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Sensitivity of Optical Fiber Sensors to Deflection of Reinforced Concrete Beam

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Sensitivity of Optical Fiber Sensors to Deflection of Reinforced Concrete Beam

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Abstract. The capacity of concrete beams will decrease by many external factors. To find simple and reliable method to monitor the quality of concrete beams is a challenging task. An optical-based fiber sensors is very interesting to develop for such task because of its many advantages. In this study, the optical fiber sensors were embedded in reinforced concrete beams to detect and to monitor deflection of the beam where a straight-line configuration of optical fiber was used. We perform experimental work to test performance of the use of optical fiber sensor by collecting data from flexural testing the concrete beam with the Universal Testing Machine (UTM). While the concrete deflection was measured by (linear variable diffential transducer (LVDT) as elongation unit, the fiber optic sensor output was observed in volts unit. We test the sensitivity of the optical fiber sensor by analyzing the relationship graph between the changes in the deflection of the concrete beam and output voltage of optical fiber sensors. The results show that optical fiber sensors have good sensitivity to detect and monitor concrete beam deflection.

1. Introduction

Sensors are a major component in the development of a monitoring system. At present, research on the use of fiber optic sensors (FOS) is being developed. The advantage of this FOS is better resistance to electromagnetic interference. including storms. and the potential ability to live in a harsh environment. FOS is also resistant to corrosion when used. in open structures (such as bridges and dams) that can be used throughout the lifetime of concrete.

Fiber optic sensors that are widely applied include micro bending sensors. wave sensor. FBGs. and fiber optics interferometer [1]. Fiber optic sensors provide a good response to loads applied to concrete with embedded fiber optic sensors. Changes in load indicate changes in the intensity of light that is passed on the optical fiber sensor[2].Optical fiber sensors embedded in lightweight concrete have been applied to detect damage or cracks in concrete. Measurements were made using an optical power meter. The experimental results show that when cracks occur in concrete there is a significant decrease in the output of fiber optic sensors [3].

The use of optical fiber sensors in monitoring concrete structures has been developed previously. Detection concrete collapse by monitoring the concrete strain has been carried out. In this study, fiber optic sensors are coated with chemical material[4][5]. Lightweight concrete damage detection with

optical fiber sensors with other methods was develop. When the quality of concrete decreases, the optical fiber sensor output power also decreases [6].

In a reinforced concrete beam monitoring system, the compressive strength, strain, and deflection parameters are the main parameters monitored. Single mode type optical fiber has been applied to detect strain in lightweight concrete. The value of power loss generated by optical fiber due to loading is directly proportional to the value of the load given. The test results show that optical fiber with A wave configuration has good sensitivity to changes in load given to concrete.[7]. Distributed optical fiber sensors have also been applied to measure strain on reinforced concrete wall reinforcement [8].

Measurement of reinforced concrete beam deflection has been carried out in the laboratory, so there are many problems if direct measurements will be applied for the purposes of continuous monitoring of reinforced concrete structures. For this reason, it is necessary to develop a sensor system embedded in concrete. In this paper, the sensitivity of fiber optic sensor sensitivity to the deflection parameters of reinforced concrete beams will be examined.

2. Experimental Method
The sensitivity of the fiber optic sensor to reinforced concrete beam deflection is determined by taking data about the concrete deflection and the optical fiber sensor output power. To achieve this, the outline is divided into 3 steps, namely the design of fiber optic sensors. making reinforced concrete beam samples with embedded sensors and data acquisition and analysis.

2.1. *Design of Fiber Optic Sensor Configuration*
The optical fiber sensors used in this study is single mode with a length of 4 meters. The configuration applied is a straight line as shown in Figure 1. optical fiber sensors are implanted straight in the beam.
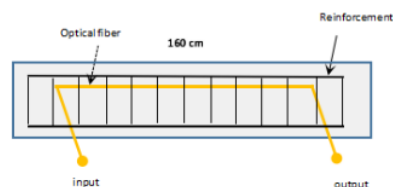
Figure 1. Stright line configuration of optical fiber

The optical fiber sensor consists of two terminals. the input terminal that conected to laser source 1310nm. and the output terminal connected to the photodetector to convert the signal from the laser wave to the voltage level. The middle part of the fiber optic sensor is peeled off the jacket and the peeled part is installed embedded in a concrete beam.

2.2. *Design of Reinforced Concrete Beams with an Embedded Sensor*
Concrete beams used in this study are lightweight reinforced concrete beams with 20MPa compressive strength. In order to reach a lightweight, plastic gravel is used [9] The size of the concrete blocks made is 8x16x160 cm. Fiber optic sensors are implanted in concrete with the straight configuration in Figure 2. The mix design of concrete is shown in Table 1.
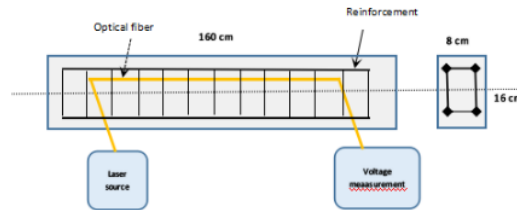
Figure 2. Model of concrete beam samples with embedded sensors

Table 1. The mix design of concrete.

materials	Concrete Volume (Kg) - Plastic	
	1 M3	2*Sil 10/20 & * 1Sil 15/30
Cement	500	17,14
sand	845	28,96
Naturak gravel	0	0
Plastic gravel	432	14,8
SP Sika LN	12	0,4
water	150	5,14

2.3. *Data Acquisition and Analysis*

Data acquisition is done by flexural testing using UTM. Concrete deflection is measured using LVDT. The observed data are changes in concrete deflection and changes in the optical fiber sensor output voltage due to loading on the concrete beam. The data acquisition scheme is shown in Figure 3.
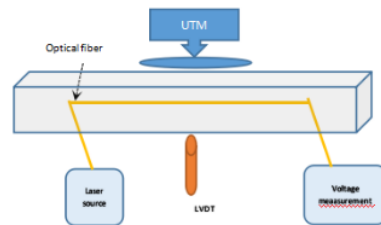
Figure 3. Data retrieval scheme

3. Result and Discussion

3.1. Data

The fiber optic configuration in the concrete is shown in Figure 4, and the reinforced concrete block with embedded sensors is shown in Figure 5.

Figure 4. fiber optic configuration inside the concrete mold

Figure 5. Flexural testing concrate beam sample with embedded fiber optic

In this study data were taken from 3 concrete beam samples with embedded sensors. The results of the data from the first concrete beam are shown in Table 2. The second concrete beam in Table 3 and the third concrete beam in Table 4.

Tabel 2. The first concrete beam sample data

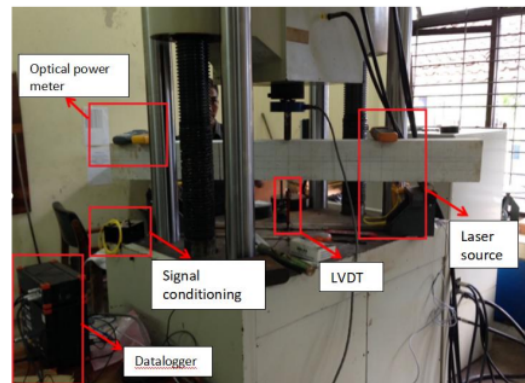| no	load (kN)	deflection (mm)	Output voltage optical fiber sensors (volt)
1	0.004941041	0.00000487	0.37
2	0.11957637	0.22377928	0.56
3	0.57090282	0.32311198	1.12
4	1.7325027	0.83081281	1.49
5	3.65113	1.196736	1.68
6	6.0351171	1.8259418	2.43
7	8.5939245	2.5912743	2.61
8	10.107606	3.0649996	3.17
9	14.518381	4.418685	3.55
10	16.03191	5.8213181	3.73
11	16.907057	8.036375	3.92
12	17.398458	9.9108582	4.11
13	17.840471	13.267413	4.48

Tabel 3. Second concrete beam sample data

no	load (kN)	deflection (mm)	Output voltage optical fiber sensors (volt)
1	0.068897821	0.036128148	0.4
2	0.51017541	0.52297401	0.6
3	1.1495951	0.72594935	0.81
4	2.6247454	1.1949829	1.01
5	3.5582852	1.4596689	1.41
6	5.3155766	2.051162	1.81
7	7.4279442	2.8705878	2.01
8	9.6917734	3.6616268	2.21
9	10.854418	4.0441976	2.62
10	13.480095	4.8764434	2.82
11	15.15642	5.4440699	3.02
12	15.846836	6.1979642	3.22

13	16.391153	6.8814449	3.62
14	16.709873	7.5666599	3.82
15	17.527981	12.060499	4.23
16	17.753162	22.424404	4.43
17	18.186796	38.390656	4.83

Tabel 4. Third concrete beam sample data

no	load (kN)	deflection (mm)	Output voltage optical fiber sensors (volt)
1	0.82641274	0.036763895	0.35
2	2.0133584	0.21275349	0.53
3	3.6153882	0.54891306	1.06
4	5.2496629	0.95169693	1.24
5	7.0092497	1.5461302	1.42
6	8.5411425	2.0465524	1.77
7	9.6772785	2.417012	1.95
8	11.71697	3.1238008	2.13
9	13.75316	3.8872695	2.3
10	14.499065	4.8545823	2.66
11	14.689847	6.7961712	3.19
12	15.386856	8.257062	3.54
13	16.247229	12.41567	4.08
14	16.62388	27.62908	4.25
15	17.472326	55.628048	4.61

Based on the test results with UTM, we obtain that the reinforced concrete beam has a maximum average load capacity of 17,833kN. While the mean deflection of reinforced concrete beams when loading is 35.62 mm. The average sensor output voltage when the concrete beam reaches its maximum capacity reaches the average of 4.64volt. From table 1, table 2 and table 3 it can be seen that both deflection and sensor output voltage increases with increasing loading test

3.2. Sensitivity Analysis of Optical Fiber Sensors

Sensitivity analysis is done by graphing the relationship between the deflection of the concrete beam and the optical fiber sensors output voltage. To determine the sensitivity, a linear region determined from the response of the fiber optic sensor, then a linear approach analysis is performed.

3.2.1. Embeded Sensor 1. Embedded sensor 1, is an optical fiber sensors that is embedded in the second concrete beam. The graph results for Embedded sensor 1 are shown in Figure 6.
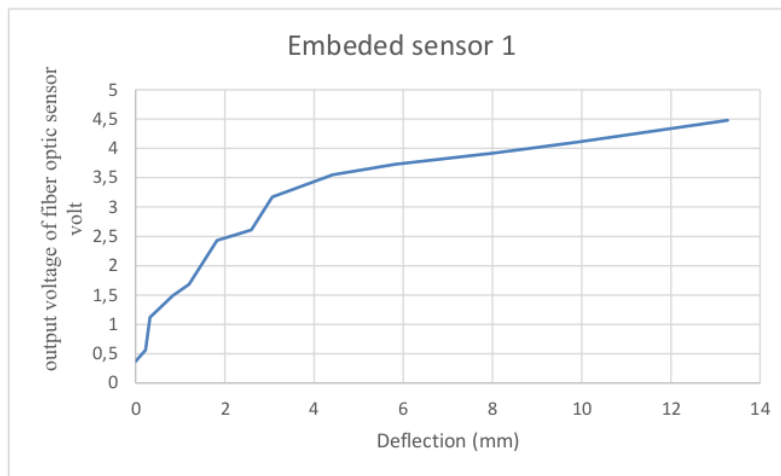

Figure 6. Graph of the relationship between the deflection of a concrete beam and the optical fiber sensor output voltage from first sensor.

In Figure 6 can be seen that there are two different linear regions. This shows that the senor has different sensitivity values for two different linear regions. Graph linear 1a where the deflection value is less than 5 mm. The linear region 1b where the deflection value is more than the same as 5 mm. The results of the linear approach are shown in Figure 7 and Figure 8
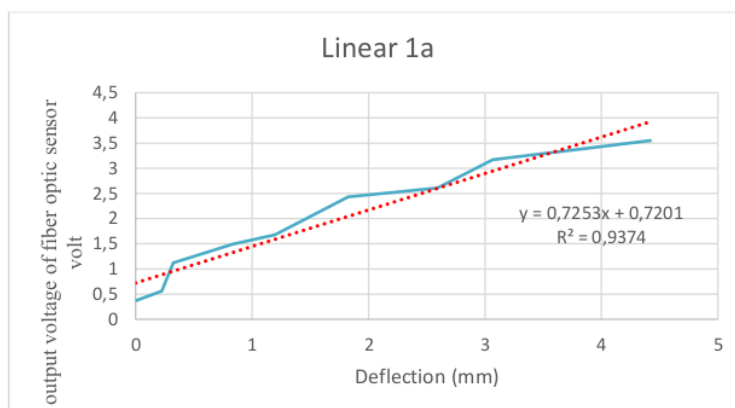
Figure 7. Linear approach 1a

In the linear region 1a in the deflection range below 5mm, the optical fiber sensor has a sensitivity of 0.7253volt / mm.
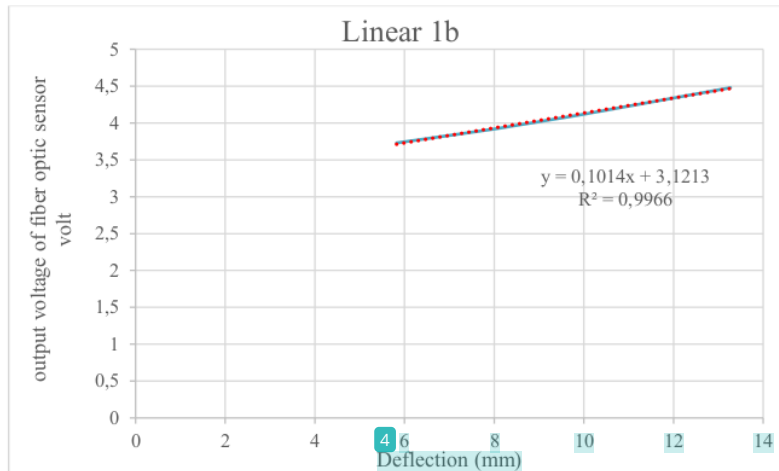

Figure 8. Linear approach 1b

In the linear region 1b, where the deflection range is more than or equal to 5mm, the fiber optic sensor has a sensitivity of 0.1014volt / mm. For embedded sensor 1, the sensitivity ratio of linear region 1a to linear region 1b reaches 7.15: 1

3.2.2. .Embedded Sensor 2. Embedded sensor 2, is an optical fiber sensor that is embedded in the second concrete beam. The graph results for Embedded sensor 2 are shown in Figure 9.
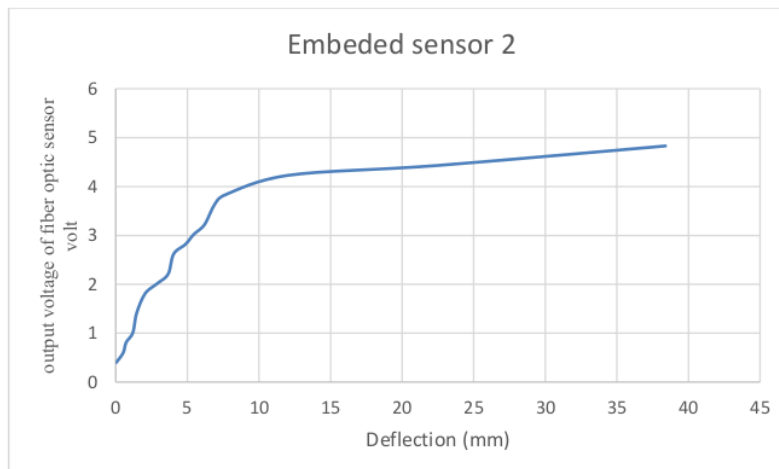
Figure 9. Graph of the relationship between the deflection of a concrete beam and the optical fiber sensor output voltage from second sensor.

In Figure 9, there are two linear region. Liear 2a show in Figure 10 and linear 2 b show in Figure 11.
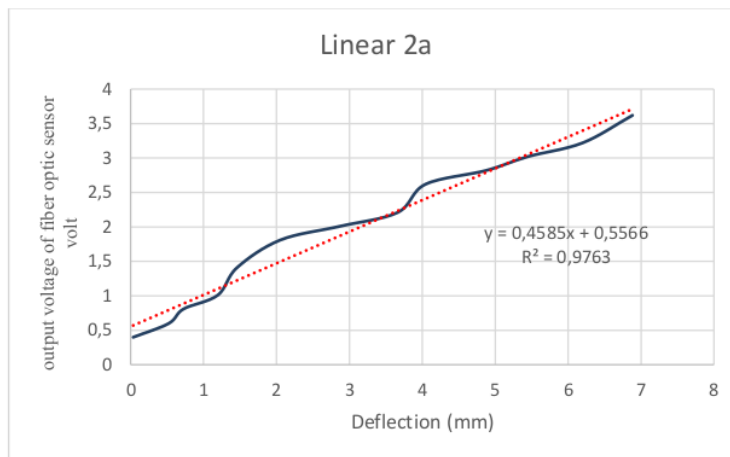

Figure 10. Linear approach 2a

In the deflection range of concrete beams less than 8mm, optical fiber sensors embedded in concrete have a sensitivity of 0.4585volt / mm.
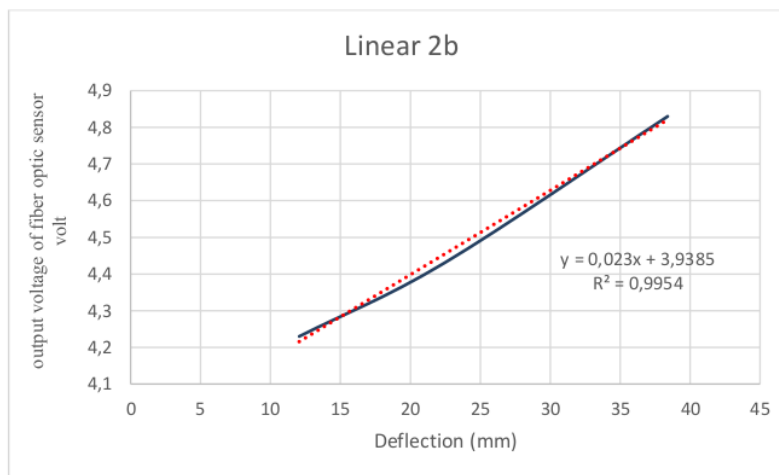

Figure 11. Linear approach 2b

In the deflection range of concrete beam more than the same as 8mm, optical fiber sensors embedded in concrete have a sensitivity of 0.023volt / mm. The ratio of linear sensitivity 2a to linear 2b is 19.93: 1

3.2.3. Embeded Sensor 3. The Embedded sensor 3 is an optical fiber sensors that embedded in the third concrete beam. The graph results for Embedded sensor 3 are shown in Figure 12.
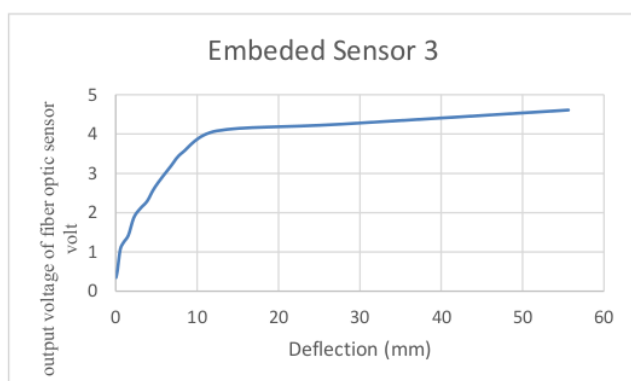

Figure 12. Graph of the relationship between the deflection of a concrete beam and the optical fiber sensor output voltage from third sensor.

Figure 12 shows the existence of two linear regions. The linear region in the deflection range is less than 9 mm, referred as the linear region 3a shown in Figure 13, and the linear region in the deflection range is greater than 9mm called the linear region 3b shown in Figure 14.

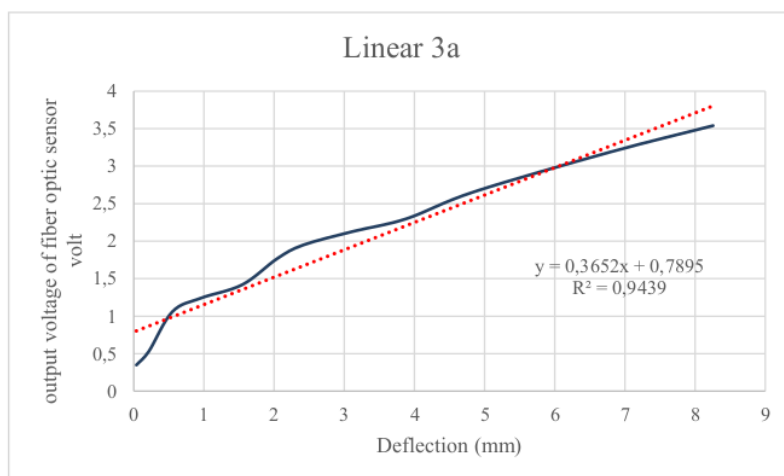$$y = 0{,}3652x + 0{,}7895$$
$$R^2 = 0{,}9439$$

Figure 13. Linear approach 3a

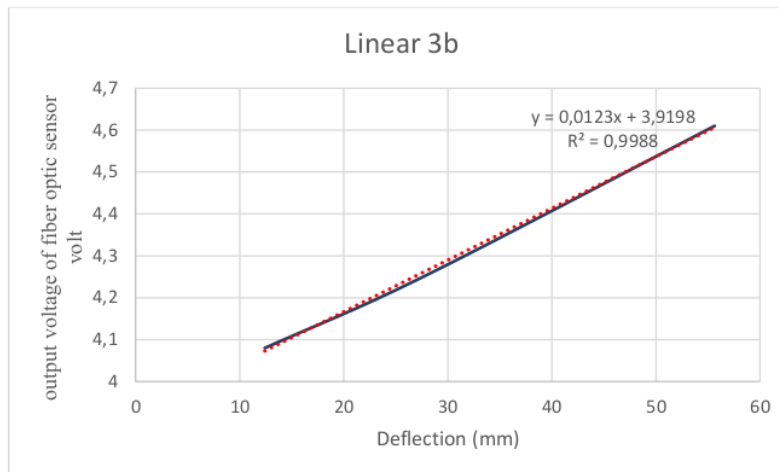In the deflection range of less than 9mm, the fiber optic sensor has a sensitivity of 0.3652 volts / mm.

Figure 14. linear approch 3b

In the deflection range above 9 mm, the optical fiber sensors have a sensitivity of 0.0123volt / mm. The sensitivity ratio of 3a to 3b is 29.69: 1.

Based on data retrieval from the three sensors, it can be seen that the sensor has a good sensitivity in the linear a region with an average sensitivity of (0.7253volt / mm + 0.4585volt / mm + 0.3652 volts / mm) / 3 = 0.5613volt / mm. The average of effective working area is for deflection value less than 7.33mm

4. Conclusion

Optical fiber sensor embedded with a straight configuration in concrete has a sensitivity related to the changes of reinforced concrete beam deflection in the number of 0.5613volt / mm and the average of effective working area is for deflection value less than 7.33mm

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