# Case Studies on Distributed Temperature and Strain Sensing (DTSS) by using optic fibre

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*Abstract* — **Brillouin backscatter is a type of reflection that occurs when light is shone into an optical fibre. Brillouin reflections are very sensitive to changes in the fibre arising from external effects, such as temperature, strain and pressure. We report here several case studies on the measurement of strain using Brillouin reflections. A mechanical bending test of an I beam, deployed with both fiber optic sensors and conventional strain gauge rosettes, was performed with the aim of evaluating: (1) the capability and performance of the DTSS technology for strain profile sensing; (2) the reliability of strain measurement using fiber optic sensor. A practical application of DTSS technology as an early warning system for land sliding or subsidence was examined through a field test at a hillside. We also carried out the first ever distributed dynamic strain measurement (10Hz) on the Korean Train eXpress (KTX) railway track in Daejeon, Korea. The results were excellent since they demonstrate that the DTSS is able to measure small, dynamic changes in strain in rails during normal operation conditions. 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.**

*Index Terms* — **DTSS, dynamic strain measurement, optic fiber, subsidence monitoring.**

## I. INTRODUCTION

All industrial structures are deformed with the passage of time by a lot of causes (for example: earthquake, vibration, ground condition). The deformation of structure can be estimated by strain measurement. If strain measurements can be repeated at many points in a structure, we can consider a counter-plan for the safety of the structure. However, if strain gauge rosettes are used for strain measurement, it is very difficult to attach many rosettes to the structure and also to measure strains simultaneously at so many positions. Meanwhile, strain measurement using an optical fibre will be more suitable for practical purposes, since strain measurements can be provided at every meter along the optical fibre attached to the structure.

In this study we report several experiments demonstrating the reliability, performance and application of Distributed Temperature and Strain Sensing (DTSS), developed by Sensornet.

## II. PRINCIPLE OF DTSS

The phenomenon of Brillouin scattering was discovered by the French physicist, Léon Brillouin (1889-1969), and its measurement is at the heart of the Sensornet DTSS system. Brillouin scattering is a type of reflection that occurs when light is shone into an optical fibre. An optical fibre guides not just light waves, but also naturally occurring sound waves. An interaction between the light waves and sound waves traveling within the fibre causes Brillouin reflections. Brillouin reflections comprise two components – Stokes and anti-Stokes light, each being a different frequency from the original light in the fibre. Brillouin reflections are very sensitive to changes in the fibre arising from external effects such as temperature, strain and pressure.

Fig. 1 shows changes in both Brillouin frequency and power caused by changes in temperature and strain. The DTSS measures the entire Brillouin spectrum (the Brillouin frequency and power for both Stokes and anti-Stokes light) at every 1m along the fibre [1]. Analysis of this data allows the Sensornet DTSS to uniquely measure strain and temperature simultaneously, and independently, at every position along the fibre, resulting in no temperature and strain cross-sensitivity.

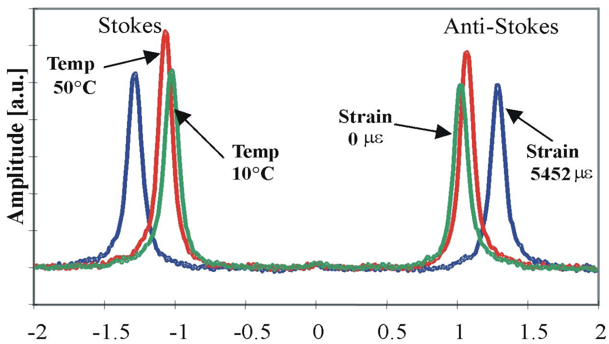


Fig. 1. Changes in Brillouin frequency with temperature and strain.

The latest DTSS system developed by Sensornet provides three different measurement methods. Firstly, the DTSS provides temperature compensated strain measurements as just described. This is essential for most applications, to account for variations in temperature. Secondly the DTSS provides a strain measurement without temperature compensation. Thirdly the DTSS provides a unique measurement of dynamic distributed strain, allowing detection of real-time changes in structures by measuring strain at acquisition rates of up to 10Hz (ten times a second).

## III. I Beam Bending Tests

Fig. 2 shows the experimental setup for I beam bending tests at the Korean Electric Power Research

Fig. 2. Steel I beam bending tests (KEPRI, 2005).

Institute (KEPRI). Both an optical fibre and strain gauge rosettes were deployed along the underneath of an I beam as shown in Fig. 3. An optical fibre was looped backwards and forwards 5 times along a central 3 m section whilst 10 strain gauge rosettes were also installed for comparison. Fig. 4(a) shows the results of distributed

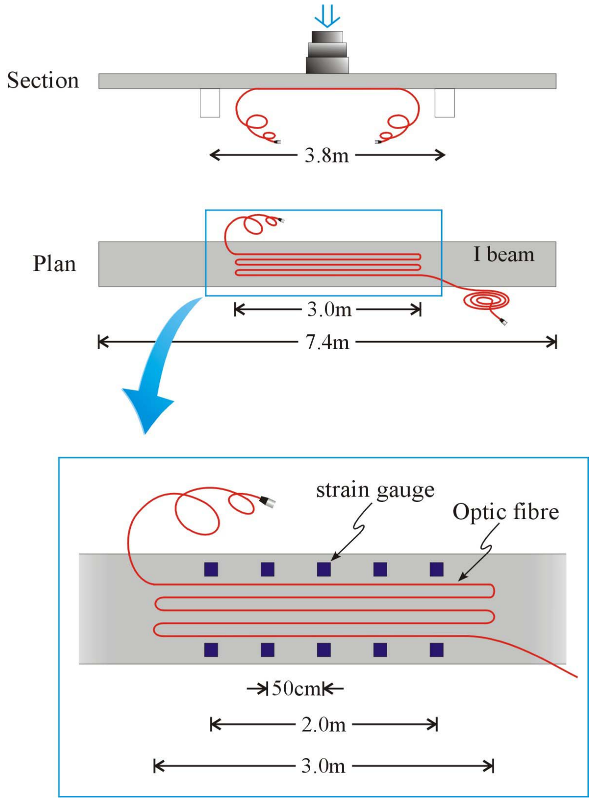


Fig. 3. Layout of an optic fibre and strain gauges attached to I beam.

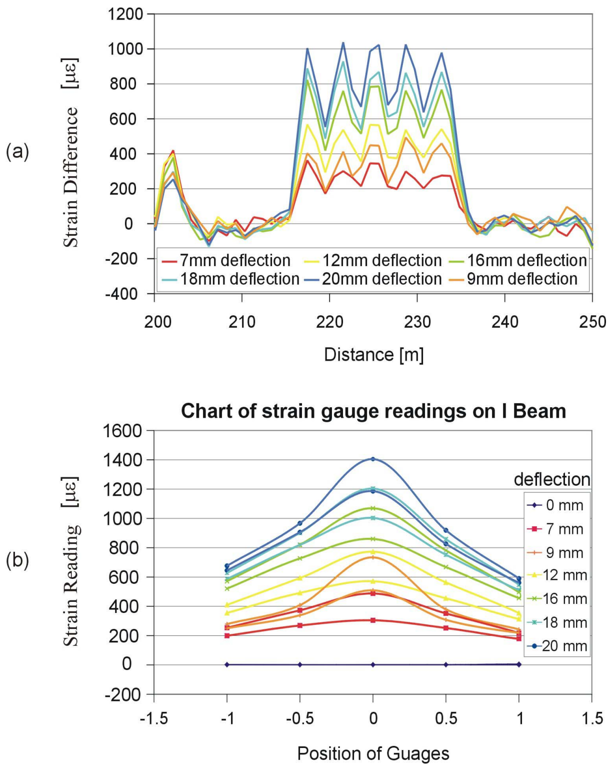


Fig. 4. Result of strain measurements.
(a) Using an optic fibre and DTSS.
(b) Using strain gauges rosettes.

strain measurements by the DTSS system. The 5 peaks in deflection are clearly seen increasing with increasing deflection of the beam. Importantly, the strain measured for both increasing and decreasing amounts of deflection. Fig 4(b) shows the results of strain measurements from the strain gauge rosettes. The average measured strain from the DTSS and the strain gauges is compared in Fig. 5. They show an excellent one-to-one, linear relationship, demonstrating the validity of using optical fibre as a strain measurement method.

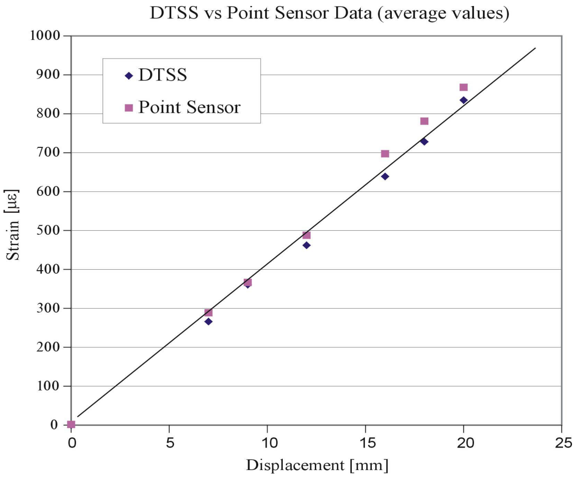


Fig. 5. Comparison of DTSS and strain gauges results.

## IV. Land Sliding and Subsidence Applications

The behavior of rock and/or ground can be verified using distributed strain monitoring. After installation of a DTSS cable underground, periodic strain monitoring can be carried out. A counter-plan for safety can be established for any detected changes in strain. Similar measurements have been undertaken in embankment dams [2]. Fig. 6 shows photos from strain monitoring of land sliding and subsidence that was performed at a hillside in the grounds of the Korea Institute of Geoscience And Mineral resources (KIGAM).

Extremely strong, lightweight, rugged cables, designed for optimal strain transfer to the fibre, were used and clamped on the subsurface at a depth of about 50cm. Because land sliding and/or subsidence could not be expected within a short period in the test area, strain changes were artificially induced by a pushing tool and a weight drop tool as shown in Fig. 6. The results of DTSS measurements are shown in Fig. 7. A pushing tool caused the effect of land sliding, the corresponding strains increased up to 1,500με depending on the pushing degree. It was expected that dropping a weight would induce slight subsidence. It actually resulted in 1,400με strain increase. It has been proven by other experiments that the DTSS cable used here can measure up to 28,000με strain, or 2.8%, for short periods of time.

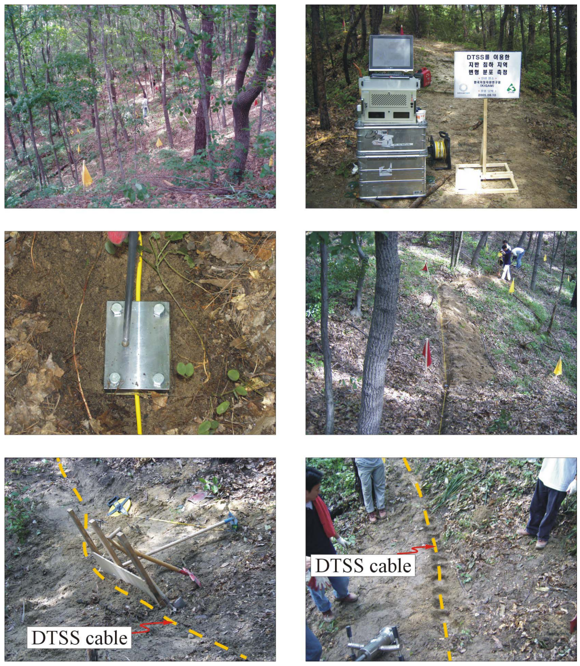


Fig. 6. Pictures of DTSS strain monitoring for land sliding and subsidence applications (KIGAM, 2005).

Since the DTSS is able to measure ground movements over a 10km length of cable, it is anticipated that the DTSS system will be an efficient and economical warning system for land sliding and/or subsidence.

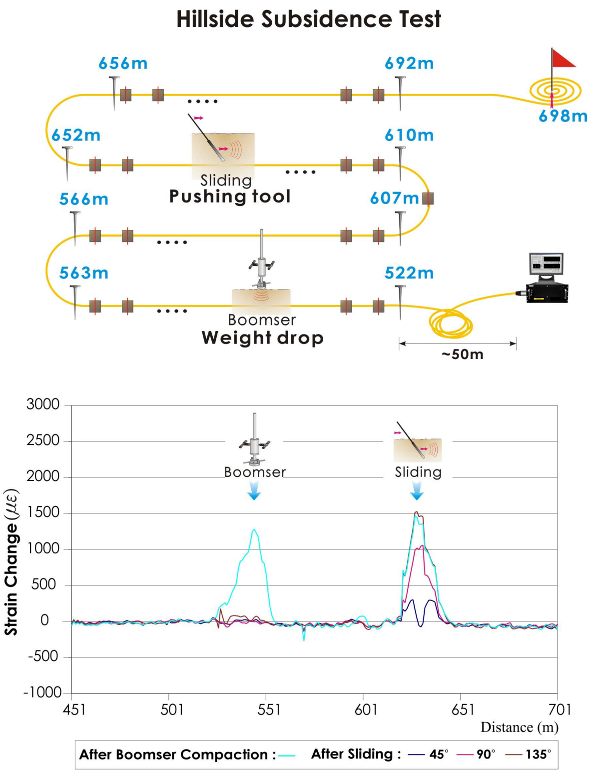


Fig. 7. The results of DTSS measurements for land sliding and subsidence applications.

## V. Dynamic Strain Monitoring of Rail Track

Fig. 8 shows the attachment of the DTSS cable to a section of rail track, close to the platform at Daejeon Railway Station. 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. Greater flexing of the rail was expected in the region of this expansion joint.


Fig. 8. A Scene of DTSS cable bonded to the rail section (Daejeon, 2005).

Dynamic strain monitoring was performed as the KTX decelerated into the station, taking approximately 1 minute to pass the monitored section of track. Fig. 9 shows the dynamic strain data which 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, 0με, to red, 90με.

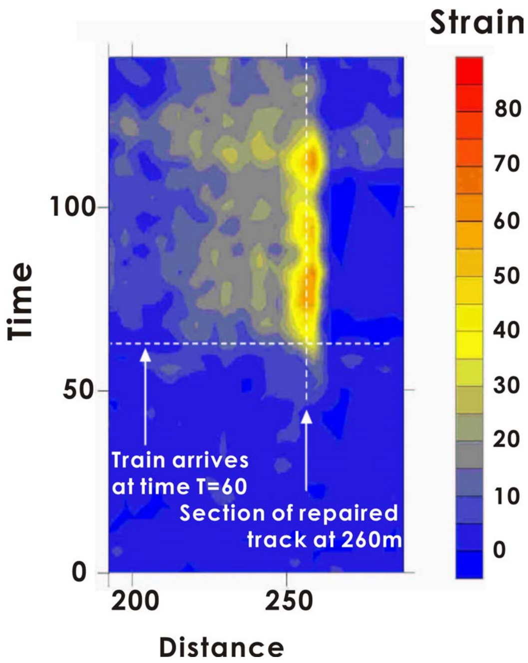


Fig. 9. Results of dynamic rail monitoring.

The train travels into the station, passing first the 260m distance, traveling towards 190m, covering the 70m monitored section. The section that had been repaired is located at 260m along the length of the sensing cable. The colour map shows the change in strain of the rail compared with a period before the train arrived when there was no loading of the rail. This is done to remove any long term variations in strain resulting from installation of the fibre, which is quite normal.

The chart indicates that the strain prior to the train arriving ($T<60$) is very small, 0 – 10με. As the train passes over the rail there is a substantial increase in the measured strain. In the repaired section the strain increases to 90με,whereas in the section of regular track the strain is in the region of 30 – 50με. This measurement demonstrates the benefit of monitoring the track under a dynamic load.

## VI. Conclusion

These experiments have demonstrated that distributed optical strain sensing agrees excellently with electrical strain gauges. Rugged and strain sensitive cable technology will allow structural monitoring of large steel and concrete structures. A demonstration of how distributed strain sensing can provide a cost effective solution to subsidence monitoring has also been presented. In a unique experiment, we have also demonstrated the ability to measure dynamic changes in strain of a rail track. This provides strong evidence for using distributed optical sensing in the future to monitor rail network infrastructure.

## References


[1] T. R. Parker, M. Farhadiroushan, V. A. Handerek, and A. J. Rogers, "A fully distributed simultaneous strain and temperature sensor using spontaneous Brillouin scatter", *IEEE Photonics Technology Letters,* vol. 9, no. 7, pp. 979-981, July 1997.

[2] S. Johansson, M. Farhadiroushan, T. R. Parker, D. Watley, "Distributed strain measurements for embankment dams – Laboratory tests, installation and initial monitoring experience", *Elforsk rapport 03:19 Stockholm*, 22p. 2003.