The renovated and modernised Barlow shed at St Pancras station is the start and end of the Channel Tunnel Rail Link.

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Built on time and to budget, the Channel Tunnel Rail Link Project will provide much more than faster rail connections to Europe when it opens in November 2007. The new railway line will also improve local rail services while playing a major part in the rejuvenation of Kent and the East Thames Corridor. Mike Glover FREng was instrumental in the design and management of the technical aspects of the £5.8bn project and gives Ingenia an overview of the challenges faced and achievements accomplished.

The Channel Tunnel Rail Link (CTRL) opens in November 2007 when the first trains arrive at the renovated and redeveloped railway station at St Pancras in London. This major rail project – now known as High-Speed 1 (HS1) – to commemorate the UK’s first high-speed railway – set out to be much more than a fast railway link for international trains. CTRL will increase the railway system’s capacity for commuter and freight traffic. At the same time, the important new addition to the UK’s transport infrastructure will also support urban rejuvenation, making the link a major wealth creator for the country.

Work began on Section 1 of CTRL in 1998. Section 1 opened for commercial services on 28 September 2003, on time and within budget (The Need for Speed: Ingenia 17, 2003). When Section 2 opens, it will also have created the opportunity for high-speed extensions beyond St Pancras to the north. When the first trains start to run on the complete link in November, they will have the current journey time from the Channel Tunnel to London to 35 minutes. This will result in journey times from St Pancras to Paris of 3 hours 15 minutes and to Brussels of 1 hour 50 minutes.

These achievements underline a further, perhaps equally important, result of the CTRL. The project has demonstrated that the British construction industry can deliver a complex major infrastructure project, right into the heart of London, on time and within budget. The project achieved this while at the same time setting new standards of safety, efficiency, environmental protection and community relations.

PROCUREMENT STRATEGY

When the procurement strategy for CTRL was established in 1996, it was against a background of lack of trust and co-operation in the construction industry in the UK, often resulting in cost and time overruns. Mindful of this legacy of mistrust, CTRL set out to devise a procurement strategy that would provide contractors with incentives to complete work ahead of time and on budget, while also encouraging competition.

To make this more likely, the strategy promoted cooperation, as opposed to confrontation, placing risks where they could be best managed, and sharing the benefits of cost-saving ideas. An important aspect of this strategy for large civil engineering was to allow contractors early involvement to contribute to the design process and pre-plan and place early orders for the works. For all this to happen, contracts for the works had to be clear, flexible and simple. In particular, the procurement strategy used contracts that provided incentives to the parties through its gain share mechanism, whereby the contractor shared in the savings or excesses of the cost of the works compared to an agreed target cost.

WORKING PARTNERS

London and Continental Railways (LCR) won the concession to design, construct, operate and finance the project in February 1996. Rail Link Engineering (RLE), a consortium of Arup, Bechtel, Hazen & Sawyer, became project manager, responsible for design, project management, procurement, construction and commissioning of the CTRL under an agreement with LCR, administered by Union Railways, a subsidiary of LCR.

The management of any major project has to adopt as circumstances change. As the work on CTRL progressed, the strategy developed to suit the nature of the activity. For example, for the tunnelling under London, the four contractors involved formed an alliance to increase collaboration on technical and resourcing aspects. Where the works were particularly complex with multiple trades and interfaces, with building works for example, RLE acted as construction manager and let individual trade contracts on fixed scope and price.

BEING SMART

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CONSTRUCTION SEQUENCE

The bridge is built on the launching bay at the abutment. Launching is carried out a span at a time using large pushing jacks which grip onto skidding beams underneath the casting area. For Thurrock Viaduct the span was cast in four segments with the more complicated pier segment being built first. The launch cycle was approximately two weeks per span. The internal cables were laid on the floor in the casting bay, providing an internal space for the horizontal reinforcing bars to be placed. At each span, the bridge is supported by temporary bearings at the front and rear ends. After launching, additional moment is allowed for the bearings to accommodate the deflections during construction on the permanent bridge section. As the bridge is projected forward over the supports, the stress regime at the top and bottom of the bridge reverses from compression to tension and vice versa. Concrete is very strong in compression but not in tension and, as a result, pre-stressing techniques have been developed to neutralise the tension fields whereby the concrete is pre-compressed to give the full concrete section compressive strength. The concept is as follows:

DURING LAUNCHING

Provide constant pre-stress to cater for set movements during launching. This is provided using internal bonded pre-stress cable within the top and bottom slab.

AFTER LAUNCHING

Provide additional community pre-stress to cater for the additional moments from trains, blast and other superimposed loads. This is provided using pre-stress located within the box of the科技大学 and held in place at the top at pier diaphragms and at the bottom at intermediate diaphragms to balance the applied loads.
There were sceptics even within the transport community, with challenges on the feasibility of a link that was purely a high-speed international railway. It was only when Arup proposed realigning the route, and setting wider objectives of regeneration and improved local rail transport, that the project gained both public and political support.

A LONG JOURNEY

The concept of a rail link from the Channel to London has a long history of failed starts. The commitment to build the Channel Tunnel introduced an important ingredient, political will, into the venture. Even so, British Rail’s initial proposals in the late 1980s and early 1990s did not go down well in the affected communities. There were sceptics even within the transport community, with challenges on the feasibility of a link that was purely a high-speed international railway. It was only when Arup proposed realigning the route, and setting wider objectives of regeneration and improved local rail transport, that the project gained both public and political support.

Urban rejuvenation became the third key objective for CTRL. The new rail link will achieve this by providing the transport spine for the development of the East Thames Corridor. The new link will stimulate rejuvenation of distressed areas, at Ebbsfleet and the inner city sites around Stratford and King’s Cross. The new and expanded transport facilities and development at St Pancras, Stratford and Ebbsfleet were also a key feature in London’s successful bid for the Olympics in 2012. The CTRL’s success is encouraging greater political will in encouraging greater political will for future grand infrastructure projects.

ENGINEERING DESIGN

There are many notable elements within the design of the CTRL. For example, the design teams had to find a route that satisfied the tight constraints associated with a high-speed railway, whilst at the same time complying with the numerous undertakings given to protect the environment and amenity and to meet political demands, as with the routing of the railway through the centre of Ashford. This resulted in some heroic engineering, and imaginative three-dimensional solutions. There is a marked difference in the nature of the engineering works for Section 1 and Section 2. Section 1 is essentially across open countryside with substantial earthworks and numerous bridge crossings, although it does include the North Downs Tunnel and the massive cut and cover tunnelling works required to bring the CTRL through the centre of Ashford. Section 2 runs through a predominantly urban environment and involves long, large diameter bored tunnels for most of its length and station construction.

Much of the work involved innovations in engineering, particularly in the construction of bridges, and of the concrete sprayed North Downs Tunnel, the Earth Pressure Balanced Tunnel Boring Machines (EPBTBM) for the tunnels in Section 2, and the active minimisation of waste, in materials and resources. As if these challenges were not enough, most of the work for Section 1 took place during some of the worst weather conditions ever recorded for Kent!

MELDING OLD AND NEW

As well as creating the UK’s most modern railway line, the project also had to respect one of the rail network’s older buildings. The huge challenge at St Pancras was to create a design which was acceptable to all stakeholders and then to restore and extend the existing, rundown, 150-year-old Grade 1 listed station, from six short operational platforms into a major new international gateway to Europe with 13 platforms and a new underground station for Thameslink.

The station had to operate throughout construction: delivering the restored and extended station as a world class public building must rank as the high point of the project’s technical and design achievements.

MIXED TRAFFIC

The CTRL is double-track with a line speed of 300 km/h, reducing to 230 km/h in tunnels in Section 2. Unlike the French TGV network, the line can handle not only high speed TGV passenger trains but lines and to each side the connections to Ashford International Station. The through two track tunnels is about 14m wide and takes the up and down lines towards the Channel Tunnel. The maximum depth of the cut and cover tunnels is about 20m below ground level.

The cut and cover tunnels comprise 10 separate underground box structures which were designed to take account of the varying ground conditions, final layout and the most appropriate method of construction. The ground conditions in the area of the tunnels comprise Fill and Alumirum overlying Hythe Beds, Atherfield Clay and Weald Clay. The groundwater level is about 1-2m below ground level.

The cut and cover box structures and retained cuts were constructed using both top-down and bottom-up methods with a combination of temporary steel props, ground anchors and shallow and deep dewatering techniques. The structures consisted of embedded contiguous bored pile walls with reinforced concrete base and roof slabs and prop beams. Construction of the tunnels adopted the principles of the Observational Method – using defined trigger levels to control wall and ground movements as well as measurement of temporary and permanent prop loads during excavation. This enabled the construction to be completed successfully within the planned programme and generated savings in construction costs by reducing the number of levels of temporary propping.

Permanent gravity relief wells have been installed beneath the tunnel base slab to control and reduce the long term groundwater pressures. This enabled the capital cost of the box structures to be reduced with the owner and the maintenance of the tunnels inspecting and maintaining these wells during the lifetime of the structure.

CUT AND COVER TUNNELS

The CTRL (High Speed 1) passes through Ashford in Kent in cut and cover tunnels. The tunnels are located beneath a light industrial area and railway lands and close to housing through the centre of Ashford. The tunnels, together with approach ramps within retained cuts, are about 1.7km long. The western tunnel is about 25m wide and is designed to accommodate four tracks which comprise up and down through tunnels in Section 1, and a single through tunnel in Section 2, which runs through a predominantly urban environment and involves long, large diameter bored tunnels for most of its length and station construction. The station had to operate throughout construction: delivering the restored and extended station as a world class public building must rank as the high point of the project’s technical and design achievements.
also high-speed commuter operations, and freight trains. The need to operate mixed traffic has a marked impact on the infrastructure. The route has to accommodate freight loops, high-speed curves that are subject to maximum levels of cant deficiency, and neutral sections to deal with a range of train lengths. The signalling also has to accommodate the different speed requirements and braking characteristics.

The need for three intermediate stations – at Stratford, Ebbsfleet and Ashford – also had significant implications for the design of CTRL. The stations added greatly to the complexity of the rail infrastructure. For example, they increased the number of turnout configurations required and the complexity of the signalling control. To satisfy security considerations and the gauge of the trains, each station had to accommodate international TGV and commuter trains on different platforms, with separate access loops off the main line to the platforms for TGV and commuter trains.

The safety of staff and public was the top priority, with constant attention to safety and training throughout our Target Zero campaign. Many parts of the works were hazardous undertakings – underground in close proximity to electrified operating rails of very fast and busy operating stations. The project’s accident frequency rate was 2.5 times better than the industry average. This substantially reduced the risk of delay and disruption due to unsafe or environmentally damaging working.

ENVIRONMENT AND COMMUNITY

From the start, the project’s managers realised that they had to forge good relationships with the community, third-party stakeholders and planning authorities. The project’s achievements on this front are all the greater when viewed against the backdrop of the scale of the works and its potential for disruption to the communities involved. As well as providing a 21st century railway line, the long-term legacy of the CTRL will be in the regeneration of the derelict lands around the new stations.

As with CTRLs engineering management, the project’s quality and environmental management systems set out to achieve their objectives through self-certification and a programme of measurable continuous improvement. A number of initiatives improved communication and information management. These included setting up at the outset of the project a pan-project electronic data management system and purpose-written software for managing the project data and records.

Attention to environmental matters was a high priority in the development of the design and execution of the works. An example of this was the route itself. Over 60% of its length, the completed railway follows existing transportation corridors, specifically the M20 and M2 Motorways in Section 1. A quarter of the route also runs in tunnels, dominated by the deep bored tunnels in Section 2 under the Thames and then under London, running from Dagenham in the east to St Pancras/King’s Cross in the west.

EARTH MOVING

A further environmental requirement was to reduce visual intrusion. This resulted in the deliberately low vertical alignment of the track through Section 1. One consequence of this need to keep the track low generated a disproportionately high quantity of earthworks and requirements for drainage. For example, more than 15 million cubic metres of material has been excavated, but the work used only 2 million cubic metres of this as structural fill in the works.

The project used this excess of excavated material to good effect, largely in earthworks to mitigate the environmental effects of CTRL and in widening the M2. At Stratford, material excavated from the London Tunnels provided a clean and raised site around the new station, on lands that were once contaminated and subject to flooding. This now forms the site for the £4 bn, 25 ha Stratford City and Olympic Village developments. At King’s Cross/St Pancras the original railway land behind the stations has been cleared and decontaminated, with the remaining tenants accommodated in new facilities. This has created 25 ha for the £3.5bn development of King’s Cross.

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The alignment and size of the running tunnel was heavily influenced by the characteristics of the high-speed railway. A 7.15 m internal diameter was required to allow for the aerodynamic effects of trains operating at 200 km/h, and to limit the air pressure changes to maintain passenger comfort. Other constraints included the space requirements needed for mechanical equipment, kinematic envelope (the extremes that a train will move during its path of the train sets, pressure relief, emergency ventilation and tunnel emergency and maintenance walkways which also provided derailment containment).

The running tunnel linings were 356 mm thick, bolted precast concrete segmental rings, with an EPDM gasket (the black rubber linings in the photo above). Segments were bolted together using spear bolts (the holes in the segments above). Supported by an extensive loading and fire testing programme, the decision was taken to reinforce the segments with Steel Fibre Reinforced Concrete (SFRC) and microfibre polypropylene fibres, rather than traditional reinforcement cages. This was to increase durability and, more particularly, to increase fire survivability throughout, building on experience from the Channel Tunnel fire. Each running tunnel ring comprised seven ordinary segments, with a further two segments to form a key to the arcing length of each segment and associated bending stresses to within the capacity of SFRC. All 26,000 precast concrete segments were cast on site at two temporary manufacturing facilities at Ripple Lane and Stratford. These locations, a fully automated four-carousel system with a computer controlled batching facility was established to manufacture segments for the four tunnel drives serviced from Stratford.
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An engineering team from Staffordshire University has met a clinical need by designing and developing a surgical device that re-aligns fractures of the tibia and distal femur. Its design impressed the MacRobert Award committee, who chose it as a 2007 finalist. Professor Peter Ogrodnik, Managing Director of Intelligent Orthopaedics Ltd, writes about how engineers and medical staff combined forces to produce the Staffordshire Orthopaedic Reduction Machine (STORM).