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# A STUDY ON OPTICAL FIBER SENSORS FOR THE DETECTION OF CRACKS IN CONCRETE-BUILT STRUCTURES

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## ABSTRACT

Pressure was applied to the surface of concrete examples, each with a fiber optic embedded in the centre. 15cm x 10cm concrete specimen with 3cm, 4cm, and 6cm thickness variations was used. Optical fiber signal light intensity decreased with increasing pressure value, the study's findings indicated. Fiber optic attenuation is the term used to describe this phenomenon, which occurs during transmission. What matters is the specimen's maximal strength, which is determined by the specimen's thickness. Soft elastomeric (SEC) capacitors are used to detect changes in capacitance as a result of a change in strain. Studies on the low-cost, high-reliability SEC for detecting fatigue cracks in steel bridges have already been conducted in the past; Fractures in structural parts may be detected and tracked using this sensor's unique capacity to be very elastic. An array of surface-deployed SECs was employed in this investigation to identify and locate bending-induced fractures. Experimental campaigns with reinforced concrete beams were used to verify the suggested strategy. They were successful. Two tiny reinforced concrete beams were put through their paces in three-point bending tests.

**KEYWORDS** Optic Sensor, Fiber, FOS, Cracking Detection

## INTRODUCTION

In most European nations, civil infrastructure building and upkeep accounts for 10% to 20% of total public spending. But in the past decade, we have seen a change in investment from new building to maintaining or extending the life span of existing facilities." Highways and rail lines are mostly constructed and ready for use; just a few high-speed rail routes need to be built. But the civic infrastructure is being put to the test by an ever-increasing number of people and products. A large number of older bridges and tunnels are in need of repairs, and in many cases an extension of their carrying capacity and life expectancy that goes beyond the original projections. Additionally, these interventions result in extra hidden costs due to traffic congestion and accidents that are caused as a result of the interruption of regular usage of the buildings. Most of these properties may be measured using mechanical and electrical transducers. Fiber optic sensors have made a modest but important entry into the sensor landscape during the last several years. Although optical fiber sensors were poised to take over the world of sensing during an early euphoric period, it now seems that this technology is only appealing in circumstances where it delivers greater performance compared to the more established conventional sensors.

## LITERATURE REVIEW

**Vanessa Saback et.al (2022)** Technology to improve inspection accuracy and efficiency and structural health monitoring is quickly progressing as reinforced concrete structures near the end of their design lifespan. Damage and safety may be assessed using concrete cracking and reinforcing stresses, two important metrics. The benefits of DIC systems and distributed Fibre Optic Sensors (FOS) over other methodologies have led to an increase in the adoption of these technologies for parameter evaluation. A reinforced concrete beam specimen's fracture propagation via FOS and DIC is examined experimentally in this research. + As a means of comparison, the FOS were set up in the concrete and inside a rebar groove. When it came to reliability, the data from within the bar stood out as being far superior than that from the outside. The FOS analysis was enhanced by the inclusion of DIC crack propagation pictures, and high visual correlation was found between the two approaches. In order to monitor the structural health of a real-world bridge, this study is part of a larger research project that uses DIC and FOS.

**Rafał Sieńko et.al (2021)**: Because DFOS can measure specified physical characteristics along the full length of the fiber, the technique is a potential one for many sectors. Local damage identification, a key need of structural health monitoring (SHM) systems, is made possible thanks to this capability. The use of DFOS-based systems has grown in civil engineering and geotechnical applications during the last several years. However, various technical issues, such as the sensor architecture (its kind) or installation method, must be carefully considered in order to reap the full advantages of such an approach (bonding properties). Precast concrete girders of 24 meters in length were fitted with composite DFOS strain sensors during the manufacturing process, as documented in the report. When the concrete was poured, composite sensors with monolithic cross sections (as opposed to layered sensing wires) were placed into the concrete. External spiral braid provided the bonding qualities necessary for precise strain transfer mechanisms, analogously to composite reinforcing bars. For the most important stages of construction, strain and temperature measurements were taken during hydration (thermal-shrinkage strains), prestressing (tendons activation to transfer compressing force to concrete), activation of structural dead-weight (as a direct consequence of prestressing phase), installation within the structure (mounting stresses), as well as during the proof load tests. It was possible to do in-depth analyses of strain profiles at each stage of construction because to the vast number of dispersed sensors installed at various girder heights. Furthermore, all local fissures might be identified and their behavior monitored over time (development during hydration process and closing during prestressing phase). Construction of the DFOS sensors, their characteristics, installation, data collecting system specifications, strain measurement results from chosen phases of construction, as well as the most significant discoveries will all be discussed in the following sections.

**Lourdes S. M. Alwis et.al (2021)** Carbon fiber technology, additive manufacturing technology, sensor engineering, i.e., wearables, and novel structural reinforcing methods have all witnessed tremendous advancements in the recent decade or so.. Despite their disparate origins, these advancements have opened the way for concrete buildings with non-corrosive reinforcing and in-built sensors. Therefore, the goal of this endeavor is to bridge the gap between civil engineering and sensor engineering communities by providing an overview of the most recent technical advancements in both fields, with a specific emphasis on textile reinforced concrete embedded with fiber optic sensors. Reinforcement methods may be used to reduce carbon emissions from the construction sector, and the relevance of this is highlighted in the introductory paragraphs. Fiber optic sensors may be used to monitor the structural integrity of buildings throughout their lifespans, enhancing the advantages of this technology even more significantly. Sensors may be included into a structure's reinforcing mechanism at the manufacturing stage, allowing for more effective monitoring and a larger variety of capabilities than can be achieved with standard methods of structural health monitoring, according to the report. Intelligent monitoring systems based on distributed sensor networks will be possible in the future, thanks to the convergence of these technological advances with artificial intelligence principles.

**Oliver Fischer et.al (2019)** Extensive new possibilities for the systematic monitoring of engineering structures may be gained via the use of fiber optic strain measurement. In real-world applications, a measuring instrument and passive optical fiber arrangement that is both durable and sensitive is preferred. At the Technical University of Munich (TUM), the Chair of Concrete Structures, a total of five different optical measuring fibers were tested on a prestressed concrete beam using two measuring devices. Fiber optics and conventional measurement technology were able to detect elastic strain, crack development, and definitive shear fractures of the fracture state when used in conjunction with each other.

**Fatimah Nur Hidayah et.al (2018)** Fiber optic sensors based on the pressure measuring method are used to identify cracks in concrete-built structures. This experiment's fiber optic sensors were created by micro-bending them. Compression Testing Machines were used to test the bends in optical cable (CTM). Specimens of concrete with fiber optics embedded in the centre were subjected to a pressure test. The concrete specimen had dimensions of 15 cm x 10 cm and came in three different thicknesses: 2 cm, 4 cm, and 6 cm. The findings indicated that the optical fiber's signal light intensity decreased with increasing pressure. Fiber optic attenuation is the term used to describe it. According to the specimen's thickness and ultimate strength, it may be determined.

## METHODOLOGY

STM C-770 is a standard test method for the measurement of pressure-optical coefficient that was used in this investigation. The SC adapter was utilized by the system devices in a simplex configuration. To connect single mode fiber optic cables, SC is the most common kind of connector. There were 1310 nm laser diode, fiber coupler, connection and photodiodes, portable data recorder, analog to digital converter (ADC), USB cable to RS232, and specimen molding. Fiber optic patch cords and concrete were also used as additional components in the design. The following equation was used to base the analysis:

$$T = \frac{V_2}{V_1}$$

T : transmittance

$V_1$ : voltage on the reference optical fiber

$V_2$ : voltage on the fiber-optic modulator

Based on the equation, it is possible to determine the optical fiber's light transmittance value. The optical fiber's transmittance value was utilized to calculate the optical fiber's attenuation in concrete specimens. Fiber optic light attenuation has the following equation as its basis:

$$dB = 20\log\frac{1}{T}$$

dB: the attenuation unit of optical fiber.

Two primary steps were included in this investigation. Concrete specimens measuring 15cm by 10cm and with thicknesses ranging from 2cm to 6cm were made as the initial phase. In the second stage, the tools pressure measuring system was installed. The attenuation of a single mode step index optical fiber was studied to see whether the pressure on the fiber within concrete had any influence on its attenuation. Concrete specimens may be used to gauge the effects of pressure. An optical fiber's distinctive features include the initial fracture, an expanding crack, and a period of time when the fiber cannot transmit light.

First, an optical cable was inserted through the concrete specimen horizontally. The optical cable was similarly placed at a height of around midway up the concrete specimen.

**Figure 1 The scheme of concrete specimen**.

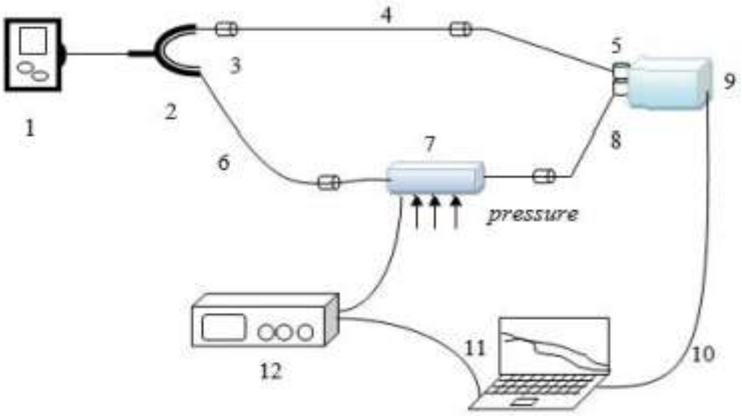

**Figure 2 The scheme of crack detection design on concrete-built infrastructure based on fiber optic sensors.**

Description:

1. Laser diode

2. Fiber Coupler

3. Connector

4. Fiber optic reference

5. Reference photodiode

6. Fiber optic modulator

7. Object research

8. Photodiode object of research

9. Analog to digital converter (ADC)

10. USB data cable to RS-232

11. Laptop / personal computer

12. Portable data logger

**Result**

The attenuation of optical fibers was used to gather data for scientific purposes. A compression force causes attenuation. The micro bending in the core of optical fiber is to blame for this. Because light transmission is disrupted by micro bending, the core is affected. The optical fiber is unable to reflect properly because of this interference in the core. An attenuation or reduction in light happens when the core is unable to reflect the light completely. Optical fiber attenuation decreases with increasing compressive strength of the concrete specimen. There are data that have an attenuation value that is directly related to pressure that must be specified for the design of concrete crack detection. There are two types of values here: the prospective crack value and the rising crack value.

There must be only one graph for these two values. In order to keep track of concrete fracture detection, this data definition is necessary. The attenuation value was near to zero when the concrete specimen was subjected to pressure, yet the fiber optic core was not harmed. Because the core was still able to properly reflect light, the graph's trendline resembled a straight line. However, the trendline graph of attenuation value began to rise when the core was damaged by distress. It was also unable to measure the attenuation value when the core was not able to reflect light. The modulated optical fiber's (V2) voltage value is 0 if the attenuation isn't there. Equation is a good match (3).

Attenuation values were measured at the lowest possible pressure rise in order to assess the research's level of sensitivity. This study's sensitivity may be stated mathematically as follows:

$$tg\ \alpha = \frac{\Delta dB}{\Delta P}$$

$\alpha$ : Angle between the value of pressure and attenuation.

$\Delta dB$ : Difference of attenuation value.

$\Delta P$ : Difference of pressure value.

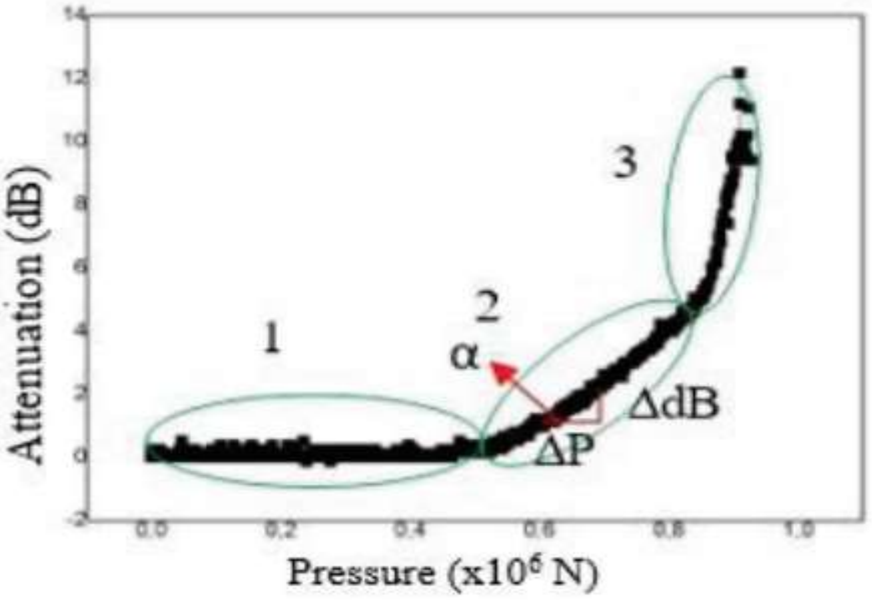

**FIGURE 3. Influence of pressure to attenuation of SM-SI optical fiber at 2cm thickness concrete.**

Pressure values between 0 and 0.57 x 106 N demonstrate that this concrete's attenuation value is near to zero on the graph. In addition, the attenuation value increases when the pressure value rises over 0.57 x 106 N. The attenuation value increases significantly from 0.9 x 106 N to 0.95 x 106 N when the pressure is 0.9 x 106 N to 0.95 x 106 N. Even though the concrete specimen is subjected to pressure, the first trendline reveals that attenuation values are near to zero. It's a sign that reflection is still happening deep inside the core. CTM pressure causes cracks in concrete specimens to begin at the perimeter when applied to them. When the pressure from CTM rises, the fracture progressively moves toward the center of the concrete. Concrete specimens that have optical fibers embedded into their cores are subjected to CTM pressure, causing the cores to be displaced. As a result, the optical fiber's light is weakened or imperfectly reflected. For concrete specimens with a pressure value of 0.55 x 106 N, cracking may begin in the range of attenuation values of trendline number two, which is around 0.55 dB. As can be seen from the trendline, there is a break in the concrete towards the edges of the samples. It was because of this that the optical fiber was bent. Fiber optic light transmission was influenced by bending. Light intensity is closely related to light transmittance in the core. Light is not reflected back to the core, but rather to the border between cores and cladding. This results in a loss. Using the second trendline, we can see that the attenuation value gradually increases as the pressure value increases. This trendline has a higher increase in attenuation value than the prior trendline. As a result, the optical fiber loss has also increased. It's possible that the growing pressure on the CTM load bent the fiber optics.

The following graph shows that at a pressure of 0.9 x 106 N to 0.95 x 106 N, there is a considerable increase in attenuation due to the fiber optic core being disturbed by continuous pressures. Cracks in the centre of concrete specimens are indicated by an increasing attenuation value. Macro bending is a problem since the core is weak. The bending caused by the loss of fiber optics is also a major factor. The following equation may be used to calculate the sensitivity:

$$tg\ \alpha = \frac{1}{0{,}1 \times 10^{6}} = 10\ \times 10^{-6} dB/N$$

The first trendline in Fig. 4 shows that the specimen's light propagation in the fiber optic core was somewhat missed when pressure was applied. As a result, the attenuation value was close to zero, indicating a weak signal. After a while, the centre of the concrete specimen begins to break. A larger amount of pressure was exerted on the fiber optic core at this point than at any other point in time. The third image shows the break in the concrete specimen that caused the fiber optic to distort and, as a result, render it unable to reflect light back. More light was blocked from returning to the center as a result of the bending (loss). An increasing amount of stress may cause a fracture in concrete sample. The attenuation values of optical fibers increased as a result of these fissures. It's also clear from this pattern that the specimen's center fracture had a maximum compressive strength of 0.55 x 106 N. CTM automatically lowered the compressive load when the concrete specimen achieved its maximum compressive strength. As a result, decreased pressure was seen when attenuation increased.

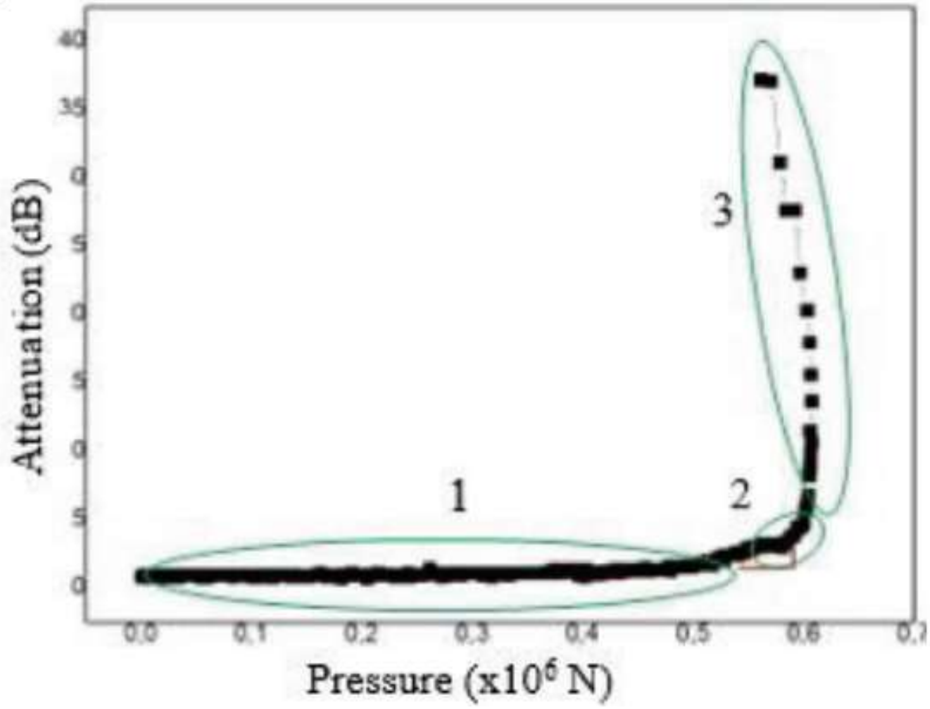

**FIGURE 4. Influence of pressure to attenuation of SM-SI optical fiber at 4cm thickness concrete.**

Sensitivity value is expressed as follows:

$$tg\ \alpha = \frac{1}{0{,}05\times10^6} = 20\ \times 10^{-6} dB/N$$

This specimen has a greater sensitivity value than the previous specimen, which had a 2cm thickness. Fiber optic sensors cannot be designed using concrete specimens with a thickness of 4 cm because the attenuation value following the fracture in the centre of the concrete specimens is too great/sharp. Also shown in this graph are the variations in attenuation levels before and after the specimen's midsection break. Near zero attenuation was found from the non-crack portion of the material. Meanwhile, the specimen's attenuation value increases dramatically as it cracks. It began with a possible fracture in the midst of concrete sample and progressed to its complete destruction. The optical cable split when the concrete specimen was broken, making it unable to return light.

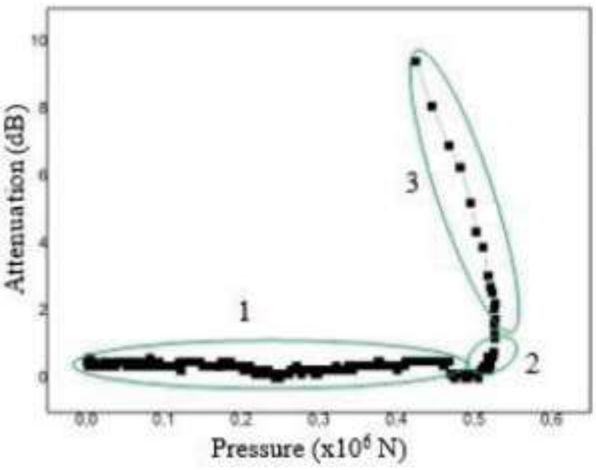

**FIGURE 5. Influence of pressure to attenuation of SM-SI optical fiber at 6cm thickness concrete**

Cracking occurred in a concrete specimen with a thickness of 6 cm when the compressive strength reached its maximum. In addition, the CTM automatically lowered the compressive load pressure when this occurred. Concrete examples were subjected to constant pressure from CTM until they broke. It caused the fiber optic core to flex, causing it to break. Even though the fiber optic core was twisted, light was still being delivered to the fiber's other end. The light sensors/photodiodes, on the other hand, were unable to detect light intensity when the fiber optic core was severed. As a result, the core was unable to transfer any light intensity.

The attenuation value trendline is flat when the fracture has not yet developed, as seen by the first trendline. The fiber optic core has a slight micro bend as a result of concrete deformation. As a result, the attenuation value rises as the pressure value falls. The second image shows the specimen's center fracture. The findings reveal that the pressure value is inversely proportional to the attenuation value following the central fracture of concrete specimens. The third trendline shows an increase in the attenuation value, which suggests the presence of a fracture in the centre of the concrete specimen. The fiber optic core was twisted because the concrete's compressive strength was reduced by the fracture. The light attenuation was a result of the bending. While the attenuation value increased, the reflected light in the core was reduced. The core's ability to reflect light is impaired by attenuation. However, the break in the centre of the 6cm thickness specimens has resulted in a large rise in attenuation value. So, it would not be appropriate for the creation of a crack detecting system.

## CONCLUSION

Concrete specimens of 2cm, 4cm, and 6cm had possible fracture pressures of 0.57N, 0.55N, and 0.5N, respectively. The rise in attenuation value at 2cm thick concrete specimen was directly related to the pressure. The rise in attenuation value coincides with the reduction in pressure value in the 4 a.m. and 6 c.m. concrete specimens. Optimal fiber optic sensor design is 2cm thick concrete with 10x10-6 dB/N sensitivity. Most of these properties may be measured using mechanical and electrical transducers.

Fiber optic sensors have made a modest but important entry into the sensor landscape during the last several years. Concrete girders with sophisticated distributed fiber optic strain and temperature monitoring coupled with precast prestressed concrete smart girder technology for industrial engineering is particularly promising in the context of infrastructure performance and dependability. Some of the technical, manufacturing, and measurement challenges that have been addressed in this study are expected to aid in the creation of intelligent concrete buildings.

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