

# Monitoring the Botlek Railway Tunnel

**Tareq Khodabacksh** of Senceive takes us on a tour through the history of Botlek and up to the construction of the very first bored railway tunnel in the Netherlands

**B**otlek is an industrial area and port near Rotterdam, Netherlands. Historically it was a port and was situated on the west of the Oude Maas river. In 1850, 750 hectares of land on the opposite side of the river was reserved for development over 25 years and rented out to various industries. The sheer volume of maritime traffic, which peaked during World War Two, highlighted the need for a bridge to be built.

In 1955 the Botlek 'Old Bridge' was opened, which carried a single track from Botlek to Pernis, serving the area well however the rise of industries such as petrochemical and an increase of import/export of containers going through the harbour meant that this bridge often had to be raised to allow container ships to pass and at a width of only 23 metres it left no room for an additional track to be built.

Dow Chemicals settled in 1956 and soon after the Cornelis Verolme shipyard opened in 1960, by now the whole 750 hectares was at capacity and in 1976 an additional road tunnel was built parallel to the Old Bridge. This carried all types of road traffic such as containers and the commuter vehicles carrying the thousands of workers to and from the newly industrialised area, except for dangerous/hazardous goods which were still carried by ship or train.

As part of the upgrade of the Betuweroute Dutch freight railway, which is a 160-kilometre railway carrying freight from Rotterdam's industrial and port areas to the German border. The Botlek railway tunnel was constructed by BAM Civiel B.V./Wayss & Freytag north of the existing Botlek bridge, crossing the river Oude Maas. This railway tunnel eliminates the traffic bottleneck at Havenspoorlijn, which occurred because of the old railway bridge at Botlek. This is the very first bored railway tunnel in the Netherlands and consists of two; partly open, partly closed ramps and two bored tunnel tubes.

Construction commenced in 1998 and it was officially opened by Netherlands' Minister for Transport, Karla Peijs, in October 2006. Construction of the 3-kilometre railway tunnel was complicated due to many reasons. Primarily there was a

lot of vulnerable infrastructure around the proposed site including power cables, storage tanks, roads and the rail bridge. Additionally, the riverbed's geological makeup was also fairly weak and required the soil to be reinforced by a concrete base layer.

The space shortage was one of the biggest obstacles, it meant that the same Tunnel Boring Machine (TBM) had to be used for both tubes, which is quite unusual. There was no room for the usual method which allows the receiving shaft of the first bore to function as the starting shaft for the second tube.

Therefore, the 800-tonne TBM was laboriously disassembled after drilling the first tube and returned to the starting shaft of the second tube for drilling. The Earth Pressure Balance (EPB) method was used for the drilling, which is the most common method used over the past 20 years and was used on the UK's Channel Tunnel and all new sections of the London Underground. The method involves excavating material and using it to support the tunnel face, by spoil being taken in by the TBM via a screw conveyor mechanism which then allows the pressure at the face of the TBM to remain balanced without the use of slurry.

This method fits best with the different soil conditions that would be encountered on the drilling path (sand, clay and peat). Most importantly the EPB method can be applied to a smaller work area, which has

been an important advantage in the limited space at this location. The resulting tunnel is double track, with two single track tubes at the location of the drill section with an inner diameter of 8.45 metres and variable 'heart-to-heart' distance of around 8.65 metres. This height accommodates trains with a double container load. The ramps were made by means of the Cut and Cover method, by driving sheet piles, excavating, pouring underwater concrete and drying the construction pits.

Ten years after the rail tunnel was completed, further reconstruction of the existing Botlek infrastructure by A-Lanes in the area meant that the new tunnel would be subjected to a potential high level of stress and deformation, and it was deemed necessary to carry out monitoring during these local construction/excavation works. Iv-Infra B.V., who provide multidisciplinary engineering service in the Netherlands and worldwide, were brought on board to carry out a monitoring strategy which was required to start from mid-2017.

In order to guarantee the safe operation of the railway, any soil movement due to the infrastructure works had to be monitored and researched to find the maximum permissible deformations of the joints between the tunnel sections in a 1.8-kilometre stretch of the tunnel. The tests estimated that the maximum movement could be up to  $\pm 3\text{mm}$  ( $2.18^\circ$  per tunnel element). The



Botlek west harbour, image courtesy of BoH, 2011



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Fig.1 shows FlatMesh™ configuration in the Botlek Tunnel

required system had to meet various strict requirements; firstly, that it accurately measures angles at a resolution of  $0.0001^\circ$  with the ability to monitor in near real-time. It also had to be easy to install, fully automatic, as well as discreet, extremely reliable and able to operate for many years without maintenance.

The system had to be robust and operate uninterrupted in the concrete tunnel which stretched for 1.8 kilometres. With no mobile signal or internet access available and no ventilation shafts or openings this was going to prove to be a challenge. Furthermore, physical intervention and maintenance had to be kept to an absolute minimum during the monitoring period so as not to interfere with the operation of the train line.

Iv-Infra identified Senceive's FlatMesh™ system as one that met all of their stringent requirements, 12-15 years of battery life, remotely configurable, excellent repeatability and they were also brought on board because of their proven pedigree with tunnel wireless remote condition monitoring systems. An example of this would be their work on the UK's Brunel Box Tunnel where they won an NCE Tunnels and Underground Structures award.

The award winning FlatMesh™ system works by creating a wireless mesh network, which allows a node to communicate with one or more of its neighbouring nodes. All the nodes in the network may act as a repeater, and this is often characterised as a non-hierarchical network architecture. The nodes forward data via their neighbours, using the most efficient route, in the direction of the gateway, which then collects the data and sends it on to users via the data backhaul. This intelligent architecture allows for the network to be self-configuring, which makes it 'self-healing' and robust, as well as easy to extend and amend (Fig.1).

The tunnel lining is composed of 1,220 tunnel rings, consisting of seven 1.5-metre wide, 40cm thick, precast concrete segments each and a closing/keystone segment, connected to each other by a groove and

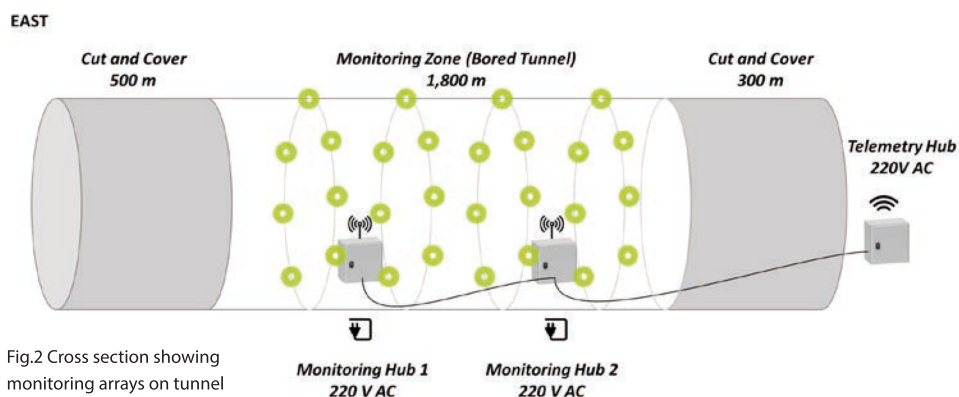


Fig.2 Cross section showing monitoring arrays on tunnel ring segments

tongue system. Collaboration between Iv-Infra and Senceive developed the design so that six segments (out of seven) and one closing/keystone segment could be monitored every 30 metres using a total 434 FlatMesh™ triaxial tilt sensor nodes installed over the 1.8 kilometres of concrete lined tunnel taking readings every 30 minutes (see node positioning in Fig.2). The tilt nodes' triaxial capability mean that they can be positioned at any orientation, with no fiddly levelling or varying bracketry needed (Fig.3). To offer further mobility and flexibility during installation, these were attached with  $360^\circ$  swivel mounts, secured with concrete screws.

To overcome the issue of lack of cellular network availability, Senceive used two monitoring hubs located 800 metres from each entrance, to receive the data from the wireless nodes. These monitoring hubs utilised the tunnel's 220V power supply and relayed data via a two-kilometre telecommunications cable to a telemetry hub located outside the tunnel entrance. Data was then easily transmitted through the cellular network to monitoring servers. Iv-Infra opted to use their own software to read and process the data, and Senceive's secure WebMonitor software also allowed the support team to undertake system health checks accessed on a computer, tablet or smart phone worldwide.

All the data from the 434 sensor nodes is accessible in real-time via these web interfaces and after the relevant calculations have been performed, the joint deformations

could then be easily displayed in millimetres. This provides an extremely reliable solution for performing measurements in tunnels, where normally the use of kilometres of cabling, access issues and lack of phone connectivity often presents a major challenge.

FlatMesh™ triaxial tilt nodes were the ideal choice, as they could be installed with ease and efficiency. This reduced man power, time and saved on costs. Senceive were also able to offer training and comprehensive support throughout the project. The extremely reliable and robust system also eliminated the need for any further maintenance or visual checks. For example, when construction works above ground commenced, Iv-Infra requested the reporting rate of the nodes to be increased to 7.5 minutes in certain areas. The system allowed this to be done remotely with no physical intervention at all. Panos Oikonomidis, the Monitoring Advisor for Iv-Infra said that: "They provide us an easy-to-place, accurate and reliable product to use and in addition to their 24/7 assistance, we are one hundred per cent satisfied. Senceive rocks!"

The tunnel is designed for a life expectancy of one hundred years and Senceive's monitoring is thought to continue for the full battery life of the nodes of up to 15 years, with the intentions to replace the batteries and continue monitoring for a duration of 25 years.

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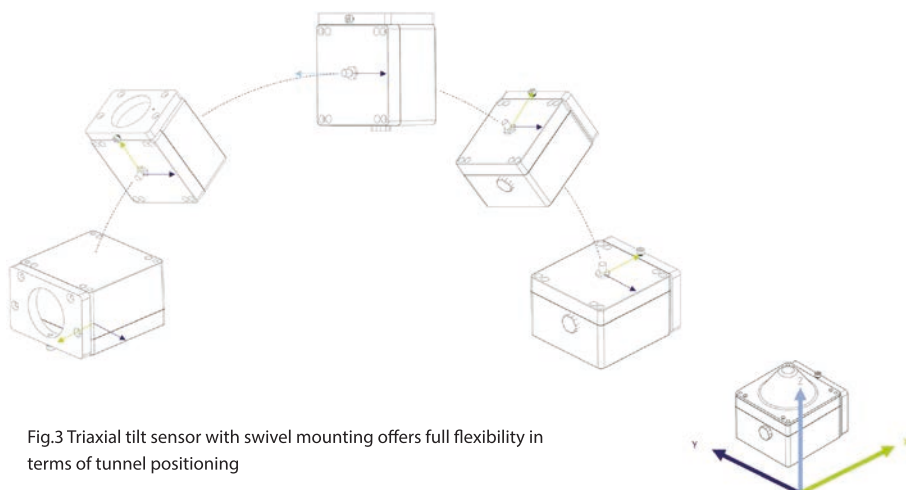


Fig.3 Triaxial tilt sensor with swivel mounting offers full flexibility in terms of tunnel positioning