil layers leading to a significant overestimate of stiffness.

An extensive geotechnical investigation was undertaken with sonic testing, pressuremeters and triaxial testing all used to determine the Elastic Modulus of the rock mass. Pressuremeter testing was found to be the most reliable with the sonic testing over-estimating the stiffness, and the triaxial testing surprisingly underestimating the stiffness in a number of cases. This was thought due to the difficultly in finding a 300 mm long specimen for testing in a material with 6 joints sets and an average bedding spacing of 190 mm. Fortunately some good quality rock joint shear box testing was undertaken that provided a lower bound for strength and stiffness interpretations.

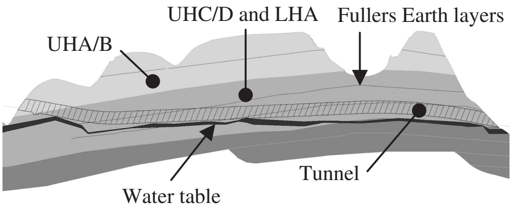

Figure 3. Geological longsection and vertical alignment (1H:4V).

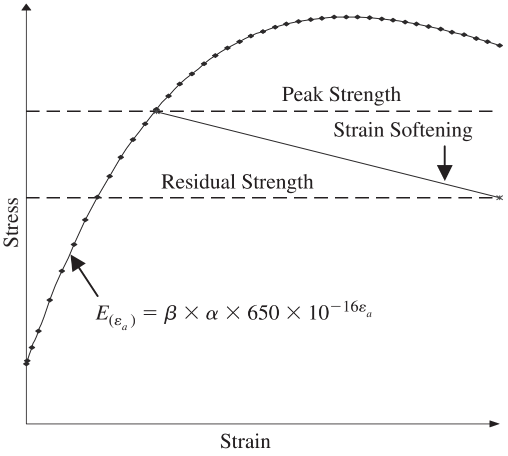

Figure 4. Ground model used for design.

The interpreted model used in design was a small strain stiffness model ($E_{(\varepsilon a)}$) that varied the stiffness of the rock mass with strain, and a Mohr-Coulomb strain softening model used for strength. Due to the large variation in cover from 16 m to 58 m the rock mass stiffness was also related to depth (α) in order to take advantage of the positive effect of larger insitu stresses as depth.

4 ALIGNMENT

The horizontal alignment for the tunnel was determined based on road design considerations and environmental constraints resulting in a reverse curve through the tunnel with a minimum radius of 1050 m.

The vertical alignment was determined based on geological constraints with the desire to minimize the length of tunnel through the sand at the southern end, to keep the tunnel above the water table and to also maximize the vertical clearance to the Lower

Hythe B material which has insufficient strength to carry horizontal stresses around the tunnel opening. The tunnel passes beneath the Devil's Punch Bowl which is a re-entrant, primarily spring-sapped valley system with erosion feeding backwards from the Hythe Bed/Atherfield Clay interface at the valley base. The crossing of the punchbowl provides a cover constraint to the tunnel, and the cover changes rapidly from around the minimum cover of 16m to the maximum cover of 58 m within a horizontal distance of 130 m.

The decision to follow the optimal tunnel material and to avoid the softer Lower Hythe B material results in a low point within the tunnel.

5 DESIGN

5.1 *Cross section*

The Hindhead tunnel consists of twin 2-Lane bores with cross passages at 100 m nominal centers. Refer to the typical cross section in Figure 5 below. Each bore has two 3.65 m lanes, with full batter curbs and 1.2 m wide verges on each side of the tunnel. The verges are required for sight-lines due to the horizontal curvature of the tunnel, to accommodate electrical services and also to provide wheelchair access to the cross passages and emergency points at 100 m nominal centers along the tunnel.

The vertical traffic gauge provided is 5.03 m with an additional clearance of 250 mm to the Equipment Gauge.

A continuous drainage system is utilised, located beneath the curb and verge with the cable duct bank. Other services such as the fire main, high voltage cables and pump mains are buried beneath the carriageway, with jets fans, lighting and communication cables contained within the crown.

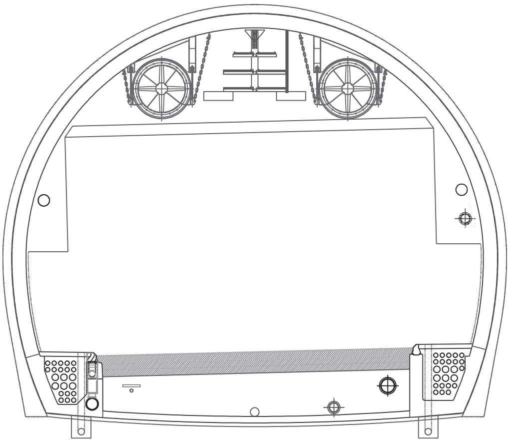

Figure 5. Typical SCL tunnel cross section.

These requirements result in a horseshoe shaped tunnel structure with an internal diameter of 10.6 m and an excavated diameter of 11.6 m.

5.2 *Fire and life safety provisions*

The tunnel has cross passages at 100 m nominal centers for escape to the non-incident bore. Cross passages include fire hydrants, dry pipe connections, fire extinguishers and emergency telephones. Emergency Points (EP's) are also provided at 100 m nominal centers located at the mid-point between cross passages. Each EP has an emergency telephone and fire extinguisher.

A longitudinal ventilation system comprising 20 jet fans per bore is provided for smoke control. Consideration was given during the preliminary design phase to the inclusion of a Fire Suppression system, however it could not be justified on cost benefit grounds. The decision was taken to make space provision for the future installation of a fire suppression system, should further evidence of the benefits become available or standards and or technology change.

5.3 *Design for maintenance*

Due to the life cycle cost of managing tunnel assets and more stringent health and safety regulations, the design team focused on minimization of whole life costs and the development of corresponding design details. Design for maintenance included:

- Minimization of unplanned maintenance interventions
- Consideration of the safety of maintenance
  - deletion of equipment where possible
  - selecting materials with the longest design life
  - Provision of safe maintenance access
  - Provision of replacement options for all infrastructure and equipment
- Maintenance risk assessments

Specific design initiatives incorporated in the works included:

- Provision of spare HV conduit and blind pits to allow replacement of HV cables in routine closures
- Modular hydrant connections allowing replacement in routine closures without disturbance of cable ducts and other services
- Relocation of in-tunnel sump to outside the tunnel by using a directional drilled gravity drain allowing maintenance access to sump without a tunnel closure

5.4 *Tunnel excavation and support*

The presence of the sand layers, in one location up to 2 m thick, led to the selection of sequential excavation methods and support techniques commonly used in the Sprayed Concrete Lining (SCL) technique also known as the New Austrian Tunneling Method (NATM) where shotcrete is sprayed at the face following each excavation advance. Standard hard rock tunnel support techniques such as pattern bolting where not considered suitable due to the sand layers and the very low bond stress negatively impacting the effectiveness of rock reinforcement.

The tunnel is generally excavated with a full face heading followed at a distance by the bench excavation. Due to the generally stable nature of the ground and location above the water table, a closed invert is not required and the horse shoe shaped primary lining is supported on elephants feet. One main support type has been adopted through the sandstone with additional support measures such as spiling, face support wedges and/or face dowels to be triggered should an instability in the excavation occur. Refer to Figure 6 for details of the primary lining in the sandstone section.

In the sand section at the southern end the excavation will be carried out on dayshift only due to constraints on working hours and is made stable with the use of a steel pipe umbrella and face dowels. In this section three support types are required as the area of sand in the face transitions to a full sandstone face. Figure 7 shows a typical support type in the SAND section.

A principal innovation with the support measures is the design of primary lining as permanent. This is possible due to a number of advances in tunneling technology in recent years. Firstly, non-alkaline accelerators are now available with no loss in shotcrete strength with time. A recent innovation is the use of 3-D scanning survey equipment that provides excellent shape control for both excavation and spraying, and allows SCL tunnels to be constructed without lattice girders. This technique has been recently used successfully for the Heathrow T5 project (Williams et al. 2004). Historically the inclusion of lattice girders meant the primary lining had to be considered temporary due to the corrosion potential of the steel lattice girder within the primary lining. Spiling is envisioned in several locations due to adverse soil layers. This will be carried out with self-drilling Glass Reinforced Plastic (GRP) dowels, again with no adverse durability issues. The sprayed concrete will be reinforced with steel fibers as is required for safe installation, however the design does not rely on the flexural capacity of the steel fibers, and the lining is designed as plain concrete. This is possible due to the curved shape of the section with all moments resisted by axial forces within the lining.

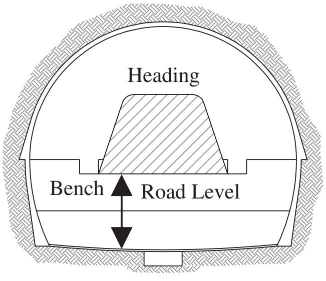

Figure 6. Typical primary lining through rock.

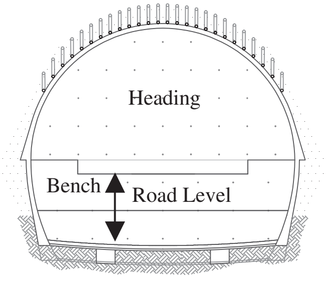

Figure 7. Typical primary lining through sand.

5.5 *Secondary lining design*

A secondary lining is provided to support the proposed sheet waterproof membrane, and also to provide fire resistance to the tunnel. The secondary lining is constructed from plain concrete, with all tensile loads in the lining resisted by the tensile capacity of the concrete. The main concern is to minimize the heat of hydration and shrinkage, and this is achieved with a 35% Pulverized Fly Ash (PFA) cement replacement mix design with low shrinkage. Fire resistance is achieved by adding 1–2 kg/m^3 of polypropylene fibers to the concrete mix in order to prevent explosive spalling. The precise dosage of fibers will be confirmed by fire testing.

6 COMPARISON BETWEEN SCL AND TBM TUNNEL OPTIONS

6.1 *Chemical Hazard Alert Notices (CHAN's)*

Towards the end of the preliminary design period, the UK Health and Safety Executive (HSE) issued three Chemical Hazard Alert Notices (CHAN's) relating to a reduction in the allowable exposure levels of Respirable Crystalline Silica (RCS) and NO$_x$ during construction. The recommended changes to exposure levels are shown in the following Table 2.

All project development up to that stage has been based on excavation of the tunnel with diesel equipment. It was not possible to achieve these proposed limits with the diesel based construction methodology. The lower CHAN limits produced conflicting

Table 2. Details of Chan's

CHAN	Particulate	1989 COSHH regulations	Proposed limit (ppm)
28	NO	25 ppm	1 ppm
29	NO_2	3 ppm	1 ppm
35	RCS	$0.3\ mg/m^3$	$0.1\ mg/m^3$

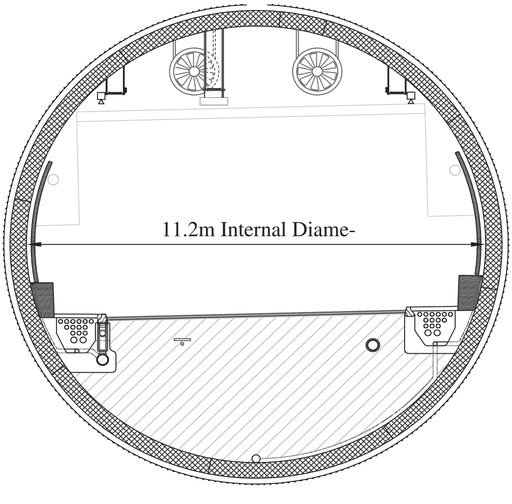

Figure 8. TBM tunnel cross section.

demands, as the lower NO_x limits require increased ventilation, but increased ventilation produces more dust causing problems with respirable silica.

This resulted in the consideration of an alternative method of construction, and a preliminary design prepared for a tunnel constructed using an Earth Pressure Balance (EPB) Tunnel Boring Machine (TBM).

6.2 *Comparison of SCL and TBM options*

The TBM tunnel cross section is shown in Figure 8 below. One of the benefits of utilizing a TBM was that it was no longer necessary for the vertical alignment to follow the optimal material for ground support. This meant that the tunnel could fall from south to north, allowing the deletion of the low-point sump. Another advantage of TBM construction was that a single-pass lining could be utilized. A fully gasketed segmental lining fire hardened with polypropylene fibers was proposed.

The main disadvantages with the TBM options were the openings required at cross passage junctions and for Emergency Points. The junctions are significantly more expensive for a TBM tunnel, and where the benefit cost ratio (BCR) for the Emergency Points was greater than 1 for the SCL tunnel, the cost of the opening for a TBM tunnel resulted in $BCR < 1$, however once a safety measure is proposed to the Emergency Services it is very difficult to withdraw it at a later date.

6.3 *Program*

There was a small benefit to the program for the TBM option however this was minimal due to the fact that the SCL tunnel is proposed to be excavated concurrently from 4 faces, whereas the TBM had to excavate 1 bore, and then be turned for excavation of the second bore. The total bore length of 3.6 km was insufficient to give the TBM option a significant program advantage. A tunnel of 2.5 km length would have been required to see a significant program advantage for the TBM.

Another disadvantage with the TBM option was the long lead time for the procurement of a 12.0 m diameter machine.

6.4 *Risk assessment*

A rigorous risk management procedure has been used through the project, and allowances for commercial risks are included in the project target cost. The assessed commercial risk for the SCL tunnel was significantly higher than for the TBM due to the larger potential impact from adverse ground conditions and the uncertainty of achieving the new exposure levels.

6.5 *Outcome*

An interim guidance note "Occupational Exposure to Nitrogen Monoxide in a Tunnel Environment" based on the ALARP principals applied to NO exposure limits has been prepared by the BTS (2006), was used to develop a modified SCL construction methodology such that NO limits of 3–5 ppm and the revised CHAN limits for NO_2 and RCS could be achieved. Additional measures include increased ventilation, more electric plant including an additional face conveyor and diesel plant conforming to the Stage III emissions standards in the Non-road Diesel Engines Directive. The modified SCL solution was still more economic than the TBM alternative.

7 CONCLUSIONS

The development of the planning and design of the A3 Hindhead project has been outlined in this paper. The main conclusions are:

- Projects through environmentally sensitive areas need to provide special mitigation measures in order to achieve planning consent.
- Tunnel details have been developed to avoid non-routine maintenance closures through the life of the tunnel.

- The design of the tunnel support includes a permanent primary lining possible due to:
  - Availability of non-alkaline accelerators
  - Use of 3-D laser scanning survey technology for control of robotic spraying equipment to achieve tight shape tolerances avoiding the need to use lattice girders
  - Use of self-drilling GRP spiles in areas of poor ground.
- Alternative designs have been prepared for an SCL tunnel and a TBM tunnel with the following conclusions:
  - Below a length of 2.5 km the TBM option had no program advantages
  - The TBM option had a lower assessed commercial risk due to the insensitivity to adverse ground conditions; however this was insufficient to overcome the increase in cost.
  - A modified SCL methodology that using ALARP principles for airborne pollutants in accordance with the BTS best practice document was developed.

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