Case Study

Structural Monitoring in Railway Infrastructure

Dynamic Integrity Monitoring for Rail Infrastructure Using Distributed Fibre Optic Strain Sensors

Introduction

Sensornet & SOAM Consultants, together with the Koran Railway authorities (KORAIL), carried out the first ever distributed dynamic strain measurement on the Korean Train eXpress (KTX) railway track in Daejeon, South Korea.

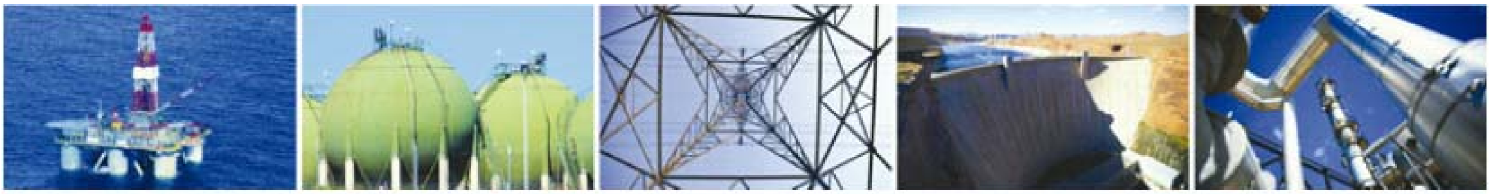
The aim was to analyse the integrity of a section of track that had recently been repaired. The Sensornet Distributed Temperature and Strain Sensor (DTSS) was used to monitor this 60m section of track while a KTX train passed over.

Distributed Strain Sensing

The unique Sensornet DTSS is capable of independently measuring strain and temperature at every position along an installed length of optical cable. The system achieves this by interrogating the backscattered Brillouin light but, unlike other Brillouin based sensors, does not suffer from a temperature and strain cross-sensitivity.

The DTSS is optimised for single-ended measurements, needing access to just one end of the installed cable. Sensornet's revolutionary approach replaces the need for multiple point sensors with one distributed sensing cable, reducing design, installation & instrumentation costs and greatly improving the amount of information obtained.

During 2005, Sensornet introduced a new innovation to the DTSS, for the first time achieving fast (dynamic), fully distributed measurements of strain. The instrument can now measure strain at acquisition rates of up to 10Hz (ten times a second), allowing detection of rapid deformations or movements in structures.



Previously, Brillouin based distributed sensing systems would taken anything from 20 seconds to 20 minutes to compete a single measurement. The introduction of dynamic distributed strain sensing opens up a range of new monitoring applications. SOAM Consultants & KORAIL were quick to explore the benefits of this revolutionary new technology with the dynamic strain sensing trial on the KTX track at Daejeon.

Monitoring the Section of Track

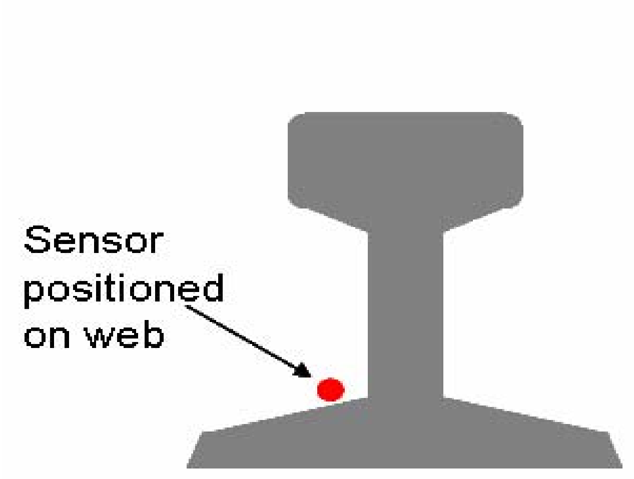
For this trial the DTSS sensing cable was bonded to the flange of the rail, close to the intersection with the lowest part of the web. This position was chosen for ease of installation and higher sensitivity to flexural movements. The sensing cable was installed as a temporary trial and so un-armoured fibre optic cable with an OD of 1mm was used. For longer term installations, Sensornet can supply a range of cables which provide greater protection to the fibre, while still transmitting the strain from the monitored structure to the fibre inside.

Bonding of Sensor cable to Rail

The cable was bonded to the rail along a 60 m section of the track, close to the platform at Daejeon. Towards the far end of the 60m section the fibre crossed over a section of track which had been previously repaired. An expansion joint was inserted here to alleviate problems arising from expansion during the winter and summer months. Additionally, one of the concrete sleepers was replaced with a wooden sleeper and so overall, greater flexing of the rail was expected in the region of this expansion joint.

KTX Train

With the historical opening of the KTX in April 2004, Korea has joined the league of France, Japan, Germany and Spain and entered into the super high-speed train era, operating at speeds of 300km per hour. Each KTX train consists of 2 power cars, and 18 passenger compartments, resulting in a total length of 388 m in length and has a weight of 771.2 tons (with passengers onboard).



Measurement Results

The KTX was monitored as it decelerated into the station, taking approximately 1 minute to pass the monitored section of track.

The dynamic strain data was captured by the DTSS and converted into a 2-dimensional colour map to visualize the changes in strain.

The distance along the sensing cable is shown along the X-axis and time along the Y-axis, while the intensity of strain is visualized according to colour varying from blue (0 microstrain) to red (equaling 90 microstrain). Note, that the DTSS was situated at a distance from the track and so there was a communication lead of 190m between the DTSS and the monitored section. The section that had been repaired is located at 260m along the length of the sensing cable. The colour map indicates the change in strain of the rail relative, to a period of time just before the train arrived when there was no changing strain in the rail. This is done to remove any long term variations in strain resulting from installation of the fibre, which is quite normal.

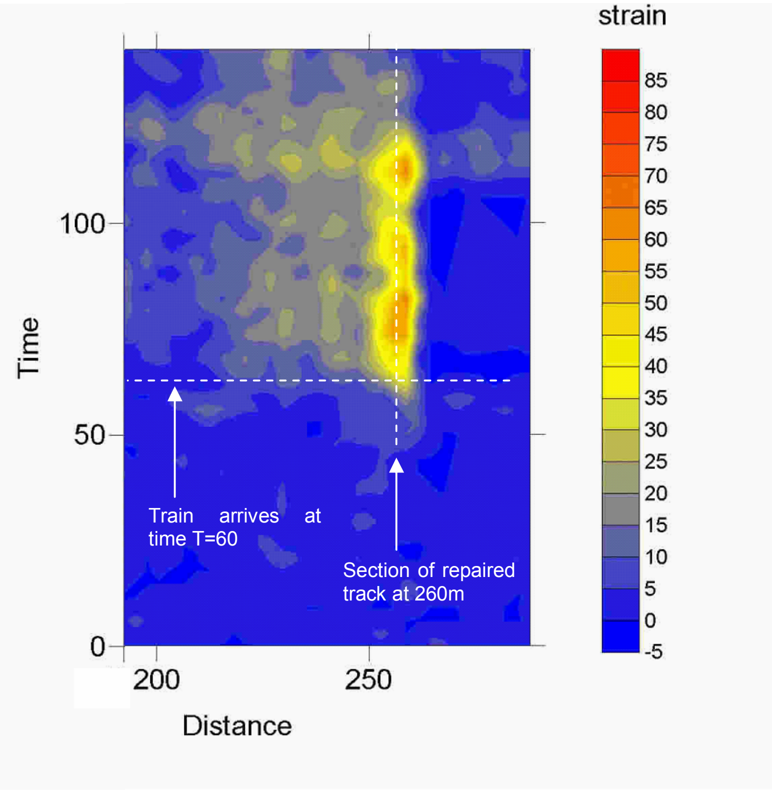
As can be seen from the chart from time T=0 to T=60 seconds, the strain along the monitored section of rail is very small, in the range of 0-10 microstrain. Once the train arrives there is a substantial increase of strain in the rail when the train passes over it. In the repaired section the strain increases to levels of 90 microstrain, whereas in the section of regular track the strain is in the region of 30-50 microstrain.

Measured Results vs. Theoretical Calculations

An estimation of the typical strain in the rail was calculated theoretically by an independent engineering consultant. The following assumptions were made:

- 8 tonnes [80kN] on each wheel,
- wheel midway between sleepers 500mm apart.
- Rail 140mm deep, 140mm wide flange and 10mm thick web and flange

The rail was considered as a constrained beam but allowing for less moment restraint at the ends since sleepers do not typically rigidly constraint the rails. The most extreme bending moment will be in the middle.



Stress = M/Z = 3.33/0.19 Nmm^-2 = 18MPa

Strain = stress/E = 18MPa/210GPa = 100 microstrain

The theoretical calculation, whilst based on several broad approximations, yields an expected strain value of 100 microstrain, in excellent agreement with the DTSS.

Summary

According to the calculations, the stress is well within limits and so under current condition the rail is flexing within operating guidelines. The results were excellent since they demonstrate that the DTSS is able to measure small, dynamic changes in strain in rails during normal operating conditions. Measuring the change in strain of a rail during dynamic loading provides a far more relevant indication of rail integrity than long term strain monitoring. The current 10km range of the DTSS creates a potential to monitor the integrity of large lengths of track, and especially higher risk sections such as bridges, repaired track and areas at risk of subsidence.