Key Engineering Materials Vol. 558 (2013) pp 424-434
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doi:10.4028/www.scientific.net/KEM.558.424

Distributed Optical Fibre Sensors and Their Applications in Pipeline Monitoring

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Keywords: Brillouin scattering, structural health monitoring, distributed sensor, OTDR.

Abstract: Health monitoring of civil infrastructure systems has recently emerged as a powerful tool for condition assessment of infrastructure performance. With the widespread use of modern telecommunication technologies, structures could be monitored periodically from a central station located several kilometres away from the field. This remote capability allows immediate damage detection, so that necessary actions are taken to reduce the risk. Optical fiber sensors offer a relatively new technology for monitoring the performance of spatially distributed structures such as pipelines. In this regards, several commercially available strain and temperature sensing equipment such as discrete FBGs (Fibre Bragg Gratings) and fully distributed sensing techniques such as Raman DTS (distributed temperature sensor) and Brillouin Optical Time Domain Reflectometry (BOTDR) typically offer sensing lengths of the order of 100 km's. Distributed fiber optic sensing offers the ability to measure temperatures and/or strains at thousands of points along a single fiber. In this paper, the authors will give a brief overview of these optical fiber technologies, outline potential applications of these technologies for geotechnical engineering applications and experience in utilising BOTDR in water pipeline monitoring application.

Introduction

Water pipeline integrity and potential threats of failure are generally not monitored at the present time. A major issue of monitoring existing pipelines is that most pipelines are buried and it is not easy to get access to retrofit monitoring sensors. However, when new pipelines are installed, it is relatively easy to install monitoring systems. Such installations are expected to monitor the pipelines continuously providing warnings of any direct damage to pipelines and any deterioration of pipe and environment that can lead to reduction of the life of pipelines. Depending on the pipe characteristics, a range of measurands such as pipe strain, temperature, corrosion and thickness reduction, leakage acoustics, and pressure transient responses have been used to detect the pipe condition. Various non-destructive evaluation (NDE) methods, such as ultrasonics, radiography, acoustic emission, magnetic flux and eddy current, have been developed to detect damage in civil infrastructure, especially for the pipe networks. While these methods provide useful approaches in highly localized situations, many of these methods suffer from distinct disadvantages such as the lack of portability, susceptibility to electromagnetic interference on electrical/electronic instruments, and lack of capability for continuous performance monitoring. In addition, the ability to deploy these techniques over large and remote distances is extremely limited.

In many structural and geotechnical applications, it is often desirable, and sometimes even imperative, that strain and temperature are monitored at multiple locations at the same time. In recent years, the use of wireless sensors has emerged overcoming some of the difficulties, but still the need for continuous power supply remains an obstacle. When traditional electrical sensors are used, the sensor network is complex, difficult to install and maintain, and expensive. Moreover, the use of these discrete sensors for large civil structures is simply impracticable and not cost effective.

A distributed sensor network is in great demand in harsh environments or large structures. Fibre optic sensors offer the possibility of supporting a large number of sensors in a single optical fibre line owing to the tremendous optical bandwidth and low power loss. Further, it has the capability to evaluate distributed engineering parameters (i.e., strain and temperature) over several tens of kilometers in various types of large-scale structures, as shown in Fig. 1. It is a powerful diagnostic instrument for the identification and localization of potential problems. It allows the monitoring of local strain, temperature, and corrosion rate, etc at thousands of locations distributed along a single mono-mode optical fibre. These sensors can be distributed along the pipe network via the guiding of lightwaves along the fibre optic lines.

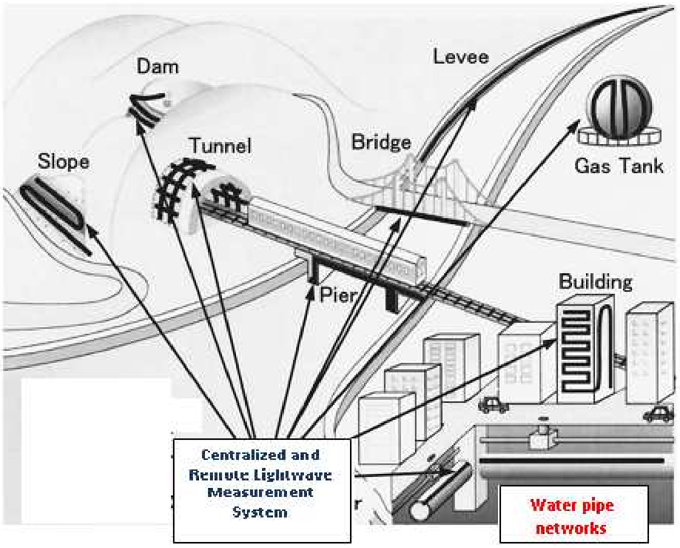


Figure 1. Structural monitoring by optical fibre sensor

However, this technology is relatively new and there are still many areas where research effort is required before field deployment: (1)The commonly advocated and highly attractive continuous measurement of parameters using single optical fibre without specific sensor points (e.g., gratings) may provide only a qualitative output and may not be useful for engineering analysis, if the post processing of the signal is not adequate. Thus, work is required to establish a good understanding in processing these measurements into useful engineering quantities; (2) Sensor development is still very much at its infancy (e.g., for detection of corrosion); (3) The long term durability and stability of the sensing system in the real world environment also needs to be established.

In this paper, the available optical fibre technologies for condition monitoring of civil structure is summarised, an outline of potential applications of these technologies for geotechnical engineering applications and experience in utilising BOTDR in pipeline monitoring application. Finally, a conceptual condition monitoring approach for new pipeline is proposed.

Overview of optical fibre technology

An optical fibre is a cylindrical dielectric waveguide made from silica glass or a polymer material. A schematic of a common form of commercial telecom fibre optic cable is shown in Fig. 2. Both the core and the cladding are made from glass or plastic, and the surrounding coatings used to protect the optical fibre are made from acrylate or polyimide materials. Optical fibres come in two configurations, multi-mode (core size 50~100 μm) and single mode (core size <10 μm).

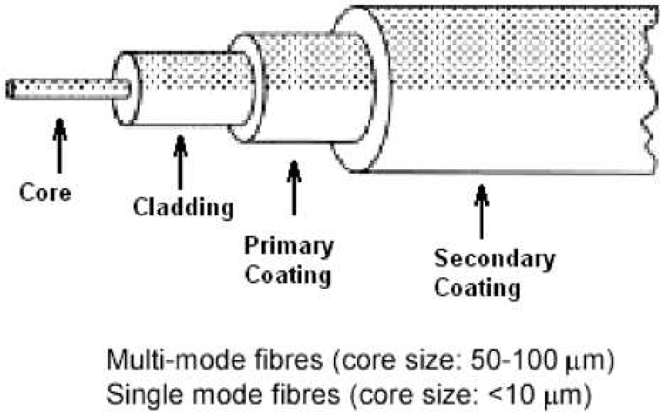


Figure 2. Structure of an optical fibre

An optical fibre sensor embedded in or attached to structures expands or contracts by small amounts according to strains on the structure and temperature variations. When a portion of the light is sent down the fibre to the sensor, it is modulated according to the amount of the expansion or contraction (change in the length of the sensor). Then, the sensor reflects back an optical signal to an analytical device which translates the reflected light into numerical measurements of the change in the sensor length. These measurements indicate the amounts of strain or temperature within the structure.

Optical fibre sensors can be divided according to the sensing technology such as distributed sensing and multipoint localized sensing (i.e., discrete sensors). If sensing is distributed along the length of the fibre, an optical time domain reflectometry (OTDR) is needed to determine the location of any variation in the measurand. Localized or point sensor, as the name implies, detects measurand variation only in the vicinity of the sensor. A Raman Optical Time Domain Reflectometer (ROTDR) used for distributed temperature measurement and a Brillouin Optical Time Domain Reflectometer (BOTDR) used for distributed strain and/or temperature measurement belong to the distributed sensing technology. Fibre Bragg Grating (FBG) belongs to the localized sensing technology and measure the strain and temperature separately. The basic concepts of these two types of sensor technology are shown in Fig. 3.

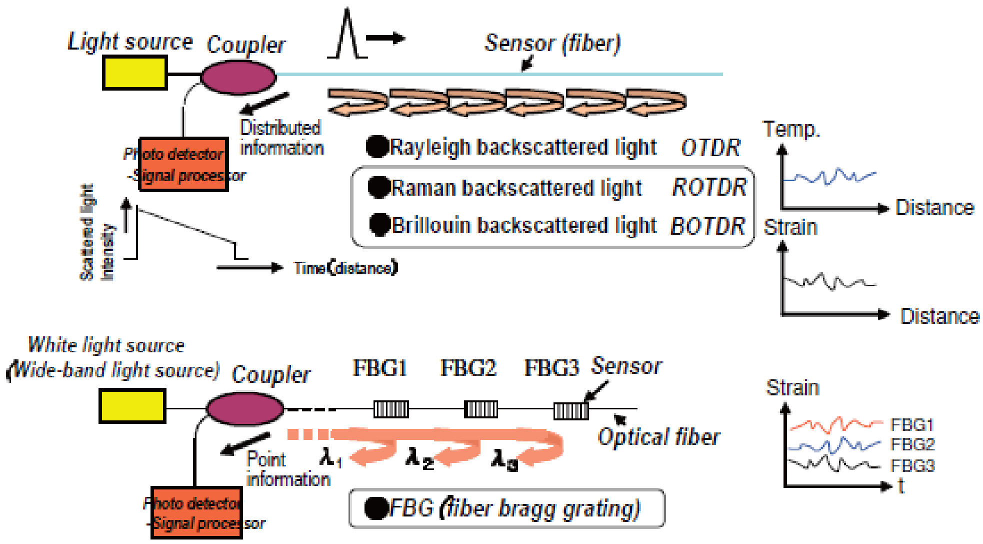


Figure 3. Basic concept of optical fibre sensing

As stated above, distributed fibre optic sensing offers the ability to measure temperatures and strains at thousands of points along a single fibre. This is particularly interesting for the monitoring of large structures such as dams, tunnels, pipelines, bridges and landslides, where it allows the detection and localisation of movements, leakage, deflection and seepage zones with sensitivity and localization accuracy unattainable using conventional measurement techniques. Sensing systems based on Brillouin and Raman scattering are used to detect the localised strain and/or temperature, allowing the monitoring of hundreds of kilometers along a structure with a single instrument with an accuracy of 1 meter.

Both the Raman and Brillouin scatterings make use of a nonlinear interaction between the light and the glass material of which the fibre is made. If an intense light at a known wavelength is shone into a fibre, a very small amount of it is scattered back from every location along the fibre itself. Besides the original wavelength (called the Rayleigh component), the scattered light contains components at wavelengths that are higher and lower than the original signal (called the Raman and Brillouin components). These shifted components contain information on the local properties of the fibre, in particular its strain and temperature. Fig. 4 shows the main scattered wavelength components for a standard optical fibre. If λ_0 is the wavelength of the original signal generated by the readout unit, the scattered components appear both at higher and lower wavelengths. The two Raman peaks are located symmetrically to the original wavelength. Their position is fixed, but the intensity of the peak at lower wavelength is temperature dependant, while the intensity of the one at higher wavelength is unaffected by temperature changes. Measuring the intensity ratio between the two Raman peaks yields the local temperature in the fibre section where the scattering occurred. The two Brillouin peaks are also located symmetrically at the same distance from the original wavelength. Their position relative to λ_0 is however proportional to the local temperature and strain changes in the fibre section. Brillouin scattering is the result of the interaction between optical and ultrasound waves in optical fibres. The Brillouin wavelength shift is proportional to the acoustic velocity in the fibre that is related to its density. Since the density depends on the strain and the temperature of the optical fibre, the Brillouin shift can be used to measure those parameters. For temperature measurements, Brillouin scattering is a strong competitor against systems based on Raman scattering, while for strain measurements it has practically no rivals. Location can be determined by measuring the arrival time of the scattered light.

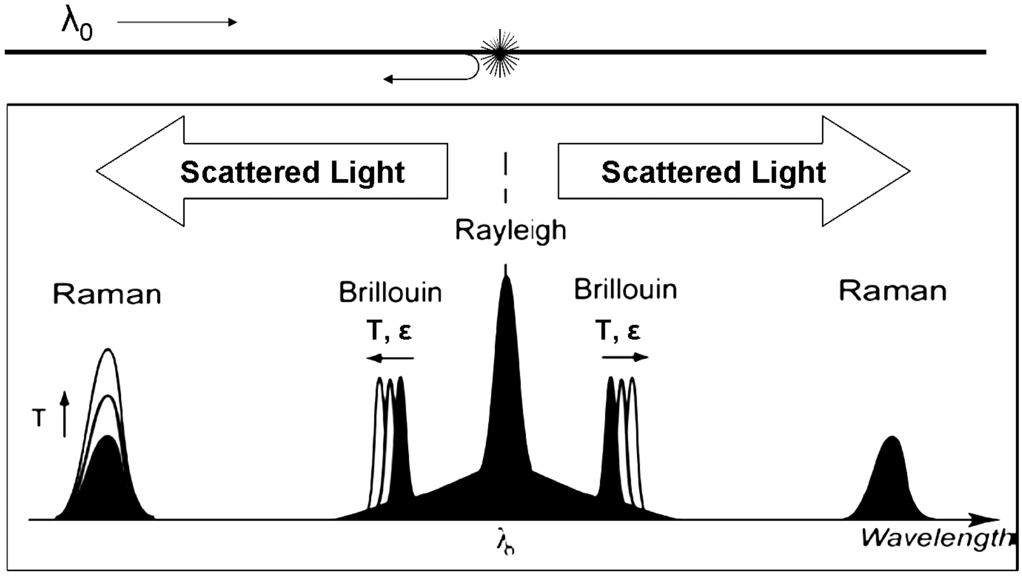


Figure 4. Light scattering in optical fibre and its use for strain and temperature sensing

Since the Brillouin frequency shift depends on both the local strain and temperature of the fibre, for measuring temperatures, it is necessary to use a cable designed to shield the optical fibres from an elongation of the cable. The fibre will therefore remain in its unstrained state and the frequency shifts can be unambiguously assigned to temperature variations. Measuring distributed strains also requires a specially designed sensor. A mechanical coupling between the sensor and the host structure along the whole length of the fibre has to be guaranteed. To resolve the cross-sensitivity to temperature variations, it is also necessary to install a reference fibre along the strain sensor. Special cables, containing both free and coupled fibres allow a simultaneous reading of strain and temperature.

Compared with the conventional strain monitoring techniques, the advantages of distributed optical fibre sensor technology (BOTDR) can be summed up as the follows:

1. Distributed: BOTDR can continuously and simultaneously measure the strain and/or temperature of the structure at any point distributed along the optical fibre from only one end of an optical fibre. With a network of optical fibres, the BOTDR can perform full scale monitoring for the structure, which is very difficult or impossible for the conventional point-measurement monitoring techniques to do.

2. Long distance: Large infrastructures such as tunnels, dams, pipes, subways, and large bridges often span the tens or hundreds of kilometers, which is too long for the conventional point-measurement monitoring techniques to monitor and measure the deformation distributed in various parts of the structure. BOTDR, however, can do that due to its long monitoring distance of over 1000 kilometers. On the other hand, the optical fibre in BOTDR serves as both the sensor and the signal transmission medium, so BOTDR is able to monitor the structure from the remote monitoring center and doesn't need somebody on the site to do it.

3. Real-time: BOTDR is capable of monitoring the strain abnormities along the optical fibre in real time and of showing where, how much, and when the strain occurred. Thus, BOTDR can be used to monitor the strain and/or temperature distribution of infrastructure systems dynamically.

4. Resistibility: Optical fibre is made of a nonmetal, quartz glass, so it resists rusting and environmental erosion and can be used in most severe conditions such as humid or arid, high or low temperature. In addition, it can protect itself from electric and electromagnetic interference and avoid signal error in the transmitting process.

5. Compatibility: Optical fibre is thin, flexible, and lightweight, so it is easy to install in or on the structure without degrading the structure's strength.

6. Accuracy: BOTDR can detect small strains along the optical fibre, and its distance resolution can reach less than 1m, which enables it to meet the needs of strain measurement and health diagnosis of tunnel engineering.

Application of optical fibre sensing in geotechnical engineering

Optical fibre sensors have long been employed in diverse domains for various applications in geotechnical engineering such as monitoring of slopes, dams and tunnels. One of the most common and important geological problems is the slope stability encountered during and after building road in mountainous areas. Stability monitoring and health diagnosis are imperative to the natural slope and slope engineering with potential sliding. Commonly the slope monitoring includes two aspects: one is the deformation monitoring of the rock and soil mass, and of the retaining wall, anchor cable and frame beam; the other one is the stress and pressure monitoring of the rock and soil mass and retaining wall. Conventional monitoring methods include the inclinometer, crack detector, reinforcement detector and displacement meter. Obviously these monitoring methods are of point-mode and cannot meet the monitoring requirement for the whole slope stability, especially for large-scale slopes. In addition the conventional measuring instruments are often incompatible with rock-soil mass deformation, and the installation difficulties and erratic readings due to unforeseen circumstances. An BOTDR-based distributed optical fibre sensing monitoring system for the slope has been demonstrated in Shi et al. (2009). The system advantages are that it is able to continuously measure the strain in all the parts of the slope using a single fibre. The optical fibre arrangement is shown in Fig. 5 and more details about the fibre attachment and spacing can be found in Shi et al. (2009).

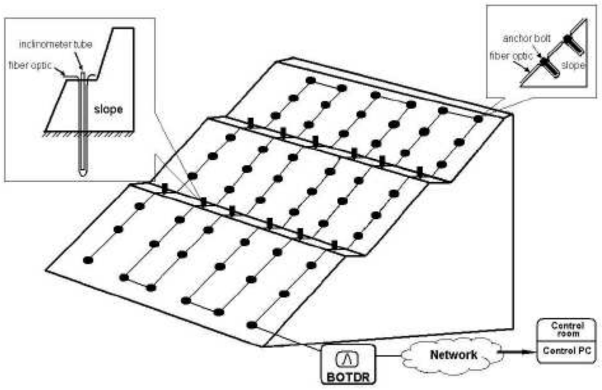


Figure 5. The diagram of BOTDR-based distributed fibre optical sensing monitoring system for the slope (adapted from Shi et al., 2006)

Increasingly attention is turning towards dams for which it is imperative to detect the possible anomalies such as leakages (significant flow of water) in advance so as to take preventive measures accordingly. The early conventional methods for detecting leakage in dams are based on visual inspections and scheduled investigations performed at the site. The measurements of different parameters such as flow rates, pressure, and deformation form some of the contemporary conventional methods. Recently, some nonconventional methods such as the self-potential method, the resistivity method and the temperature based methods have been used for detection of leakage (Rozycki et al., 2005; Vogel et al., 2001; Johansson and Sjödahl, 2004). The self-potential and resistivity methods have been used for internal erosion and leakage detection in dams. Even if the aforementioned methods provide good solutions for detection of anomalies, the major constraint is that these methods are manual. Moreover, the data acquisition setup is not economically viable.

Fuhr and Huston (1993) reported the application of optical fibre sensors to the Winooski One hydroelectric dam in Vermont. Multi-functional fibre capable of simultaneously sensing vibrations and pressures was developed and embedded to measure and monitor the water pressure exerted on the upstream face of the dam's spillway and the vibration frequencies and amplitudes induced in the powerhouse section of the dam as the electrical and water loads vary. Vibration frequencies obtained from the embedded sensors were in good agreement with the induced frequencies, with an average full scale error level of 0.77% and a peak error of 2.03%.

Khan et al. (2008) showed how the distributed temperature sensor (DTS) can be used to monitor the leakage in dams. Großwig et al. (2001) showed an application of optical fibre in a long-term survey to detect and localize dam sections with increased water seepage. Measurements were done in open drainage ditches running parallel to lateral dams of a waterway. The temperature of the groundwater seepages through the dam is different from the temperature of the non-influenced soil or open drain systems. Therefore, temperature anomalies are found at locations of preferred seepage paths. The temperature is used as a thermal tracer to detect seepage sections and the observed temperature variation is shown in Fig. 6. The optical fibre cable can be installed in any configuration along the dam either in vertical or inclined boreholes and can also be installed in existing drain systems. The optimal installation of the cable depends on the monitoring problem.

Another aspect is to monitor the displacement of the dam's foundation and the settlement in new or existing dams. There are two practical cases reported in Kronenberg et al., (1997). The first case is a study showing the technical and economic feasibility to install an extended optical fibre deformation sensor network to detect the relative displacement of an entire shell dam. For this purpose, a theoretical study has been evaluated on the basis of typical load situations with their effective deflections on the Schiffenen dam, a shell shaped concrete structure near Fribourg (Switzerland). The second case concerns the development and realization of two long fiber optic deformation sensors (30 m and 40 m) anchored in the rock to monitor the displacement of the dam relative to its underground substructure foundation. These sensors have been installed in the Emosson shell dam (Switzerland).

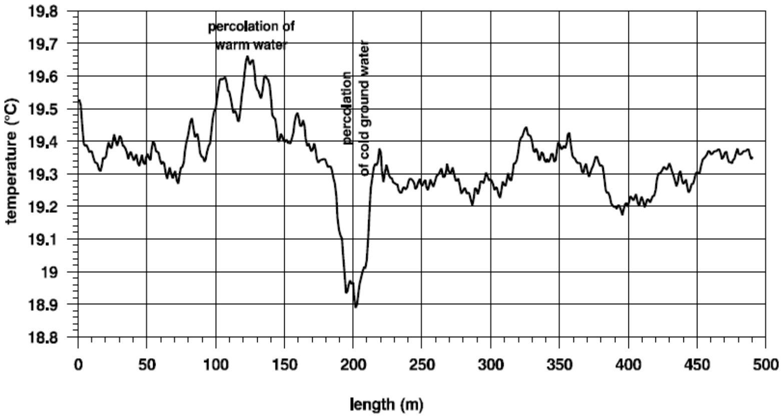


Figure 6. Temperature distribution in a drainage ditch of a lateral dam with clear indications of warm seepage water from the canal and of cool ground water

The Brillouin Optical Time Domain Reflectometer (BOTDR) has been used to monitor the deformation/settlement (i.e., ground strain) during and after building the Taiwan Strait Tunnel, which is the longest tunnel in the world, extending 150 kms and runing over a variety of complicated topographic and geologic units under the seafloor, including seismic and tectonic zones. Further, BOTDR has successfully been applied in the strain measurement and monitoring of two tunnels, Nanjing Gulou tunnel and Xuanwuhu lake tunnel.

A feasibility study of BOTDR application in tunnels is given in Shi et al. (2000). The Gulou tunnel, located in Nanjing City, China was selected for the study. The approximately 1150m long structure runs from south to north, including a 400m approach and a 750m arch. It has twin, side-by-side concrete arches each with 11.6m span and is separated by the inner concrete wall with 1m thickness between two the arches. The maximal cover thickness of the tunnel is 12.9 m, and the minimum 0.26 m. The tunnel was completed in 1996 and had been in use for six years at the time of the study.

In light of the deformation characteristics of the tunnel and 1m distance resolution of BOTDR, the optical fibers were installed on the surface of the concrete arch with two configurations:

1. Overall Adhesion Method - This means the optical fiber is entirely affixed to the surface of the concrete arch. This method is designed to examine the entire deformation of the tunnel such as the uneven subsidence of the tunnel.
2. Fixed-point Adhesion Method - This means the optical fiber is bonded onto the fixed points on the surface of the concrete arch at a certain intervals. This installation method is used so as to detect the partial deformation caused by the crack zones with widths less than the distance resolution of BOTDR.

Several fibres were installed to measure the deformations and cracks along the tunnel. All the optical fibers were centralized to connect to an optical cable after they were set, and then link to the management room located in the middle of the tunnel for BOTDR monitoring.

On the basis of the monitoring results and analyses, the following conclusions were made: the distributed BOTDR monitoring scheme is feasible and effective to monitor tunnel deformation. The functions and monitoring results of the BOTDR monitoring system can meet the needs of the tunnel monitoring. However, BOTDR needs to be verified for long-time monitoring applications and needs improvement in both its non technology and in its application.

Another application of BOTDR for settlement monitoring during tunneling was in Cairo, Egypt. In this study, optical fibre cable was designed to monitor the bending strain at different locations. The axial strain was calculated on the basis of the bending strains, which helped increase the resolution of axial strain.

In Switzerland, optical fibre sensors were applied for long term surveillance of a tunnel near Sargans. The sensors were made of glass fiber reinforced polymers (GFRP) with embedded FBG sensors and were used to measure distributed strain fields and temperature (Nellen et al. 2000).

Optical fibre use in pipeline monitoring

The number of field applications of optical fibre in pipeline condition monitoring is less compared to other civil infrastructure.

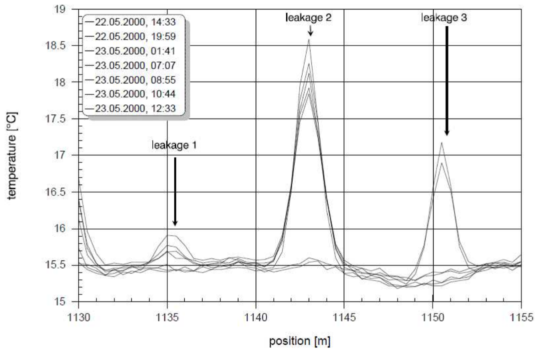
Yasue et al. (2000) reported the laboratory study on a concrete pipe to measure the distributed strain using optical fibre. A load carrying test on a concrete pipe (3000 mm inside diameter x 2300 mm long x 250 mm thickness) was performed and the distributed strain inside the pipe was monitored. The study confirmed that it is possible to detect the strain in a concrete pipe by using optical fibre sensors after a crack has occurred on the concrete surface. Tensile and compressive strains were measured with high resolution using BOTDR. Different types of bonding configuration of optical fibre cable were also studied to check the effectiveness in strain measurement.

In structural integrity monitoring of long pipelines, optical fibre sensors have demonstrated their great potential since it is difficult to detect damage to pipelines with conventional methods. In Indonesia, a 110 km pipeline was equipped with one type of vibration sensor to monitor its integrity and to alert ongoing damage caused by excavation equipment, theft, landslide or earth movement (Fernandez et al. 1996). Based on the principle of modal-metric interference effect, the vibration monitoring unit can pinpoint the location of an anomaly by detecting the changes of backscattered light characteristics caused by disturbances of fiber compression, elongation or twist. This monitoring system can monitor a fiber of length up to 50 km with a resolution of 0.1 km. The system successfully detected damage to the pipeline at a precise position, caused by a landslide (Li et al. 2004).

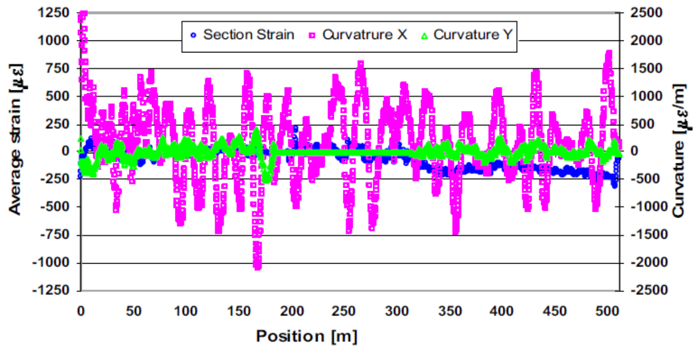
Tennyson et al. (2003) investigated the application of "long gauge" optical fibre sensors to monitor the behavior and integrity of pipelines. Tests were conducted on pipe sections under a variety of load conditions including internal pressure, axial compression, bending, and local buckling, and test data was monitored remotely through internet access. Results obtained showed that the optical fibre sensors could track changes in loads, detect pre-buckling deformations, and measure post-buckling plastic strains. Using analytical models in combination with real-time measurements of the pipe's response, predictions of the operational lifetime for the pipe were made.

Monitoring the leakage in oil and gas is important to prevent the environment hazard and economic losses. Escaping oil contaminates soil and groundwater while gas can cause explosions and is harmful to vegetation and atmosphere. Therefore, it is necessary to have a leakage detection system which is able to detect even small leakages with a high spatial resolution. A number of case studies have been reported in the literatures on the use of optical fibre in leakage detection in oil and gas pipelines. The distributed temperature sensing technique is predestined to this task. The optical sensor cable, which includes the temperature sensitive fibres on its entire length, is installed parallel to the pipeline to measure the temperature profile in the soil close to the pipe. Leaking oil or other products can usually cause a temperature anomaly below the pipeline while gas propagates along the pressure gradient - mainly upwards - and causes a temperature anomaly around the pipeline due to the expansion of the gas. St. Großwig et al. (2001) showed the application of optical fibre monitoring for gas leakage detection. The pipelines were buried at a depth of about 1 m and 1.8 m. The gas pressure within the pipeline was about 64 bar. The fibre optical temperature sensing cable was installed along the pipeline in the 6 o'clock position. Fig. 7(a) shows test results for certifying the system as a leakage detection system for a brine pipeline. The lower curves in Fig. 7(a) show the soil temperature before opening the leakage. The upper curves show the temperature distribution around the leakages for a leaking rate of 50 ml/min.

Another case study by Inaudi and Glisic (2010): about 500 meters of a buried 35-year old gas pipeline, located in Italy, lie in a landslide-prone area. Distributed strain monitoring was selected in order to improve an existing vibrating wire strain gage monitoring system. The landslide progresses with time and could damage the pipeline until it would be put out of service. Distributed strain and temperature sensing cables were installed. Three parallel lines consisting of five segments of strain sensing cable were installed over the whole length of the pipeline at approximately 0°, 120° and -120° around the pipeline circumference. The sensing cables were epoxy-glued to the surface of the pipeline along their whole length and protected with a neoprene mat. This instrumentation allows the monitoring of strain, curvatures and deformed shape of the pipeline every meter. The temperature sensing cable was installed onto the upper line (0°) of the pipeline in order to compensate the strain measurements for temperature and for leakage detection purposes. All the sensors are connected to a central measurement point by means of optical extension cables and connection boxes. They are interrogated from this point using one single readout unit. Since the landslide process is slow, the measurement sessions were performed manually once a month. Fig. 7(b) shows the strain and curvatures monitored at pipe.



(a)



(b)

Figure 7. (a) Temperature distribution along a brine pipeline with a leakage rate of 50 ml/min (adapted from Großwig et al., 2001) and (b) cross-sectional strain and curvature distributions measured by SMARTape sensors (adapted from Inaudi and Glisic , 2010)

Acoustic monitoring has played a major role in the management of large pre-stressing wire precast concrete pipeline. It has been used in both short and long-term monitoring programs. The major advantage of acoustic monitoring over other methods is the availability of real-time information on the deterioration rate of the pipe. When a tensioned wire embedded in a piece of Prestressed Concrete Cylinder Pipe (PCCP) fails, its stored energy is released suddenly, causing a dynamic response in the section of pipe. Acoustic monitoring was used to monitor the 700 km long PCCP in Libya.

Conceptual approaches for new pipeline monitoring

Previous sections highlighted that optical fibre sensing technology can be a powerful technique for infrastructure monitoring in civil engineering. However, there is a range of factors that need to be considered for cost-effective monitoring of new pipelines and to identify critical or vulnerable locations along the pipeline. These factors include the physical environment of the pipeline such as terrain and urban developments, geological environment such as soil type and corrosivity, pipe characteristics such pipe material and the mechanical behaviour, design considerations and critical locations, and risk of pipe failure. The pipelines may be laid above or below the ground or as a combination. The monitoring of buried pipelines is more challenging than monitoring of above ground pipelines. Therefore, the developments will place more emphasis on monitoring of buried new pipelines.

For new pipelines, pipeline managers are interested in instrumenting the pipelines so that they are intelligent enough to provide information on the condition of the pipe and any warnings of distress to the pipeline. Depending on the level of sophistication in instrumentation, these pipelines may be called "smart" or "intelligent" pipelines. However, due to the relatively low cost of water, for water pipelines these technologies need to be cheaper than for gas and fuel pipelines. Therefore, cost effective strategies need to be developed taking into account the factors discussed above. Further, decision should be made on the parameters such as strain and temperature to be monitored in the field to compute the short-term and long-term factor of safety. For the continuous safety factor calculation, the deterioration of pipe material strength due to creep and fatigue can be obtained from the material testing manuals. The corrosion rate can be identified using the soil corrosivity data. The pipe stresses due to external and internal loads can be calculated using the measured strain and temperature values in the field. The strain and temperature can be monitored using fiber optic sensors at discrete locations or using distributed optical fibres for continuous readings. The observed data can be used to calculate the present safety factor of the system. Fig. 8 shows the flowchart to compute the short-term and long-term factor of safety.

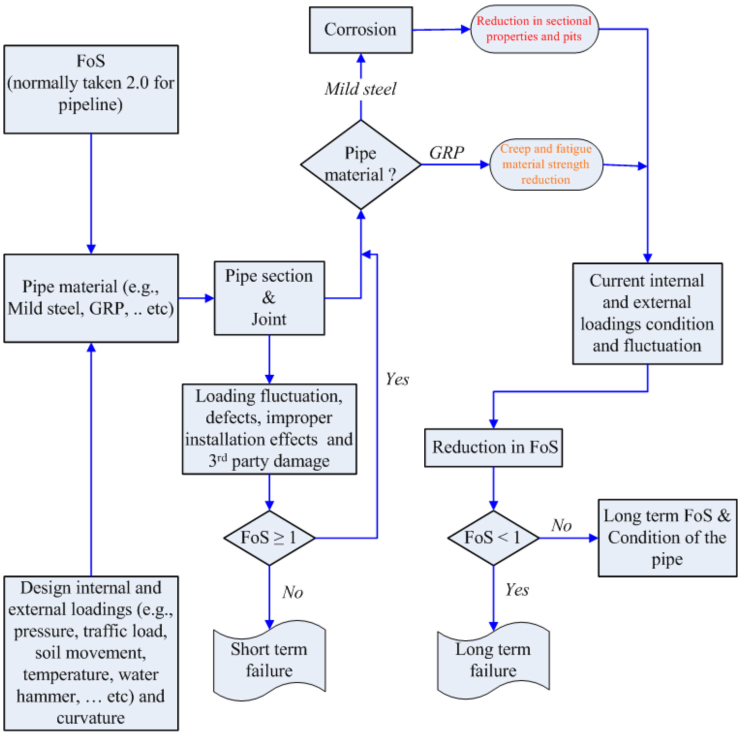


Figure 8. Design of pipe section and calculation of long term safety factor

Finally, the type of sensor and the optimum sensor arrangement should be decided to get the effect measurement. As discussed earlier, why and what parameters we do measure need to be assessed. For instance, is it sufficient to measure only the longitudinal strain of the pipe on the crown of the pipe? Or should we provide sensors in a certain grid arrangement so that we can get information about the pipe distress around its entire surface? And how do we measure them? How do we convert these measurements into assessment quantities? These are the typical research questions that need to be answered in deciding the type of sensors and their arrangements. It may be possible that a combination of sensors in various arrangements (other than optical fibre) are required to measure all the quantities that are required to provide sufficient pipeline condition information.

Summary

This paper summarises the information in optical fibre technology and its application in civil infrastructures, which is available in the literature. The basic principles of optical fibre technology on distributed and point sensing were summarized. Further, the application of optical fibre sensors in pipeline monitoring was highlighted together with case studies. It was found that the applications of optical fibre sensors in water pipeline monitoring are relatively low in comparison to applications in other infrastructure. The distributed optical fibre sensors (i.e., BOTRD) have been used to monitor slopes, dams and tunnels.

Optical fibre technology offers superior performance compared with the more proven conventional sensors, especially in relation to monitoring of linear structures such as pipelines. This paper examined the issues that need to be examined, the research opportunities and knowledge gap that need to be addressd in developing a monitoring strategy for new water pipelines. These issues include physical and geological environments of the pipeline, pipe characteristics and pipe failure considerations identifying the critical parameters for pipeline monitoring. A conceptual approach was developed. However, a substantial research effort is required to advance these concepts so that their full potential can be realized.

Acknowedgements

This publication is an outcome from the Advanced Condition Assessment and Pipe Failure Prediction Project funded by Sydney Water Corporation, Water Research Foundation of the USA, Melbourne Water, Water Corporation (WA), UK Water Industry Research Ltd, South Australia Water Corporation, South East Water, Hunter Water Corporation, City West Water, Monash University, University of Technology Sydney and University of Newcastle. The research partners are Monash University (lead), University of Technology Sydney and University of Newcastle.

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