Box Tunnel, which runs under Box Hill in Somerset, is an impressive Victorian structure. Designed and built between 1836 and 1841 by engineer Isambard Kingdom Brunel when he was just 27 years old, the 2.9km railway tunnel passes through four different geological strata and fault zones.

Box Tunnel carries the Great Western Mainline in both directions between London and Bristol. When Network Rail wanted to electrify the line to improve efficiency and reduce environmental impact, the challenge was how to lower the track bed by 350mm to create room to install overhead catenary wires without disturbing this historic structure.

Network Rail employed Aecom to assess the condition of the tunnel and devise a strategy to protect it. Network Rail had a six-week window to carry out the work. The planned construction sequence involved the excavation and replacement of 100m of track-bed per shift.

Structural analysis and deformation modelling showed that it would be necessary to monitor the tunnel before, during and after the construction period as parts of the structure would be susceptible to damage when the track bed was being excavated.

Aecom elected to use Senceive’s wireless tilt sensors and FlatMesh system. The wireless mesh allows the sensors to talk to each other, sending the signals through a variety of routes to a battery-powered gateway which then transmits the data to the internet. The short window given to implement an asset protection system meant that something had to be in place very quickly as there was not enough time to set up a power source for a 3km tunnel. A traditional optical system using total stations and prisms would have been inappropriate as dust and plant would have obscured lines of sight and surveying equipment could have interfered with the kinematic envelope for both trains and construction plant.

Constructed by drill and blast, two-thirds of Box Tunnel was lined with four or five rings of brick in 1894, due to instability.
where it passes through mudstone. The remaining third, through limestone, is unsupported but for three free-standing arches, designed to prevent rock fall.

The task of modelling the tunnel was made more challenging by a number of other features. The tunnel has multiple vent shafts running up from the crown of the tunnel, some open, some closed and others hidden. Additionally, in the area surrounding the tunnel are a plethora of disused mining tunnels, including a subway that passes underneath, built to create access to limestone seams – although it was never used. The subway was filled with concrete before the track lowering began.

A number of investigation techniques were used to assess and model the structure and the ground surrounding it, including trial holes, structural cores and ground penetrating radar. The results of these investigations then informed finite element analysis for the brick-lined sections which would be most susceptible to instability during and post-construction.

The data advised whether it was safe to continue, whether the excavation lengths needed to be reduced or increased and when the contractor was approaching a fault or a section around a shaft.

In designing the monitoring regime, the most challenging aspect was installing the tilt sensors in such a way that their readings could be converted to measurements that were representative of the model deformations.

By experimenting with tilt sensors on different lengths of beam, 0.5m emerged as the optimum length. Over the space of two engineering shifts, 250 Senceive tilt sensors were installed, one on each side wall at 20m centres in high-risk zones and at 50m centres elsewhere. At critical locations, such as construction changes and shafts, sensors were installed in arrays, all the way round the tunnel. The arrays measured the convergence as well, rather than just the tilt. The accuracy and stability/repeatability of the data from the sensors was also critical.

Senceive made two developments to its system for this application. First, automatic backup gateways were required to provide resilience should the primary gateway fail – although these were never used. Secondly, a system was needed to switch between batteries to power the gateway should the first one fade.

Once installed, the sensors sent readings every 15 minutes with trigger levels which were set from the model. Engineers were on site 24-7, to work with the construction team, so that they could understand the impact their activities were having on the tunnel structure. The sensors were able to provide highly stable and repeatable data at below 0.1mm/m which meant early indication of any potentially significant movement.

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The track lowering, including the installation of 50,000 tonnes of ballast and 14,000 new sleepers, passed without incident, the only alarms triggered being false ones. The 175-year-old tunnel stood firm throughout the construction period, with the maximum deformation experienced less than 2mm.

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