Application of plastic optical fiber sensor for large strain measurement in geotextile containers

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ABSTRACT: The measurement of large strain of up to 40% strain in geotextile materials has been achieved using extrinsic plastic optical fiber sensor (POF). Typical fiber optic sensors can measure strain up to 5% based on fiber stretching, but this cost-effective high-strain optical fiber sensor system allows strains to be measured even after exceeding strain levels of 5%. Initially, this new POF sensor system has been calibrated using linear variable displacement transducer. A series of tensile tests on different geotextile fabrics have shown to be able to compare well with other reference measurements such as video strain. The response of the POF sensors has been compared with resistant type strain gages in both centrifuge modeling and actual field work. Observation shows that POF sensors compare well with the resistant type strain gages.

1 INTRODUCTION

Geotexile application in hydraulics and coastal engineering has gained popularity in recent years. It has been widely used for flood protection, scour protection, coastal erosion control and containment of dredged materials in reclamation projects. In a recent costal project in Singapore, stacking of geotextile containers have been proposed as a solution for the containment of dredged material and at the same time, as part of the revetment structure in the project. There is a concern on the integrity of the geotextile containers during dumping and impact on the subsoil. Hence, continuous strain measurement of the geotextiles during these stages has been planned to provide more insights into the behaviour of geotextile containers and tubes.

The common method in geotextile strain measurement involves the use of conventional resistance-type strain gauges which are attached directly onto the geotextile substrate. In order to avoid stiffening the localised area of geotextile due to the introduction of the adhesive, the use of an thin plastic strip connected to the geotextile substrate via its two end plates has been reported to be successful (Chew et al. 2000). However, for the application of resistance-type strain gauge for the purpose of monitoring the behaviour of geotextile in hydraulic or marine conditions, it is susceptible to water proofing issues. In view of that, the availability of an alternative non-electrical based sensor has been sought.

In addition, high strain level of more than 20% can be expected in the geotextile containers during dumping and at impact on the seabed. Typically, woven geotextiles are capable of withstanding strain values of 12%-30% while non-woven geotextiles can experience strains of up to 80% before failure. Currently, a typical high-yield strain gauge has a failure strain of 20% (e.g. the YL series manufactured by Tokyo Sokki Kenkyujo Co. Ltd. (TML)). Therefore, currently available strain gauges are not able to measure large strains beyond 20%.

Optical fiber sensors have developed very rapidly over the last few years. Plastic optical fibers may offer some useful features for the application of large strain measurement in geotextiles. An intensity-based sensor has been developed and proven to be an attractive alternative for damage detection in structural health monitoring (Kuang et al. 2004). With proper calibration, this sensor can be customised to monitor strains of more than 20%. The plastic optical fiber protected with polyethylene jackets and has no problem with water under marine conditions.

Compared to other optical-based sensors such as fiber Bragg grating (FBG), this POF sensor is more cost-effective because it does not require special optical signal interrogation unit. In addition, strain tests on FBG optic sensors embedded into geotextiles are known to be able to endure up to 5-6% strain (Briancon et al. 2004), which is the failure strain of silica in FBG.

This paper summarises the results of a series of strain measurements on tensile tests conducted on different geotextile fabrics. The POF sensor's response was compared with resistance-type strain gauge and video strain.

2 EXPERIMENTAL PROGRAM

Three series of tests were conducted, and their experiment procedure and sensor preparation will be discussed below.

2.1 *Sensor Design and Construction*

The operating principle of the POF sensor used relies on measuring the change in the gap of two plastic fiber housed within the tube as shown in Fig. 1. The signal output of the sensor is directly related to the change in the separation of the two end faces. The POF sensor is housed in a polytetrafluoroethylene (PTFE) sleeves and a PTFE outer tube as shown in Fig. 1. The sensor provides output signal voltage, which can be easily logged. The POF sensor can be customised to various strain levels by proper selection of gauge length and extensions of the fibre leads. For the tensile test, the POF sensor has been calibrated for a maximum strain of 40%, although higher strains are possible.

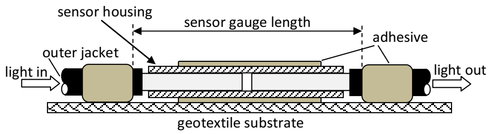

Figure 1. Schematic diagram of POF sensor.

2.2 *Specimen Preparation for Geotextile Wide-Width Tensile Test*

Two types of geotextile fabric were tested using a wide-width tensile test machine. The wide-width tensile tests were performed in accordance to EN-ISO 10319:1993. A summary of the characteristics of the geotextile fabrics are given in Table 1.

Table 1. Summary of Characteristics of Geotextile Fabric Used.

	Geotextile A	Geotextile B
Type	Non-woven	Woven
Material	Polypropylene	UV-stabilized, carbon black, polypropylene
Maximum Elongation	35% in XD 70% in MD	20% in XD 20% in MD
Max. Tensile Force	9.5kN/m	180kN/m

For the non-woven geotextile specimens (Geotextile A), two parallel lines were drawn on one face with a distance of 60mm apart, to allow measurement of strain via the non-contact video strain measurement unit equipped in this Instron Tensile Test Machine. For the woven geotextile specimens (Geotextile B), resistance-type strain gauges (YL-60 from Tokyo Sokki Kenkyujo Co., Ltd.) were installed based on method recommended by Chew et al. (2000). The reason that the video strain system was chosen instead of strain gauges for Geotextile A is that the expected strain of these samples at failure exceeds the measurement limit of conventional resistant type strain gauges.

2.3 *Sensor Preparation for Testing in NUS Geotechnical Centrifuge*

The National University of Singapore's geotechnical centrifuge was used to test model-sized geotextile container. The detailed centrifuge model of geotextile container is given by Tan and Chew. (2008). The position of the POF sensor and resistant type strain gauge is shown in Fig. 2. The level of gravitational acceleration used for the centrifuge test was 100g. This means that the size of the geotextile container is 6m in diameter (prototype scale) and 15m in length (prototype scale).

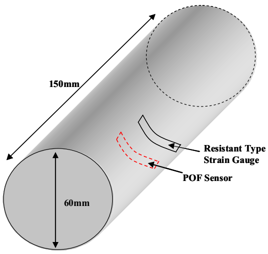

Figure 2. Position of POF Sensor and Resistant Type Strain Gauge in Model Geotextile Container for Centrifuge Test.

2.4 *Sensor Preparation for Testing in Actual Field Work on Geotextile Container*

In conjuction with the actual construction field work, the POF sensor and resistance-type strain gauge has been installed onto a geotextile container measuring 5m in diameter and 25m in length. The geotextile container was filled with soft dredged material and was dumped into the sea, with water depth of up to 15m. In order to monitor the response of the POF sensor in both the longitudinal direction and circumferential direction, the sensors were installed in both directions as shown in Fig. 3. Strain readings were captured during the filling up of the geotextile container stage, as well as during the dumping stage

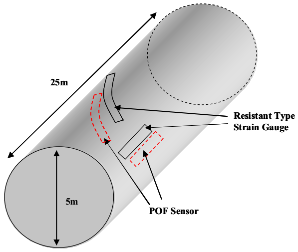

Figure 3. Position of POF Sensor and Resistant Type Strain Gauge in Geotextile Container Actual Field Work.

3 RESULTS AND DISCUSSION

3.1 *Strain Measurements in Geotextile Wide-Width Tensile Test*

The results of strain measurements in the wide-width tensile test are given in Fig. 4 to Fig. 7 for two specimens each of geotextile A and B. Fig. 4 and Fig. 5 show that for Geotextile A (non-woven) specimens, the POF sensor matched well with the video strain recorded for both specimens up to 40% strain. A slight deviation of about 2% strain towards the end of the loading regime was observed in Fig. 4. This deviation is not significant, especially for large strain measurements. In Fig. 5, the POF strain values deviated significantly after exceeding 40% strain. This is because the POF sensor has stretched beyond its intended design maximum strain value of 40% strain. As a result, the POF leads might have protruded out from its housing. The results, however clearly show the potential of the POF sensor in monitoring the strain development in non-woven geotextile for up to 40% strain.

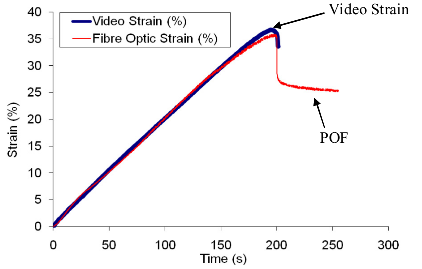

Figure 4. Comparison of POF vs Video Strain for Geotextile A (Sample 1).

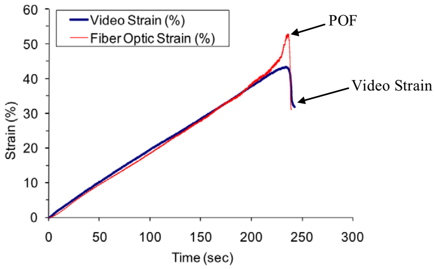

Figure 5. Comparison of POF vs Video Strain for Geotextile A (Sample 2).

In a separate wide-width tensile test, as illustrated in Fig 6 and 7, the POF strain readings was compared with the conventional resistance-type strain gauges installed onto the specimens. Both figures show that the POF sensor demonstrated excellent response and effectively measured the strain development in the Geotextile B (woven) of up to 20% strain. The POF sensors demonstrated some deviations in readings at high strain value of about 20% (close to the failure strain of geotextile B). This is due to the non-uniform rupture of geotextile specimens width-wise that propogated from one end of the specimen to another. Hence, the POF sensor showed slight difference in strain response towards the end of the test. It is also clear here that the POF sensor results match the conventional strain gauge very well in measuring strain in woven geotextile material.

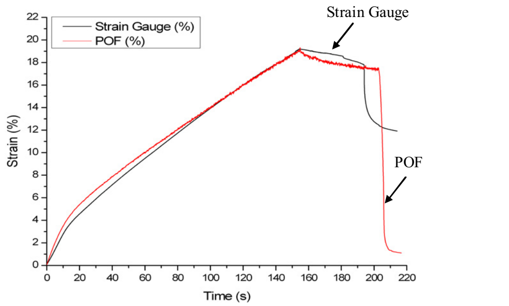

Figure 6. Comparison of POF vs Strain Gauge for Geotextile B (Sample 1).

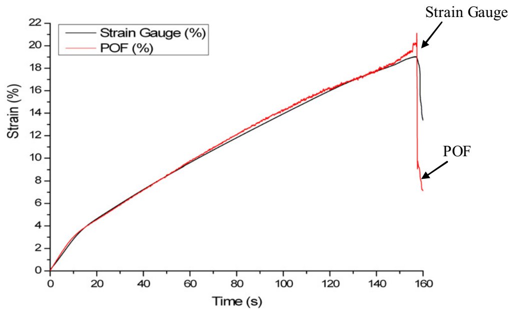

Figure 7. Comparison of POF vs Strain Gauge for Geotextile B (Sample 2).

3.2 *Strain Measurements in NUS Geotechnical Centrifuge Test*

The dumping stage of a geotextile container was modeled using the geotechnical centrifuge. To compare the responses in strain measurements, the POF sensor and resistance-type strain gauge was installed in a centrifuge model geotextile container as shown in Fig. 8. It was observed that as the barge opening width increases as model time increases from 0.0s onwards, both the strain gage and POF sensor exhibited the same trend in terms of the response of increment in strain at the beginning. The POF sensor indicated that the geotextile container started to leave the opening at 5 seconds (model time). While the resistance type strain gage did not show any significant change until 5.8 seconds (model time). Subsequently, the impact of the geotextile container was recorded by the resistance-type strain gauge by a clear peak in terms of strain at around 6.1 seconds. During the impact, the POF sensor showed a fast increase in intensity loss from approximately 55% to over 90%..

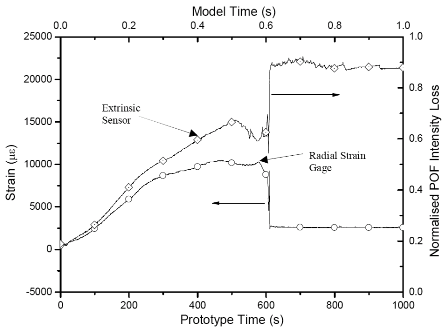

Figure 8. Comparison of POF vs Strain Gauge in NUS-Geotechnical Centrifuge.

3.3 *Strain Measurements in Actual Field Work on Geotextile Container*

In an actual construction work, the geotextile container was filled with soft dredged material and was dumped into the seabed using a split hopper barge. The results of POF sensor compared with the resistant type strain gauge test are shown in Fig. 9 and Fig. 10. Figure 9 shows the response of both sensors in the longitudinal direction. It can be seen that resistant type strain gauges and the POF sensor are able to capture the strain development in the geotextile container during the barge opening, during the leaving of geotextile container from the barge and at the time of impact on the seabed. After the impact of geotextile container (at t=45.5s), the strain gauge showed a high strain of 25% and maintained constant after that, while the POF sensor indicated a peak of 27% strain, followed by a reduction to 17%. In this case, the strain gauge was damaged, but the POF sensor was found to be still functioning and showed the reshaping of the geotextile container following the impact event.

Figure 10 shows the response of both sensors in the circumferential direction. It was observed that there was signal noise in the strain gauge data while the POF sensor showed less susceptibility to electrical noise. The general trend however showed that the response from both sensors matched well.

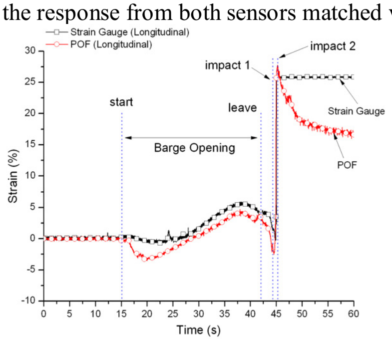

Figure 9. Comparison of POF vs Strain Gauge in Actual Field Work A.

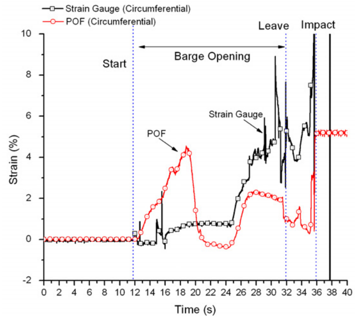

Figure 10. Comparison of POF vs Strain Gauge in Actual Field Work B.

4 CONCLUSION

The strain measurement results in the POF and strain gauge installed obtained from a wide-width tensile test, centrifuge modeling test and actual field work test clearly demostrated the potential and effectiveness of the POF sensor in measuring high strain in geotextile fabric. The POF sensor has shown to be able to measure up to 40% strain. POF sensor can be an attractive alternative to existing sensors that are limited in their high strain measurement capabilities.

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