Journal of Engineering Science and Technology
Vol. 18, No. 1 (2023) 406 - 423

DISTRIBUTED FIBER OPTIC SENSING IN LANDSLIDE MONITORING – A COMPARATIVE REVIEW

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Abstract

Forecasting landslides is the main component in risk reduction where it can minimize the losses, but it is subtle and hardly predictable. Over the years, many technologies were developed to monitor landslides or soil movement. Fiber optics exhibiting various applications have been successfully adopted in landslide monitoring. Most of the time, they used an array of fiber Bragg grating (FBG) sensors in series form, Brillouin optical time-domain analysis (BOTDA), and Brillouin optical time-domain reflectometry (BOTDR). FBG detectors produce point sense only where the sensor exists, while BOTDA and BOTDR have advantages as they provide distributed sensing throughout the optical fiber length. However, the latter method is more expensive and complex for long-distance monitoring. These methods are useful for comprehending the slope displacement. However, real-time monitoring can only provide an effective landslide monitoring system for early detection to reduce risk factors by understanding the dynamic behavior of landslides. To overcome this, a distributed sensing optical time-domain reflectometer (OTDR) was implemented. Distributed scattering sensors based on OTDR can be used for continuous long-distance measurements. The slope deformation can be determined in conjunction with the fiber when using distributed fiber optic sensor technology for monitoring landslides. The distributed sensing feature enables optical fiber to be an effective method of monitoring landslides. The different approaches of distributed sensing for landslide monitoring that were investigated and deployed by many researchers were reviewed in this paper. Also, a comparative analysis regarding the characteristics, advantages and disadvantages of different techniques are discussed and presented.

Keywords: Distributed sensing, Fiber optic, Landslide, Landslide monitoring, Optical fiber.

1. Introduction

Landslide or landslip is described as the sliding and outward expansion of a part of the slope. This may include rocks, sand, and trash which are quickened by the earth's gravity and further result in overflowing floods, deforestation, seismic tremors, and land mining. This sliding development of the soil will bring everything that comes in its way [1-4]. Landslide monitoring is a strategy by which one can comprehend the process of landslide and can take up preventive measures to lessen losses and damages. In locations with significant seasonal rainfall, rain has been identified as the primary cause of most landslide incidents. Scientists have long been interested in determining the total precipitation that can induce slope failures in various local climate circumstances [5, 6]. Long-term monitoring uses a variety of satellite observations, Global Positioning System (GPS), Geographic Information System (GIS), and associated statistical approaches to the long-term prediction of landslides.

Short-term monitoring uses a range of sensors to detect landslide early warning indications, such as acceleration, soil, rain, and temperature [7-9]. Disastrous debris slides or mudflows have destroyed an enormous number of towns and inclined houses, by tidying vehicles up the road and it is more ruinous than flood where the mud does not go back after the landslide [10]. Landslides cause high human perishability and move 0.01 mm~10 mm a day consistently in the wide region [11]. Therefore, it is well-grounded that maintaining the stability of the slope is a critical aspect of any geotechnical project, and the mechanics of landslides can be better understood by tracking a slope's surface displacement monitoring the surface displacement, which depends on saturation conditions and seismic load [2, 12-17].

Optical fiber gave the first-rate outcome compared to other old-style sensors and optical fiber sensors are utilized latterly to anticipate any related harms. Besides, the optical fiber sensors are lightweight, have high environmental and electromagnetic resistance, are low cost, and can transfer data rapidly for continuous monitoring [18-20]. Optical fiber sensing was already considered a significant tool for evaluating strain variations. Environmental changes affect the fiber core specifications that is the optical properties such as refractive index, optical length, and diameter, which modifies the backscattered light, such as intensity, phase, and frequency. Figure 1 shows the distributed sensor classification based on backscattering, i.e., Rayleigh, Brillouin, and Raman [21].

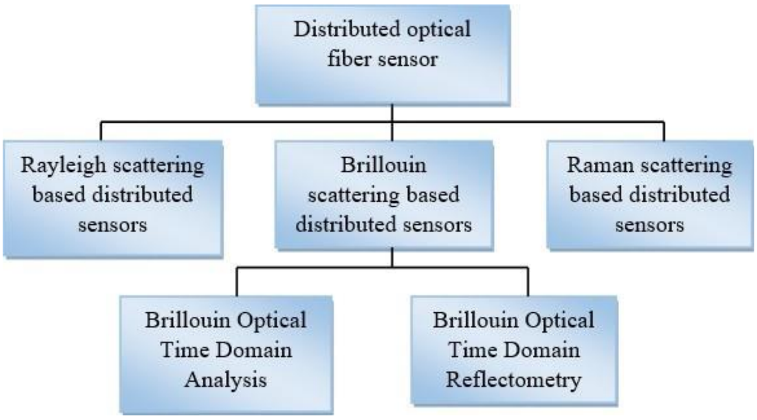


Fig. 1. Classification of distributed sensor based on scattering [21].

Optical fiber sensing was already considered a significant tool for evaluating strain variations. Fiber Bragg grating (FBG) and distributed fiber optic sensing (DFOS) are the two main methods of optical fiber sensing. An FBG involves detecting a specific point that works in a similar way to a strain gauge, but with significantly better strain resolution. As a result, FBGs with higher spatial resolutions are more expensive and take longer to build. DFOS has the advantage of being able to extract observed data (such as temperature, strain, pressure, corrosion, and vibration) as a function of position over the whole length of the sensing fiber, unlike FBGs [22-25]. Observable properties scattered throughout the spatial channel of the optical fiber can be continually monitored using DFOS. In the meantime, data on spatial distribution and changes in physical features can be collected over time. Traditional point-by-point and electrical measurement monitoring systems have distinct advantages, but there is an optimal economic take between performance characteristics including sensing range, spatial resolution, and sensing resolution in DFOS. Therefore, DFOS can perhaps replace a huge number of discrete sensors [26-28].

The different approaches of distributed sensing for landslide monitoring that were investigated and deployed by many researchers were reviewed in this paper. The paper emphasizes the distributed sensing of fiber optics, which measures strain in the soil as the optical fiber effectively couples with the soil. The detection of soil displacement is measured to determine the movement causing landslides. This review aims to outline the research findings of distributed sensing for landslide monitoring. In addition, this paper further gives a comparative study of the different distributed sensing technologies for landslide monitoring.

2. Distributed Fiber Optic Sensing for Landslide Monitoring

This section describes the research findings for landslide monitoring using distributed sensing. Distributed fiber optic sensing is offering new possibilities in geotechnical monitoring. Koyamada et al. [29] described a novel method to measure temperature and strain by distributed sensing using coherent optical time-domain reflectometry (COTDR). This method has achieved temperature measurement, 0.01 resolution for 1 meter along the length of 8 km fiber. The Rayleigh-based DFOS technique of COTDR has a greater resolution for measuring strain and temperature than Brillouin-based DFOS. Lu et al. [27] and Higuchi et al. [30] selected the OTDR method of the various methods of optical fiber sensing as the cost of it is lower than other methods. OTDR and the sensing system (18 optical fiber sensors and the conventional sensor (SH-29)) were set up at the Takisaka landslide test measurement site, located in Fukushima Prefecture in eastern Japan. OTDR detects the transmission loss at various locations of the sensors, the installation of optical fiber sensor is shown in Fig. 2. The result obtained showed the tensile displacement is similar to the extensometer with an error of several mm. So, the study further involves measurement precision improvement.

For landslide monitoring, Liu et al. [31] designed a system with high sensitivity and a wide dynamic range. As shown in Fig. 3, it was based on polarization-sensitive optical frequency domain reflectometry (P-OFDR), a sensing system that incorporates a polarization-maintaining (PM) fiber and an OFDR with a spatial resolution of 5 cm, a dynamic range of roughly 70dB, and a theoretical measuring range of 10 km. It has relatively low robustness, analysis of mechanical property distribution and measurement database built requires periodic measuring and long-time monitoring.

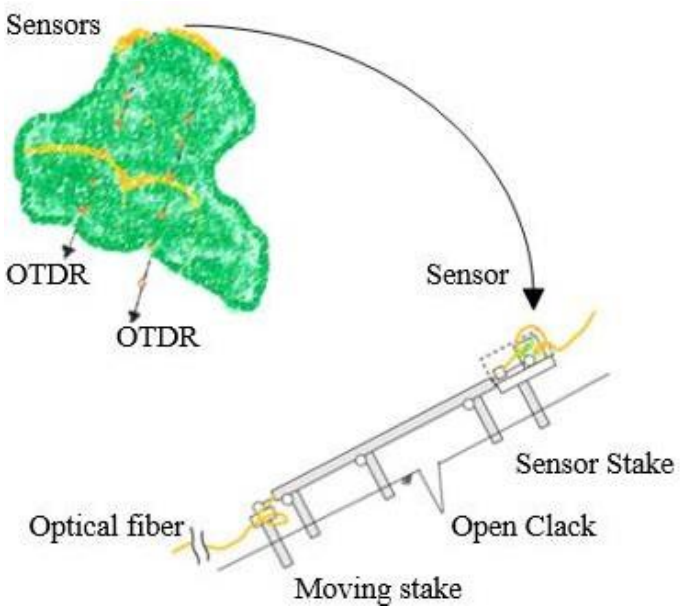


Fig. 2. Installation of Optical fiber sensor [26].

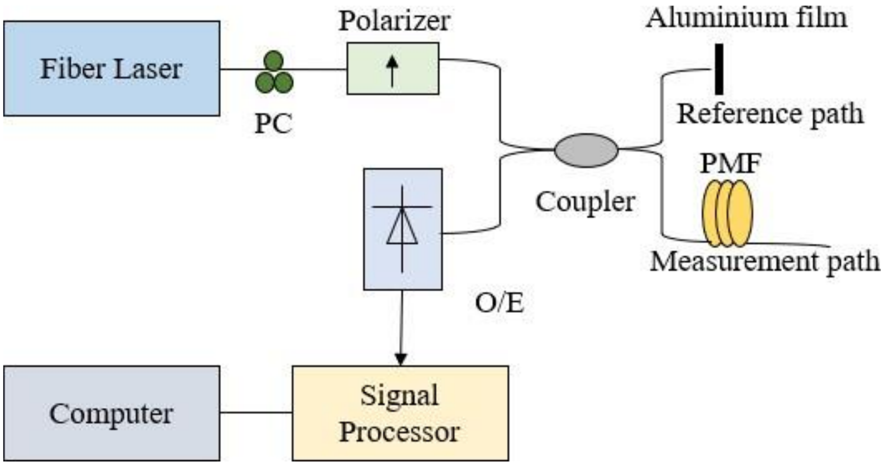


Fig. 3. The sensing system configuration [31].

Also, a vertical strain distribution of an artificially triggered soil deformation by computing Rayleigh scattering was measured by Kogure et al. [32]. This technique enables monitoring deformation of soil activated by rainfall, leading to significant disaster management using distributed fiber optic sensing. BOTDA is efficient enough to monitor and analyse landslides but there are major limitations such as difficulty in interpretation and no proper standard procedure in the installation of optical fiber cables in large areas. An early alerting system utilizing optical fiber innovation was manufactured, the structured system could identify the progressions inside the soil by the guide of delicate regions (sensors) observed by the OTDR and it is overseen remotely by the developed Geo-lab programming. This product recognizes any progressions around and offers a chance to contrast the actuated condition and the reference estimation speaking to the underlying condition. Along those lines, information flow effortlessly furnishes ceaselessly and prompts high sensitivity monitoring [33].

In optical fibers, the Brillouin effect is increasingly commonly used for strain and temperature monitoring. Brillouin scattering is a phenomenon in which light from a source is directed along the length of a silica fiber. A portion of the light is spread out in the thermally stimulated acoustic stages as it goes through the fiber. The frequency shift of backscattered light is proportional to both the longitudinal pressure of the optical fiber and its temperature at the scatter point in this case [34, 35]. Iten et al. [36] and Minardo et al. [37] illustrated a new approach for determining the boundary of a creeping landslide relying on the use of BOTDA technology for the calculation of distributed optical fiber strain. Although BOTDA has a range of tens of kilometres, it is a very lengthy process (seconds to minutes) [21, 38].

Lately, several ways have recently been developed to allow Brillouin dynamic sensing, Slope-assisted Brillouin optical time-domain analysis (SA-BOTDA) technique, and differential pulse-width pair Brillouin optical time-domain analysis (DPP- BOTDA), which can preserve all the advantages of the classic BOTDA and at the same time offering real Slope-Assisted sensing [39-42]. The specifications of the Brillouin optical time-domain reflectometer (BOTDR) application require direction and are restricted by applicable industry norms, such as how to conduct the field installation of the sensing fiber and how to perceive the significance of the observed Brillouin frequency shift (BFS) transition. Using BOTDR, the resulting signal was weak; thus, the information on the frequency change was not quite reliable, the effective signal transmission distance was small, and also it has poor real-time performance for monitoring slow-moving landslides [43-46]. Zeni et al. [47], and Hong et al. [48] reported different applications of distributed sensors based on BOTDA for geotechnical monitoring.

Optical fibers embedded in the soil monitored and detected soil movement with great capabilities. The basic equipment and instrumentation of the experiment are shown in Fig. 4. However, this proposed technology has certain restrictions when it is applied for larger areas mainly due to lack of standard installation procedures for sensing cables, and challenges in performing proper data analysis as well as getting an accurate interaction model between the ground and sensor.

Landslide deformation monitoring using distributed strain sensing system based on COTDR with Rayleigh backscattering as shown in Fig. 5 was suggested by Yu et al. [49], and Qin et al. [50]. This sensing system offers the advantages of real-time and distributed performance with good initial measurement and strain distribution, thereby achieving high resolution and sensitivity for long-distance. Wang et al. [51] and Cheng et al. [52] tested the deformation of a laboratory-based soil slope model using the BOTDR technique. BOTDR has its predominant characteristics such as distribution, ant- electromagnetic interference, and long-distance. The results show that the strain measurement analysis gives valuable information, useful for ensuring soil stability, early detection, and monitoring in soil slope engineering. However, the strain distribution and distance resolution are not expressed clearly in this small-scale model.

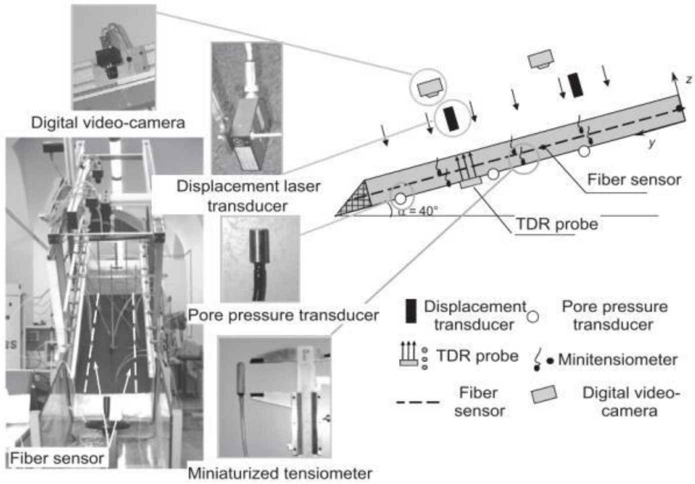


Fig. 4. Instrumentation for geotechnical monitoring [48].

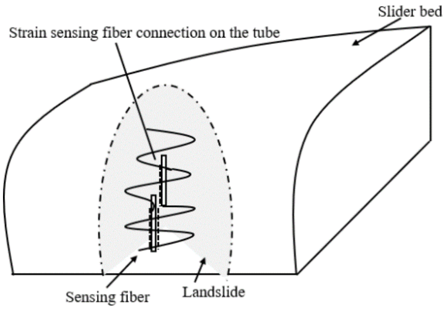


Fig. 5. Schematic diagram of sensing fibers for landslide monitoring [50].

A low-cost system for detecting landslides in advance using displacement fiber sensors formed by encasing a polymer optical fiber (POF) was developed by Marzuki et al. [53] and Zheng et al. [54] based on macro-bending loss. Other components of this system are the pulley system, landslide model, siren, Short Messaging Service (SMS) gateway, and computer shown in Fig. 6. Nevertheless, using a low-cost fiber sensor (polymer optical fiber) makes it low quality and flammable and it cannot be used for long-distance communication systems.

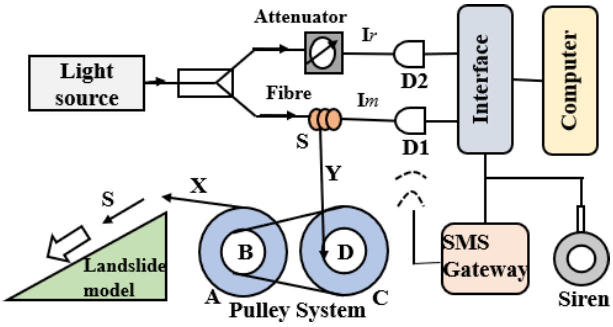
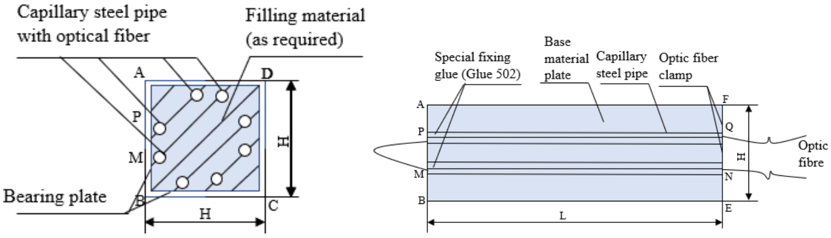


Fig. 6. Schematic model for landslide monitoring using POF [54].

Zhu et al. [55] and Pei et al. [56] developed the first-generation transducer. It was designed using common plastic as the base material with four sides as shown in Fig. 7(a). Optical fiber here is protected using two capillary stainless-steel pipes which are attached to ABEF base material Fig. 7(b). The cross-section size was about 25 mm and 50 mm with a length of 500 mm. The result and analysis show that the transducer has an unsatisfactory effect. The transducer achieving 0.1 dBm loss exceeded 5 mm vertical displacement. The sliding distance measured with a vernier caliper was only 1 mm and these results make the first-generation transducer not feasible.



(a) Cross-section view. **(b) Base material ABEF plan view**

Fig. 7. First-generation transducer [56].

They have also proposed a transducer with bowknot to monitor unstable slopes based on space frame theory [55]. The proposed strategy aims to overcome the drawbacks of OTDR and BOTDR technologies which are reported as not able to meet the needs simultaneously to measure high initial accuracy, distributed sensing, the wide area of sliding, and high dynamic level. This method shows a result of a maximum sliding distance of 21.8, 26.5, and 30.6 mm with corresponding initial accuracies of 1.2, 2.3, and 3.3 mm, and the dynamic ranges are 0–20.6, 0–23.2, and 0–27.3 mm of the transducer. It offers good monitoring and stability in analysing civil projects. It is used for economic applications and has a transducer cost is USD 0.15/m. Figure 8 shows the view of a second-generation transducer with a bowknot.

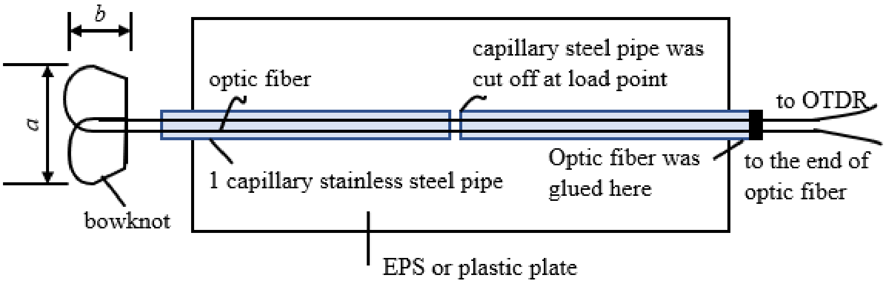


Fig. 8. Vertical views for Second-generation transducer with bowknot [56].

In their subsequent work [57, 58] a fourth-generation transducer was developed, and it is the new improved combined optical fiber transducer (COFT) to surpass the higher complexity in transducer construction of third-generation transducer drawback that occurred at double shearing tests by the new design shown in Fig. 9. The transducer test results show that it has a good dynamic range, good improved initial measurement precision and this enables it to monitor the deformation and thus making it capable of slope stability monitoring.

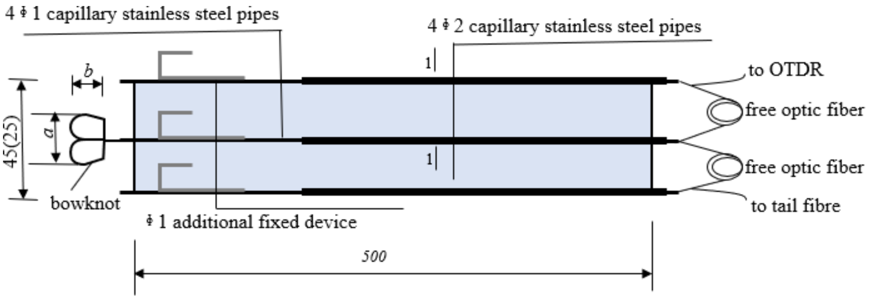


Fig. 9. Fourth-generation transducer draft (elevation view) [58].

Comparing different generations of COFT for landslide monitoring, the first-generation transducer does not satisfy the actual measurement as the technique was not feasible because the micro-bending operation of the fiber optics was not constructed appropriately. The transducer of the second generation with bowknot in one end has been used for improving the measurement effectiveness and it gave better results compared to the first generation with an effective low economic cost at USD 0.15/m but with low robustness [55]. The third-generation transducer used expandable polystyrene (EPS) as a base material, but the performance was poor. By using the same base material, a fourth-generation transducer was invented, it was capable of detecting the load movement direction making it relevant for landslide monitoring purposes with medium robustness and unit price of USD 0.2/m [57].

An experimental study according to a combined fiber optic transducer (COFT) for slope deformation monitoring was carried out by Zheng et al. [59, 60]. The equivalency point for the shear displacement of the moving structure versus optical loss has been determined using optical fiber micro-bending loss and the stretching test of the optical fiber bowknot. The slope deformation variation is shown in Fig.10. The findings of this systematic study reveal that the COFT- based empirical formula was verified successfully using numerical modeling. Also, it proves that the transducers with EPS as the base material are better for monitoring slope deformation with fair robustness and can be used for practical fieldwork.

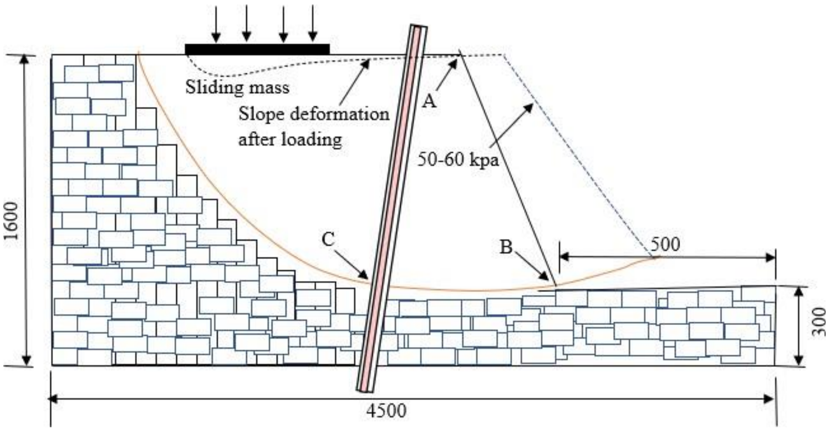


Fig. 10. Model of Slope deformation variation [60].

An Optical Fiber Sensor (OFS) based on OTDR for landslide monitoring [61, 62]. The system based on composite optical fiber transducers (COFTs) observed an adequate measurement displacement and a low financial impact of 36 mm, 0.98 mm, and USD 0.45 / m respectively. A direct-shear test with the OFS was performed to examine its efficiency in tracking the damage caused on slope stability. Model test for OFSs direct shear is done by simulating sliding effect using a concrete apparatus as loading device and a hydraulic jack to control it as shown in Fig. 11.

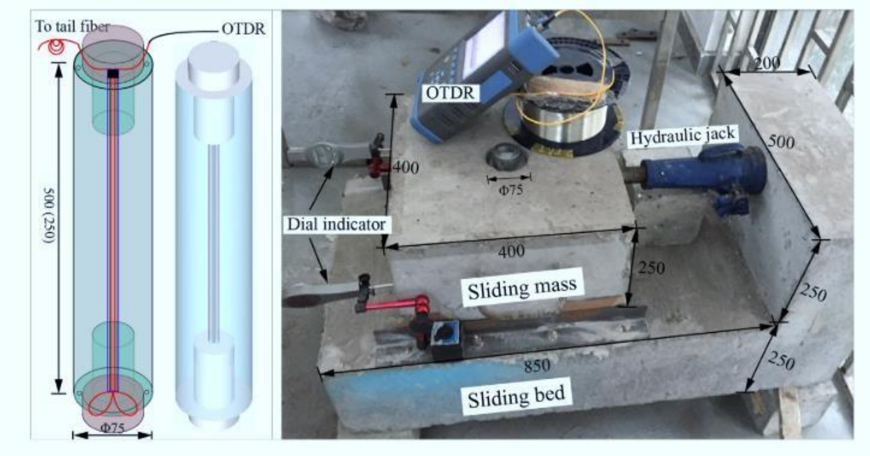


Fig. 11. Model of Slope deformation variation [60].

A comprehensive ground-monitoring evaluation of the proposed OFS on deep artificial slopes was carried out and deformation behavior was recorded accurately. These OFS can be connected in series to discover the underground properties of deep-sea landslides. This functionality promotes the successful usage of the OFS to check the stability of slopes in real-time. From the field test performed on an artificial slope, this method is revealed to demonstrate high robustness and reliability which provide the most benefits such as paving convenience, largest sliding distance, highest measurement accuracy to determine the potential sliding surfaces, but at a cost of USD 0.45/m.

To measure the landslide, Lebang et al. [63] employed a displacement sensor based on Glass Optical Fiber (GOF) and an Optical Time Domain Reflectometer (TDR). In the sensor manufacturing process, materials, topologies, combinations, sizes, and orientations all play a role. This sensor is made of GOF and is available in single-mode and Single Mode-Multimode-Single mode (SMSM) configurations. Figure 12 shows the GOF - based OTDR - based displacement sensor technology for detecting landslides. Each system may be set up in a variety of ways, such as gamma, bowknot, or three loops. Landslides and sensor modifications occur as a result of displacement, resulting in power losses and changes to the sensor's properties. The best measurement results were achieved with sensitivity and resolution of 0.241 dB/mm and 0.004 mm, respectively. The landslide displacement sensor was built to keep track of the area's landslides.

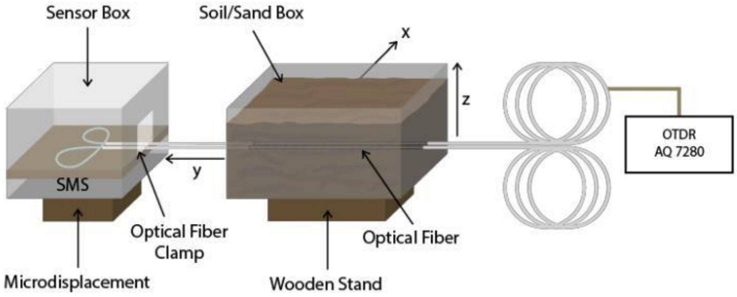


Fig. 12. The GOF - based OTDR - based displacement sensor technology for detecting landslides [63].

Based on optical time-domain reflectometer (OTDR) technology, a spring-shaped fiber-optic displacement sensor (SSFODS) for subgrade settlement monitoring was suggested by Zheng et al. [64], which is simple to build and low in cost. Figure 13 shows the Calibration test of the designed SSFODS. Theoretical explanation and development of the sensing concept between visible external displacement and optical fiber bending loss were given. The SSFODS featured a measuring range of 90 mm, a minimum displacement resolution of 0.173 mm, and maximum hysteresis and repeatability error of 2.81 percent and 8.42 percent, respectively, according to sensor calibration. The SSFODS was put to the test to see how accurate it was in detecting soil compression deformation. Two SSFODSs linked in series accurately captured the increasing compaction behavior of the fill slope in a simple field monitoring application.

Fig. 13. Calibration test - designed SSFODS [64].

3. Discussions

Table 1 is presented to highlight the performance and characteristics of several typical distributed optical fiber sensors which have been applied for landslide monitoring. On the basis of this review, it can be concluded that the fibers with relatively low robustness cannot withstand rigorous condition during monitoring which potentially causes fiber cuts and configuration errors; in moderate robustness, to some extent, fiber can withstand loading, and a load can be calculated based on this load [31, 47, 55, 59]; potentially high robustness was analysed in COFT with an innovative structure based on OTDR, which reduces the possibility of fiber damage and makes it easy to determine the potential sliding surface with highest measurement accuracy and largest sliding distance [49].

The technique using simple and cheapest fiber sensor relying on a macro-bending loss in POF has been used to detect landslide in the early stage; however, the use of a simple and cheap fiber sensor makes it low quality and flammable, and also it cannot be effectively used for long-distance communication systems [57]. From the table it can be configured that the methods with high resolution have the ability to perform distributed measurements with high sensitivity; besides, it requires periodic measuring and long-time monitoring and also inconsistency of strain measurement has been seen [31, 55].

As mentioned, the method based on COFT that uses first and second-generation transducers with a bowknot has an effective low cost at USD 0.15/m. However, it cannot determine the loading movement direction [55]. Meanwhile, for third and fourth generation transducers with a bowknot using EPS COFT and empirical formula verification are at the cost of USD 0.2/m but the construction and installation are rather complex [59, 61]. So, it can be concluded that the method using COFT with an innovative structure based on OTDR and OFS provides most benefits which include paving convenience, largest sliding distance, highest measurement accuracy to determine the potential sliding surfaces but it comes with the highest price of USD 0.45/m [61]. GOF-based OTDR- based displacement sensor technology for detecting landslides measurement results was achieved with sensitivity and resolution of 0.241 dB/mm and 0.004 mm [63]. The SSFODS featured maximum hysteresis and repeatability error of 2.81 percent and 8.42 percent [64].

Table 1. Performance comparison of distributed optical fiber sensing for landslide monitoring.

Technique	Advantages	Disadvantages	Performance Metric Parameters
P-OFDR [31]	High spatial resolution; High sensitivity; Good dynamic range	It requires periodic measuring and long-time monitoring.	Spatial resolution: <5 cm. Measuring range: 10 km. Dynamic range: 70 dBm. High sensitivity: -80 dBm
BOTDA [47]	Allows strain measurements in the micro strain range; Provides information about the position of the object	No standardized procedures: Data interpretation is complex; Provides information only at specific points.	Spatial resolution: 1 m Sensing range: 50 km
Rayleigh backscatter- based COTDR [49]	High sensitivity: High-resolution strain measurement Provides early detection of landslides using only a basic and inexpensive fiber sensor	There is a discrepancy of less than 0.1μξ strain	Spatial resolution: 1 m. Sensitivity resolution: 0.1μξ
Macro-bending Loss in POF [53]	Provides early detection of landslides using only a basic and inexpensive fiber sensor	Low quality and flammable; It cannot be used for long-distance communication systems.	Displacement range: 40 cm. Linearity: 99.5%. Sensitivity: (5.9 ±0.2) dB/cm

Novel distributed optic fiber transducer: 1st and 2nd generation with a bowknot [55]	Large sliding distance of measurement. Largest dynamic range	It cannot determine the loading movement direction.	Maximum sliding distance: 30.6 mm; Corresponding initial accuracy: 3.3 mm. Dynamic range: 0-27.3 mm USD 0.15/m
COFT: 3rd generation transducer and 4th generation transducer with a bowknot using EPS [57]	High initial measurement precision; large sliding distance; wide dynamic range; ability to determine loading movement direction	Higher complexity in transducer construction; Inconvenient for practical applications	Maximum initial measurement precision: 1 mm. Sliding distance: 21 mm; dynamic range: 0-20 mm USD 0.2/m
COFT based landslide monitoring using empirical formula and verification [59]	High initial measurement precision; Good dynamic range; Capable of determining the direction of loading movement	Monitoring is most effective only on sandy clay slopes. Installation is challenging.	Dynamic range: 0-23.2 mm. Initial measurement precision: 1 mm. Sliding distance: >26.5 mm USD 0.2/m
COFT: novel OFS with an innovative structure based on OTDR [61]	Largest sliding distance; Highest measurement accuracy; Paving convenience; Easy to determine the potential sliding surfaces.	It requires OFS to be multiplexed or connected in series to detect the multi-slip surfaces or complex deep-seated landslides.	Maximum sliding distance:36 mm. Effective initial measurements: 0.98; Average displacement ratio range: 0.974 - 1.081; Dynamic range: 0-34 mm. USD 0.45/m
The displacement sensor based on GOF and OTDR [63]	With good resolution, easy fabrication, and operation.	Model applicable for laboratory scale.	Sensitivity: 0.241 dB/mm Resolution: 0.004 mm.
SSFODS based on OTDR [64]	Has a wide measuring range, and two SSFODSs can correctly capture the increasing compaction behavior of the fill slope.	Only given physical size of the spring has a significant influence on sensor response, it is imperative to identify the shortest connecting fiber length that still satisfies the accuracy criteria.	Measuring range: 90 mm; Minimum displacement resolution: 0.173 mm. Maximum hysteresis: 2.81%: Repeatability error: 8.42%

4. Conclusions

The landslide monitoring system is necessary and significant for the living environment. The distributed sensing aspect of fiber confirms that it is low-cost, has a simple testing approach, and offers significant advantages over conventional point-based sensing and monitoring methodologies. There has been a lot of study on FBG arrays and optical fibers, but most of them have not been able to detect long-distance signals. With distributed sensing, uninterrupted long-distance testing with optimal performance parameters such as sensing range, spatial resolution, and sensing resolution is feasible. They can also be employed in inaccessible regions such as beneath bridges, outside of passage dividers, along with dams, and along pipelines and railroads in isolated areas. Furthermore, the optical fibers can be controlled from a distance, allowing fibers to be laid and left without the need for routine investigations while data is being transferred via optical fiber. This review study analysed the impact, performance, and characteristics of several typical landslide monitoring systems using distributed optical fibers, leading to the development of an improvised solution for the real-time, cost-effective, and efficient landslide monitoring system.

An Eye Towards the Future:

This review provides a base for the fiber-optic landslide monitoring using distributed sensing. The performance comparison results will be useful to identify the methods or techniques carried out and incorporate these ideas for developing an efficient monitoring system. A substantial amount of research on the use of distributed fiber-optic sensing for landslide monitoring has been explored, the vast majority of these sensing systems are simple and employed in a laboratory setup. Although the methods suggested are straightforward to use in a lab context and small area, they are impractical for real- time landslide monitoring. This emphasizes the importance of a specially designed fiber optic cable and an OTDR system capable of monitoring the status of a large area in a landslide-prone zone. The environmental data from the slope recorded by OTDR can be obtained and transmitted to associated computer systems for long-term storage. The ability of the monitoring system to quickly detect slope movement will enable early warning of potential slope failures, giving people enough time to move to a safer region and by this we can reduce fatalities and damages.

Abbreviations

BFS	Brillouin Frequency Shift
COFT	Combined Optical Fiber Transducer
COTDR	Coherent Optical Time-Domain Reflectometry
DFOS	Distributed Fiber Optic Sensing
DPP- BOTDA	Differential Pulse-width Pair Brillouin Optical Time-Domain Analysis
EPS	Expandable Polystyrene
FBG	Fiber Bragg Grating
GIS	Geographic Information System
GOF	Glass Optical Fiber
GPS	Global Positioning System
OFS	Optical Fiber Sensor
OTDR	Optical Time-Domain Reflectometer
PM	Polarization-Maintaining
POF	Polymer Optical Fiber
P-OFDR	Polarization-Sensitive Optical Frequency Domain Reflectometry
SA-BOTDA	Slope-Assisted Brillouin Optical Time-Domain Analysis
SMS	Short Messaging Service
SMSM	Single Mode-Multimode-Single Mode
SSFODS	Spring-Shaped Fiber-Optic Displacement Sensor

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