

Assessment of Soil-embedded POF Sensor Performance for Geotechnical Monitoring

L.S.Supian

Department of Electrical & Electronics
Engineering,
Faculty of Engineering, National
Defence University of Malaysia,
Kuala Lumpur, Malaysia
cawa711@gmail.com

Nani Fadzlina Naim

School of Engineering, College of
Engineering,
UiTM
Shah Alam, Malaysia
fadzlina007@hotmail.co.uk

Nur Masyitah Muhmin

Department of Electrical & Electronics
Engineering,
Faculty of Engineering, National
Defence University of Malaysia,
Kuala Lumpur, Malaysia
cawa_711@yahoo.com

Harry Ramza

Department of Electrical Engineering,
Faculty of Industrial Technology and
Informatics,
Universitas Muhammadiyah Prof. Dr.
HAMKA
Jakarta, Indonesia
hramza@uhamka.ac.id

Chew Sue Ping

Department of Electrical & Electronics
Engineering,
Faculty of Engineering, National
Defence University of Malaysia,
Kuala Lumpur, Malaysia
sueping@upnm.edu.my

Norhana Arsad

Photonics Technology Laboratory,
Department of Electrical, Electronic
and Systems Engineering, Faculty of
Engineering
Universiti Kebangsaan Malaysia
Bangi, Malaysia
noa@ukm.edu.my

Abstract—Fiber optic sensing technologies have recently been used to measure geotechnical structures like slopes, tunnels and retaining walls due to their light weight, high precision, durability, wide measurement range, and long-distance data transmission. However, the interaction between the sensing fiber and soil mass affects optical fiber data dependability. Monitoring soil and rock deformation, especially sub-surface measurement is difficult in geotechnical engineering. This study examines soil-embedded plastic or polymer optical fiber (POF) sensor performance for geotechnical monitoring. The polymer optical fiber's capabilities were optimized by studying soils type, sensor cores, tapering length, and soil settings for pressure sensing implementation. Despite promising results, polymer optical fibers for monitoring soil and rock displacement have limitations, and strain between implanted sensor fibers and soil is unclear. This research optimizes polymer optical fiber for geotechnical monitoring sensors in several conditions. The investigation used various soil types with differing weights and settings, several fiber optic sensor samples with different core widths, and tapered length. This study considers sensitivity and resolution of the fiber sensors after embedded in those variables. The results may quantify how different parameters affect sensor performance in its intended applications based on the sensitivity and the resolutions of the sensor.

Keywords—polymer optical fiber, sensor, soil, monitoring, landslides

I. INTRODUCTION

Engineering applications for polymer optic fibers (POFs) sensors include temperature [1], pressure [2], displacement [3], biomedical [4], food quality [5,6] chemical or liquid contamination [7], and also the detection of deformation in steel-reinforced concrete structures. It is appropriate for long-term monitoring applications since polymer optical fiber is extremely resilient and can survive conditions of extreme weather [8]. Polymer or plastic optical fiber is a dependable device for geotechnical monitoring, with many advantages over more conventional approaches. With its long lifespan, high sensitivity, simple installation, and low price, it is a great choice for many geotechnical engineering tasks. Monitoring geotechnical constructions and other

infrastructure is becoming increasingly important as natural disasters like floods and storms become more frequent and rising land consumption causes unexpected challenges [9]. Therefore, slope monitoring is determined essential for the growth of geotechnical engineering to assure the safety of engineering facilities.

Inclinometers, multi-point extensometers, and tiltmeters are just a few of the devices that have been created to measure the deformation of geo-structures [8]. There are also drawbacks to these tools, such as the fact that inclinometers aren't as precise as certain other devices and can be a hindrance in some situations [10]. Measurement range is limited on multi-point extensometers, while tiltmeters tend to be only usable in one orientation [11].

Landslides are one of the most dangerous geohazards. As a non-precipitous country with 25% mountains and hills, Malaysia's landslides differ from those elsewhere [2]. In Malaysia, most landslides are caused by poor planning and human errors. Due to a scarcity of adequate property near major cities like Kuala Lumpur, Penang, and Johor Bahru, industrial, commercial, and housing developments on soft ground and hill sites have increased in Malaysia over the past 15 years. Despite the unstable ground's well-known issues, recurring failures can be reduced with the correct strategy, research, design, construction supervision, and monitoring.

According to research, Malaysia has had a few major landslides in the past. First is the 14-story Highland Tower block; Malaysia's biggest landslide occurred in Ulu Klang, Selangor, which killed 48 people. Slope collapse and landslides at many hillside development sites in Malaysia were caused by rainfall, storm water activities, and poor slope control [12]. In 2008, a landslide in Bukit Antarabangsa killed 5 individuals, buried 14 bungalows, and forced approximately 2000 residents to evacuate their houses. Geological measurements indicated no ground displacement, ruling out seismic forces as the source of the 2008 landslide [13]. The landslide that wrecked Hidayah Madrasah Al-Taqwa Orphanage in Hulu Langat on Saturday, May 21st, and killed 16 people was triggered by three days of unexpected torrential rain [14]. On December 16, 2022, a landslide buried an organic farm's campgrounds

near Batang Kali, Selangor, Malaysia [15]. When the slope collapsed, 92 individuals were buried, 61 victims were saved, 8 were hospitalized, and 31 died.

A variety of geotechnical structures, such as deep and shallow foundations, embankments and reservoirs, tunnels and excavations, and naturally occurring and artificially created slopes, have been monitored with excellent outcomes using inclinometers, multi point extensometers, and tiltmeters in recent years. Inclinometers, multi-point extensometers, and tiltmeters have demonstrated the superior advantages of distributed fiber-optic sensing technologies, such as long-distance detection, high repeatability, and superior corrosion resistance. Although this easy approach is more efficient in terms of money, time, and adaptability to hostile site circumstances than others, the processing and error analysis of vast measurements of data monitoring are tough challenges for geotechnical practitioners. The strain transfer process between the embedded sensor fiber and the surrounding soil is poorly understood, which presents a significant challenge. In light of these issues, the purpose of this experiment is to develop a better polymer optical fiber sensor for use in a geotechnical monitoring system. The polymer optical fiber sensor used in this project is small and lightweight. Not only that, the cost of this sensor is also inexpensive, and easy to fabricate. The designed POF sensor will be embedded in soil to monitor geotechnical activities, and this project will examine its performance in terms of sensitivity and resolution.

An understanding of the mechanical interaction between implanted POFs and the surrounding soil or rock is needed to create an efficient POF-based geotechnical monitoring system. In this study, POFs supervises and monitors the possible landslip. Three variables will be used to test POF's landslip detection ability. First, are the various weight soils with different type of soils that commonly can be found in Malaysia is utilized in this experiment. Malaysia has 40% peat soil, 20% clay, and 40% sand, therefore these soils will be used as one of the variables in this experiment [16]. Next, evaluation of the sensor's sensitivity using fiber optic core diameters of 0.98 mm, 0.96 mm, and 0.94 mm and tapered length of 2 cm, 4 cm and 6 cm. The settings of the soils are the last variables where the vibration of the soils and the conditions of the soils will be tested. These factors were analyzed to find the optimum sensor performance, including sensitivity and resolutions to observe whether POFs is suitable for becoming a sensor for geotechnical monitoring.

II. METHODOLOGY

A. Overview

For geotechnical monitoring, this project develops an integrated polymer optical fiber sensor. To execute the experiment, POF's properties and mechanism must be understood. To test the sensor's sensitivity, the parameters are measured. In this experiment, four factors will be tested: soil types, core's width, tapered length, and the vibrations level. The first variable is soil types. Peat soil, coarse sandy soil, and sandy soil are Malaysia's main soils. This experiment investigated whether soil types affect sensor displacement detection. The second variable is length of the

tapered area. When sandpaper erodes cladding to the core, it becomes tapered. To monitor the landslide, it will sense soil sensitivity at the core. Core width is the third variable. After the core is tapered, different widths can be tested to see if they affect the sensor. The last variable is the vibration of the soil. The vibration will mimic as it was the earthquake to measure the sensitivity of the sensor. These four parameters are compared among each other. This work also characterizes the sensor-soil interaction by testing the optical fiber sensor. For instance, sensor condition, soil-sensor interaction, and soil compression. The experiment will be repeated until it yields an average result. After that, the data was analyzed so that the results meet POF sensor performance requirements for sensitivity, efficiency, linearity, and resolution.

B. Conditions and Types of Soils

The type of the soils is chosen based on the frequent soils that can be found in Malaysia. Peat soils, coarse sandy soils and sandy soils have been categorized into dry set and wet set with mass of 300 grams, 600 grams, and 900 grams. Fig. 1 illustrates a setting of wet and non-vibrate peat soil to identify the behavior of the sensor when it is raining. Another example of settings is a motor is used to introduce a vibration for the soil to mimic the earthquake as shown in Fig. 2.

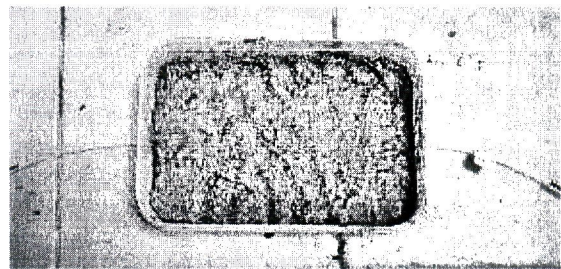


Fig. 1. Setting of wet and non-vibrate peat soil.



Fig. 2. Setting of dry and vibrate sandy soil.

C. Sensors Fabrication: Polishing and Tapering

The effective transmission of light through optical fibers is the basis for the great sensitivity of fiber optic sensors. Signal attenuation, decreased sensitivity, poor precision can all result from a contaminated or damaged fiber's end face. Because of this, it is critical to keep the end face clean and polished for optimum efficiency. In the process of polishing a fiber optic connector, flaws like scratches and dust are eliminated from the fiber's exposed face. The end face of the

fiber was carefully wiped using a cotton pad dampened with isopropyl alcohol, in order to eliminate any dirt or oils that might obstruct the polishing process [17]. The value before and after the polishing needs to be recorded as a reference before starting the experiment.

The middle section of a fiber optic sensor were tapered by gradually decreasing the diameter of the fiber over a particular length, in order to enhance the efficiency of light transmission. The ends of the fiber sensor were polished to ensure that they are smooth and perpendicular to the fiber axis. To taper the fiber, the length that needs to be fabricated were marked at 2 cm, 4 cm and 6 cm in order to set the tapered length. Then pressure is applied by stroking the adjusted area while holding the ends firmly, as illustrated in Fig. 3. In response to this, the fiber thins down, adopting a more tapered character. The stroking process needs to be managed meticulously to achieve the perfect taper profile like 0.98 mm, 0.96 mm, and 0.94 mm. The amount of the original fiber removed during the tapering process can be determined using a vernier caliper.

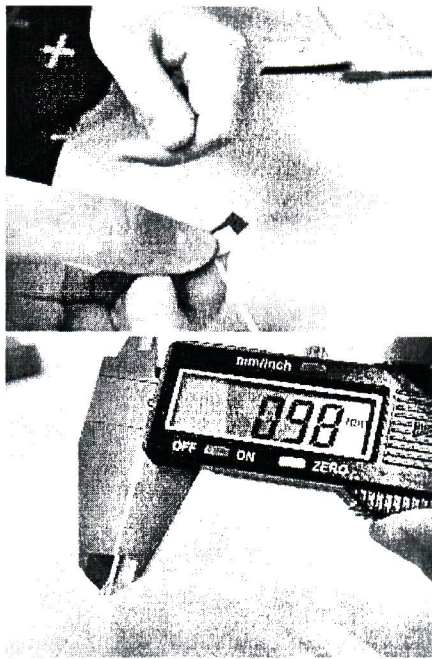


Fig. 3. Tapering the fiber optic sensor using sandpaper.

D. Testings

In order to guarantee optimal functionality and dependability, fiber optic cables are often put through several types of tests before being put into operation. Data may be transmitted quickly and over great distances using fiber optic lines. Due to the tapering, the light source is reflected outward and seen at the tapered area. The result of this testing will be the reference value. After the reference value has been recorded, the sensor is then tested under various settings and conditions as depicted in Fig. 4(a) and the losses were recorded. The value of magnitude is obtained by using an application on a phone called "vibration metre – seismometer" where it detects the vibration of a thing that being attached to it as shown in Fig. 4(b).

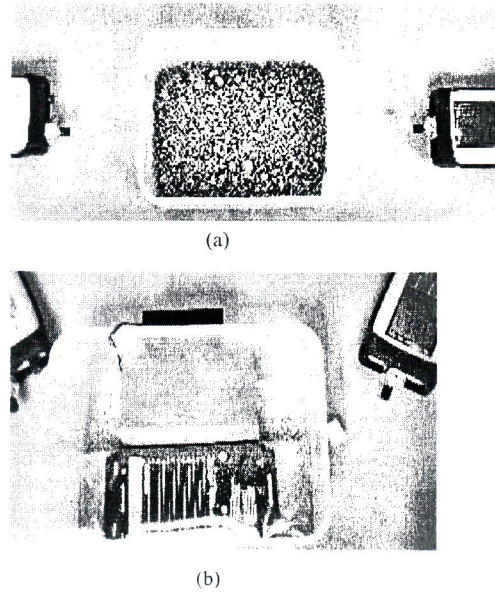


Fig. 4. Testing the fiber sensor (a) sensor embedded in dry and non-vibrate settings (b) sensor embedded in dry and vibrate settings.

III. RESULTS AND DISCUSSIONS

The samples of fiber optic sensor will go through 4 conditions which are dry soils with no vibration, dry soils with vibration, wet soils with no vibration, wet soils with vibration. The orange, blue and green colors represent sandy soils, peat soils and coarse sandy soils respectively. From here the sensitivity and resolutions of the samples will be analyzed along varies mass and types of soils.

A. Dry Soils

SANDY SOIL	Ø (mm)	l (cm)	L (cm)	INPUT			OUTPUT			SENSITIVITY			RESOLUTION		
				dBm	300g	600g	900g	ams (sand)	ams (sand)	ams (sand)	ams (sand)	ams (sand)	ams (sand)		
A	0.98	2.00	45.00	17.40	16.90	17.00	19.60	0.97	0.98	1.13	17.40	17.40	17.40		
B	0.96	2.00	45.00	17.80	19.53	19.78	20.28	1.10	1.11	1.07	17.80	17.80	17.80		
C	0.94	2.00	45.00	19.40	19.81	20.37	20.89	1.02	1.05	1.08	19.40	19.40	19.40		
D	0.98	4.00	45.00	15.50	17.34	17.60	18.00	1.11	1.14	1.14	15.50	15.50	15.50		
E	0.96	4.00	45.00	19.20	20.10	20.40	20.60	1.05	1.06	1.07	19.20	19.20	19.20		
F	0.94	4.00	45.00	20.10	21.20	21.60	22.50	1.05	1.07	1.12	20.10	20.10	20.10		
G	0.98	6.00	45.00	20.00	22.20	22.50	23.20	1.11	1.13	1.16	20.00	20.00	20.00		
H	0.96	6.00	45.00	22.80	25.00	25.30	25.70	1.10	1.11	1.11	22.80	22.80	22.80		
I	0.94	6.00	45.00	27.70	30.40	30.70	31.10	1.10	1.11	1.12	27.70	27.70	27.70		

(a)

PEAT SOIL	Ø (mm)	l (cm)	L (cm)	INPUT			OUTPUT			SENSITIVITY			RESOLUTION		
				dBm	300g	600g	900g	ams (peat)	ams (peat)	ams (peat)	ams (peat)	ams (peat)	ams (peat)		
A	0.98	2.00	45.00	17.40	18.65	18.97	19.74	1.07	1.09	1.13	17.40	17.40	17.40		
B	0.96	2.00	45.00	17.80	20.27	20.64	21.09	1.14	1.16	1.16	17.80	17.80	17.80		
C	0.94	2.00	45.00	19.40	21.80	21.53	21.93	1.12	1.11	1.12	19.40	19.40	19.40		
D	0.98	4.00	45.00	15.50	17.04	17.58	17.86	1.10	1.11	1.14	15.50	15.50	15.50		
E	0.96	4.00	45.00	19.20	19.95	20.07	20.40	1.04	1.05	1.06	19.20	19.20	19.20		
F	0.94	4.00	45.00	20.10	21.95	22.14	22.66	1.09	1.10	1.13	20.10	20.10	20.10		
G	0.98	6.00	45.00	20.00	22.76	24.35	25.10	1.14	1.22	1.26	20.00	20.00	20.00		
H	0.96	6.00	45.00	22.80	25.52	25.65	26.60	1.12	1.13	1.13	22.80	22.80	22.80		
I	0.94	6.00	45.00	27.70	33.87	34.05	34.28	1.22	1.23	1.23	27.70	27.70	27.70		

(b)

COARSE SANDY SOIL	Ø (mm)	l (cm)	L (cm)	INPUT			OUTPUT			SENSITIVITY			RESOLUTION		
				dBm	300g	600g	900g	ams (coarse)	ams (coarse)	ams (coarse)	ams (coarse)	ams (coarse)	ams (coarse)		
A	0.98	2.00	45.00	17.40	17.71	17.73	17.73	0.98	0.99	1.00	17.40	17.40	17.40		
B	0.96	2.00	45.00	17.80	17.84	18.60	18.75	1.00	1.04	1.05	17.80	17.80	17.80		
C	0.94	2.00	45.00	19.40	20.51	20.74	20.85	1.06	1.07	1.07	19.40	19.40	19.40		
D	0.98	4.00	45.00	15.50	16.48	17.54	17.80	1.06	1.13	1.15	15.50	15.50	15.50		
E	0.96	4.00	45.00	19.20	19.38	19.91	20.08	1.01	1.04	1.05	19.20	19.20	19.20		
F	0.94	4.00	45.00	20.10	21.90	22.60	22.21	1.09	1.09	1.10	20.10	20.10	20.10		
G	0.98	6.00	45.00	20.00	22.67	23.10	23.29	1.13	1.14	1.16	20.00	20.00	20.00		
H	0.96	6.00	45.00	22.80	25.56	25.75	25.86	1.12	1.13	1.13	22.80	22.80	22.80		
I	0.94	6.00	45.00	27.70	33.60	33.95	34.79	1.21	1.23	1.23	27.70	27.70	27.70		

(c)

Fig. 5. Data of sensitivity for dry and non-vibrating soil setting for (a) sandy soil (b) peat soil and (c) coarse sandy soil.

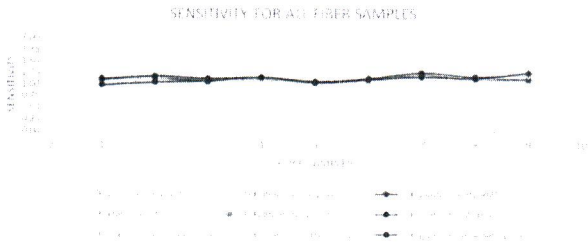


Fig. 6. Graph of sensitivity for dry and non-vibrating soil setting for all developed fibers optic sensor.

Based on the table shown in Fig. 5 and Fig. 6, the measurement of different types of soil and mass is recorded for non-vibrate condition. The formula used to measure the sensitivity and resolution is shown in equations (1) and (2) respectively [18,19]. Fig. 6 shows the sensitivity of fiber sensor when embedded in non-vibrate sandy soils, peat soils, and coarse sandy soils with mass of 300g, 600g and 900g. From the graph, we can see that the sensitivity of the fiber is nearly linear among all the soil's settings and conditions.

$$S = \frac{y}{x} \quad (1)$$

S: sensitivity of the sensor
y: output signal
x: input parameter of the signal

$$R_s = \frac{x}{S} \quad (2)$$

R_s : resolution of the sensor
x: sensor measurement
S: sensitivity of the sensor

If a fiber sensor's sensitivity is constant, it will respond consistently to an input stimulus or parameter. The sensor's consistent sensitivity permits precise calibration. By determining the sensor's reaction to known stimuli, a calibration curve can be created to translate sensor readings into meaningful values of the measured parameter. The sensor's behavior is predictable due to consistent sensitivity. After calibration, the sensor's output for any stimulus within its range may be predicted. Measurements are more accurate and repeatable with continuous sensitivity. The sensor's measurements should be consistent and dependable as long as its performance remains stable. The fiber sensor's consistent sensitivity benefits control systems. By giving a reliable and predictable measurement of the parameter being monitored, it provides feedback control by allowing the system to make necessary modifications or take actions depending on the sensor's output [18,19].

Fig. 7 depicts the resolution of a fiber sensor when implanted in vibrating sandy soils, peat soils, and coarse sandy soils with masses of 300g, 600g, and 900g from Fig. 6. Upon observing Fig. 6, it becomes apparent that the sensitivity of all the soils remains relatively consistent, which exhibits the highest sensitivity. On the other hand, the resolution of all tested samples across different soil types remains constant throughout the experimentation process.

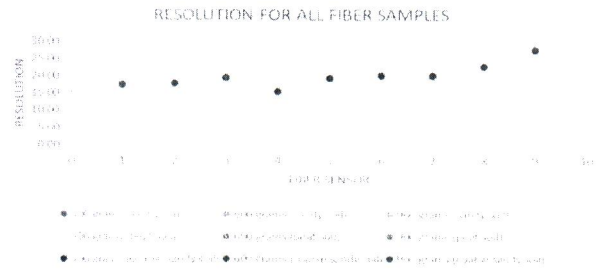


Fig. 7. Graph of resolutions for dry and non-vibrating soil setting for all fibers optic sensor.

The resolution of non-vibrate and vibrate is same for all the samples. When the resolution of a fiber optic remains constant, it implies that the fiber optic can consistently differentiate between two points even when they are separated by the smallest discernible distance. The resolution of an optical imaging system is essentially the minimum distance at which two distinct points can be distinguished. Hence, if the resolution of a fiber optic remains unchanged, it signifies that the fiber optic possesses the ability to discern between two points that are a specific distance apart, irrespective of other influencing factors. Nonetheless, it is important to note that the linearity of the fiber optic might be influenced by various factors, including the refractive index of the core and cladding materials, as well as the numerical aperture of the fiber. These factors can potentially affect the performance and accuracy of the fiber optic system beyond the resolution alone.

Fig. 8 shows the data collected for sensitivity and resolution of the fiber sensor in a dry and vibrating soil setting. As can be seen, the sixth sample fiber of 900 grams coarse sandy soils has the highest sensitivity. This can be concluded that in wet condition, polymer optical fiber is more sensitive due to the small fraction between the sensor and the rocks in the soils.

SOIL	Ø (mm)	L (cm)	L (cm)	dBm	300g			600g			900g		
					S	R	S	R	S	R	S	R	
A	0.98	2.00	45.00	-17.40	-15.29	-15.56	-16.04	0.88	0.89	1.11	1.11	1.11	1.11
B	0.96	2.00	45.00	-17.80	-17.87	-18.09	-18.73	1.00	1.02	1.02	1.02	1.02	1.02
C	0.94	2.00	45.00	-19.40	-20.63	-21.56	-22.50	1.06	1.11	1.11	1.11	1.11	1.11
D	0.98	4.00	45.00	-15.50	-16.92	-17.01	-19.37	1.09	1.10	1.10	1.10	1.10	1.10
E	0.96	4.00	45.00	-19.20	-19.24	-19.43	-19.87	1.00	1.01	1.01	1.01	1.01	1.01
F	0.94	4.00	45.00	-20.10	-21.10	-21.39	-21.69	1.05	1.06	1.06	1.06	1.06	1.06
G	0.98	6.00	45.00	-20.00	-21.28	-21.53	-21.68	1.06	1.08	1.08	1.08	1.08	1.08
H	0.96	6.00	45.00	-22.80	-26.05	-26.29	-26.90	1.14	1.15	1.15	1.15	1.15	1.15
I	0.94	6.00	45.00	-27.70	-30.60	-30.73	-31.42	1.10	1.11	1.11	1.11	1.11	1.11

(a)

PEAT SOIL	Ø (mm)	L (cm)	L (cm)	dBm	300g			600g			900g		
					S	R	S	R	S	R	S	R	
A	0.98	2.00	45.00	-17.40	-18.09	-19.27	-20.04	1.04	1.11	1.11	1.11	1.11	1.11
B	0.96	2.00	45.00	-17.80	-22.21	-23.26	-24.57	1.25	1.31	1.31	1.31	1.31	1.31
C	0.94	2.00	45.00	-19.40	-22.60	-24.30	-24.45	1.16	1.25	1.25	1.25	1.25	1.25
D	0.98	4.00	45.00	-15.50	-17.60	-17.97	-18.68	1.14	1.16	1.16	1.16	1.16	1.16
E	0.96	4.00	45.00	-19.20	-21.56	-22.29	-22.87	1.12	1.16	1.16	1.16	1.16	1.16
F	0.94	4.00	45.00	-20.10	-21.98	-22.83	-23.43	1.09	1.14	1.14	1.14	1.14	1.14
G	0.98	6.00	45.00	-20.00	-23.90	-26.10	-26.40	1.30	1.31	1.31	1.31	1.31	1.31
H	0.96	6.00	45.00	-22.80	-26.82	-27.31	-27.49	1.18	1.20	1.20	1.20	1.20	1.20
I	0.94	6.00	45.00	-27.70	-32.04	-35.94	-36.26	1.16	1.30	1.30	1.30	1.30	1.30

(b)

COARSE SANDY SOIL	Ø (mm)	L (cm)	L (cm)	INPUT dBm	OUTPUT			SENSITIVITY			RESOLUTION		
					300g	600g	900g	300g	600g	900g	300g	600g	900g
A	0.98	2.00	45.00	-17.40	-17.87	-18.23	-18.73	1.02	1.05	1.05	1.05	1.05	1.05
B	0.96	2.00	45.00	-17.80	-18.88	-19.03	-19.44	1.06	1.07	1.07	1.07	1.07	1.07
C	0.94	2.00	45.00	-19.40	-19.77	-20.31	-20.85	1.02	1.05	1.05	1.05	1.05	1.05
D	0.98	4.00	45.00	-15.50	-16.35	-16.97	-17.12	1.05	1.09	1.09	1.09	1.09	1.09
E	0.96	4.00	45.00	-19.20	-17.34	-18.66	-18.80	0.90	0.97	0.97	0.97	0.97	0.97
F	0.94	4.00	45.00	-20.10	-19.12	-19.87	-20.35	0.95	0.99	0.99	0.99	0.99	0.99
G	0.98	6.00	45.00	-20.00	-22.71	-23.05	-23.81	1.14	1.15	1.15	1.15	1.15	1.15
H	0.96	6.00	45.00	-22.80	-25.33	-26.89	-27.22	1.11	1.18	1.18	1.18	1.18	1.18
I	0.94	6.00	45.00	-27.70	-30.11	-33.27	-34.79	1.09	1.20	1.20	1.20	1.20	1.20

(c)

Fig. 8. Data of sensitivity for dry and vibrating soil setting for (a) sandy soil (b) peat soil and (c) coarse sandy soil.

B. Wet Soils

The graph shown in Fig. 9 shows the sensitivity and Fig. 10 shows resolution that have been obtained in wet soils is almost similar as the dry soils setting.

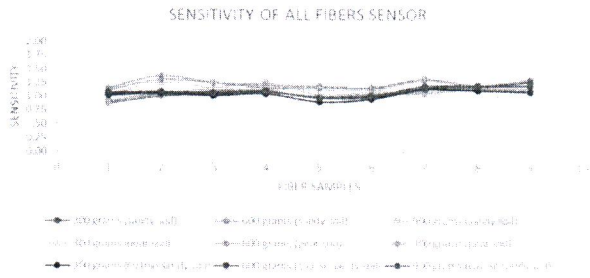


Fig. 9. Graph of sensitivity for wet and non-vibrate soil setting for all fibers optic sensor.

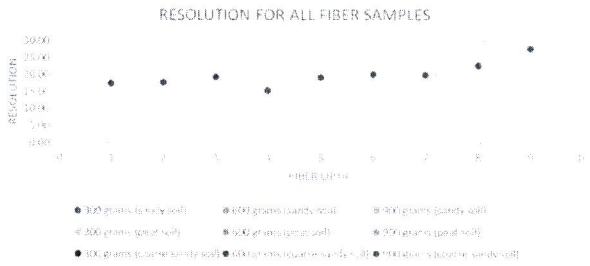


Fig. 10. Graph of resolutions for wet and non-vibrate soil setting for all fibers optic sensor.

By comparing the conditions of the soil when it is dry or wet, we can see that the sensitivity of the dry soils is nearly linear compared to wet soils as shown in Fig. 10. But for all conditions, regardless of the soils setting, the resolution of the sensor remained constant throughout the experiment. This shows that the sensor resolution is good and be used as a sensor to monitor the landslide.

IV. FACTORS THAT AFFECTING OUTPUTS OF THE SENSOR

A. Fabrication of the Sensor

The higher the sensitivities of fiber optic sensors, the smaller their core diameters. This is because the absence of cladding prevents light from being reflected back into the core, where it originated. As a result, the sensor's loss increases with decreasing core thickness. Its sensor's readings will be affected by the tapering length as well. Expenses will increase proportionally with the duration of the taper. Losses in a fiber optic sensor can be kept to a minimum via careful planning of the tapering area and through optimization of the mode matching between the fiber and the other elements of the system.

B. Conditions of the Soils

By comparing dry and wet soils, both soils have optimum outcome to the sensor as it produces a better sensitivity which is good for sensor. Fiber optic sensors have the ability to distinguish between dry and wet soils by leveraging the difference in refractive index between these two conditions. In dry conditions, the loss of the sensor is much higher compared to wet conditions. This phenomenon occurs because water has a higher refractive index than air, and the presence of water in the soil elevates the refractive index of the soil. Consequently, when the soil is dry, the refractive index is lower, leading to a decrease in the output signal of the fiber optic sensor. The fiber optic sensors may be better protected from damage in non-vibrating soils due to the

stability of the soil. Optimum readings may result from the fiber optic sensors' transmission signals being distorted by ground vibrations. Data obtained showed that the linear sensitivity is a bit higher in the non-vibrating condition compared to the vibrating state.

V. CONCLUSIONS

Geotechnical structures and infrastructure must be monitored as the frequency of climate-related disasters increases. Even if sophisticated monitoring techniques such as Fiber Bragg Grating, Brillouin Scattering, and Optical Time Domain Reflectometry are employed, the real challenge is in processing and analyzing the vast amounts of monitoring data. To combat this problem, engineers designed polymer optical fiber sensor that is both inexpensive and precise for use in monitoring geotechnical infrastructure. Using a power meter and plastic optical fiber, we can evaluate the sensor's sensitivity and resolution to find of the optimum solutions to solve issues related to geotechnical monitoring. The soil is being evaluated for its density, tapering length, width of the core, condition, and diversity. Data and graphs shown depict that the sensor performs admirably in a range of conditions, as the particles in the soil influence fiber losses during vibration and compression owing to moisture. In this experiment, the fiber sensor's resolution is optimum when the soil is dry and not vibrating, and the soil's lack of vibration provides the most constant sensitivity. This data indicates that plastic optical fiber has potential as a sensor for geotechnical applications.

TABLE I. COMPARISON ON SENSITIVITY AND RESOLUTION.

CONDITIONS	SENSITIVITY	RESOLUTION
Dry and Non-vibrate	Good	Good
Dry and Vibrating	Average	Good
Wet and Non-vibrate	Good	Good

In Table I, we can see the results of all the tests conducted under different circumstances. Because of its sensitivity, the sensor provides the optimum results in both wet and dry, vibrating and non-vibrating soil. The fiber optic resolution is consistent across all test settings, proving that it can function as a sensor. The fact that all of the situations provide essentially linear data is further evidence of the sensor's efficiency.

ACKNOWLEDGMENT

This work would not have been possible without the financial and facility support of the Department of Electrical and Electronics Engineering, Faculty of Engineering, National Defence University of Malaysia.

REFERENCES

- [1] K. Tian, Y. Liu, Q. Wang, "Temperature-independent fiber Bragg grating strain sensor using bimetal cantilever," *Optical Fiber Technology*, 11(4), 370–377, 2005, doi: 10.1016/j.yofte.2005.03.001.
- [2] W.J. Bock, J. Chen, P. Mikulic, T. Eftimov, "A Novel Fiber-Optic Tapered Long-Period Grating Sensor for Pressure Monitoring," *IEEE Transactions on Instrumentation and Measurement*, 56(4), 1176–1180, 2007, doi:10.1109/TIM.2007.899904.
- [3] L.S. Supian, D.H.M. Razali, S.A. Syed Ali, "Investigation of Scattered-Bend Loss Coupling in Polymer Optical Fiber (POF) - Based Displacement Measurement Sensor," in 2022 IEEE 9th

- International Conference on Photonics (ICP), IEEE: 13–14, 2022, doi:10.1109/ICP53600.2022.9912445.
- [4] R. Correia, S. James, S.-W. Lee, S.P. Morgan, S. Korposh, "Biomedical application of optical fibre sensors," *Journal of Optics*, 20(7), 073003, 2018, doi:10.1088/2040-8986/aac68d.
- [5] N. Albakri, S. Abdullah, L.S. Supian, N. Arsad, S.D. Zan, A.A.A. Bakar, "Assessment of Palm Oil Fruit Bunch Maturity based on Diffuse Reflectance Spectroscopy Technique," in 2018 IEEE 7th International Conference on Photonics (ICP), IEEE: 1–3, 2018, doi:10.1109/ICP.2018.8533172.
- [6] L.S. Supian, A.M.A. Amboalang, U.F.A. Rauf, K. Ismail, C.S. Ping, N.F. Naim, "Qualitative Assessment of Cooking Oil using Diffuse Reflectance Spectroscopy Technique," in 2022 International Conference on Green Energy, Computing and Sustainable Technology (GECOST), IEEE: 221–226, 2022, doi:10.1109/GECOST55694.2022.10010506.
- [7] L. S. Supian, Noor Hamisah Mohd Sahroni, Sue Ping Chew, Nani Fadzlina Naim, Harry Ramza, "Investigation of U-shaped plastic optical fiber as refractive index sensor for liquids assessment," *Proc. SPIE 12327, SPIE Future Sensing Technologies 2023*, 123271W (22 May 2023); doi: 10.1117/12.2666890
- [8] C. C. Zhang, H. H. Zhu, B. Shi, J. K. She, and D. Zhang, "Performance evaluation of soil-embedded plastic optical fiber sensors for geotechnical monitoring," *Smart Struct Syst*, vol. 17, no. 2, pp. 297–311, Feb. 2016, doi: 10.12989/sss.2016.17.2.297.
- [9] C. C. Zhang, H. H. Zhu, B. Shi, and J. K. She, "Interfacial characterization of soil-embedded optical fiber for ground deformation measurement," *Smart Mater Struct*, vol. 23, no. 9, 2014, doi: 10.1088/0964-1726/23/9/095022.
- [10] H. H. Zhu, B. Shi, and C. C. Zhang, "FBG-based monitoring of geohazards: Current status and trends," *Sensors (Switzerland)*, vol. 17, no. 3. MDPI AG, Mar. 01, 2017. doi: 10.3390/s17030452.
- [11] "Extensometers - DGSi." <https://durhamgeo.com/extensometer-introduction/> (accessed Jun. 22, 2023).
- [12] "Highland Towers collapse - Wikipedia." https://en.wikipedia.org/wiki/Highland_Towers_collapse (accessed Jan. 06, 2023).
- [13] "2008 Bukit Antarabangsa landslide - Wikipedia." https://en.wikipedia.org/wiki/2008_Bukit_Antarabangsa_landslide (accessed Jan. 06, 2023).
- [14] "2011 Hulu Langat landslide - Wikipedia." https://en.wikipedia.org/wiki/2011_Hulu_Langat_landslide (accessed Jan. 06, 2023).
- [15] "2022 Batang Kali landslide - Wikipedia." https://en.wikipedia.org/wiki/2022_Batang_Kali_landslide (accessed Jan. 30, 2023).
- [16] "JENIS-JENIS TANAH PERTANIAN | MyAgri.com.my." <https://myagri.com.my/2016/03/jenis-jenis-tanah-pertanian/> (accessed Jan. 06, 2023).
- [17] L.S. Supian, M.S. Ab-Rahman, N. Arsad, "Polymer optical fiber tapering using chemical solvent and polishing," *EPJ Web of Conferences*, 162, 01018, 2017, doi:10.1051/epjconf/201716201018.
- [18] Eric Udd and William B. Spillman Jr., Eds., *Fiber Optic Sensors: An Introduction for Engineers and Scientists*, 2nd Edition, 2nd ed. Wiley, 2011.
- [19] A. Arifin, N. I. Rusyam, A. K. Lebang, B. Abdullah, and D. Tahir, "High sensitivity and resolution sensor plastic optical fiber for determining compressive and tensile tensor concrete applications," in *Journal of Physics: Conference Series*, IOP Publishing Ltd, Feb. 2021. doi: 10.1088/1742-6596/1763/1/012004.