Feasibility Study on Structural Health Monitoring Systems Using Fiber-Optic Sensors (FOS) Technology for Transportation Infrastructures in Indonesia

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Abstract. Objective of this research is on the feasibility study to determine the possibility of using fiber optic sensor technology for monitoring structural health and integrity of transportation and civil infrastructures such as bridges and roads in Indonesia. Two aspects are discussed: cost-effective analysis and innovative technology applications. This paper presents the review results based on literature surveys and vendor product brochures of fiber-optic sensors for infrastructure health monitoring applications which could be used as a preliminary study and recommendation for current government regarding the implementation of fiber optic sensor in Indonesia. Since we realized that this topic spans out many disciplines, we limited our goal to only providing the basic conceptual framework. But experts interview will also be made in the future as supporting evidences (proofs) that the use of fiber-optic sensor technology makes it possible to realize the continuous, real-time, and automatic transportation infrastructural health monitoring. As compared to the previous conventional sensor technology, fiber optic sensor is introduced as one of smart structure sensors which is predicted as a more cost-effective and innovative solution among those. Hopefully, Indonesian government will be strongly committed to build or provide those worth optical fiber sensors in the future for the benefit of society.

Keywords: Bridges and roads, Cost-effective analysis, Fiber optic sensor technology, Innovative solution, Structural health monitoring, Transportation and civil infrastructures.

1. Introduction
Currently, public safety issue has more become a major concern in almost all aspects of our life. Especially in Indonesia, the area of transportation infrastructures such as bridges and roads absorbs much attention as one of three sectors in President Jokowi’s era, besides manufacturing and tourism [1]. It is true that everyday we see much development of infrastructures, but the construction failures were also happened many times and in many occasions [2]. From the data released by the Ministry of General Works and People Housing (Kementerian PUPR)
5 years ago, there are about 93,000 bridges (1138 km) in Indonesia, comprising of 72,000 bridges (734 km) as a part of provincial roads regency/city roads and 21,000 bridges (404 km) as a part of national roads [3].

One of the national bridges in Indonesia is Kutai-Kartanegara (Kukar) bridge which is located in East Kalimantan (see Fig. 1). It is known that this bridge is ever as the longest hanging bridge (main span) without buffer in Indonesia (about 270 m long from the total length of 710 m) and also one of the masterpieces of Indonesian’s scientists. Despite of its strength and glory, Kukar’s bridge has been collapsed on 26 November 2011, only 10 years after its construction finished (see Fig. 2). Although it was happened 7 years ago, the collapsed brought many questions to the surface. Some questions are about why and how it was collapse. Some analysis were made by Indonesian’s scholars, one of them is Joko Luknanto [4]. As a civil engineer, he raised some issues regarding this fallen bridge: (1) Was the criteria when building this bridge revisited? (2) Why after the bridge is fallen, all the vertical hanging cable also fallen? (3) Why the main cause is given to the hug top? (4) Was the design of material strength for upper hug in-line with the design criteria, such like the bolt which is used? Meanwhile, Dr. Gouw Tjie-Liong [5], Senior Technical Consultant from UGM (Universitas Gajah Mada) said that based on the facts found in the site, showing that the falling of truss bridge along with the vertical hanger cable happened caused by the construction failure of the clamps and saddles which connected to the main cable as shown in Fig. 3. Other national bridge (toll road) is Cisomang bridge as part of Purbaleunyi toll track, near Bandung, in West Java. Due to the shifted and crack along 53 cm, since 23 December 2016, the Ministry of General Works and People Housing announced a policy where trucks and other vehicles were forbidden to passing through this toll road. Why? To maintain the strength of this bridge, while doing some reconstruction works. Otherwise, this bridge will collapse and cause much losses. Therefore, the important question is how to prevent that such this problems not to happen again in the future?

Figure 1. The sketch of Kutai-Kartanegara (Kukar) bridge. Adapted from “KutaiKartanegara Bridge Structure Systems” by the Investigation Team of the Collapse of the KutaiKartanegara Bridge, Research Institutions and Community Service, Gadjah Mada University, Yogyakarta, 30 November 2011. Adapted with permission.

Figure 2. The condition of Kukar bridge after fallen. Adapted from “Bridge Reality After Collapsing” by the Investigation Team of the Collapse of the KutaiKartanegara Bridge, Research Institutions and Community Service, Gadjah Mada University, Yogyakarta, 30 November 2011. Adapted with permission.
To our knowledge, the fallen of Kukar bridge and the recent construction failure such as Cisomang bridge in West Java were showed us the importance needs of using such kind of sensor technology for structural health monitoring (SHM) system (the simplified schematic is shown in Fig. 5). Hence, material and life losses can be prevented and also avoided. The objective of this research is focused on the feasibility study of using fiber optic sensor technology for structural health monitoring of transportation infrastructures. The work plain will be divided into 3 steps: literature reviews (investigation), field visits and expert interviews (will be conducted), and design prototype of the sensor network (research outcome). Since it is realized that this topic spans many disciplines, here we limited our goal to only providing the basic conceptual framework. But experts interview will also be done in the future as supporting evidences (proofs) that the use of fiber-optic sensor technology makes it possible to realize the continuous, real-time, and automatic transportation infrastructural health monitoring. The rest of the paper is organized as follows. Section 2 describes the types, advantages, important features, and characteristics of fiber-optic sensors. Section 3 reviews selected applications of fiber-optic sensors that measure some parameters relevant to the state of the structure and its environment. Finally, section 4 is the conclusion and future research.
2. Types, Advantages, Important Features, and Characteristics of Fiber-Optic Sensors [8-13]

The importance of fiber optic sensor technology is based on the existence of optical fiber itself. As it has been seen that optical fiber is the key component in any fiber-optic communication systems, serving as the media by which information can be transported at aggregate rates, even over 1 G/T-bps. By examining the characteristics of the fiber, the dynamics of light propagation and the limitations of fiber transport, we can then see how the control of various fiber parameters can lead to the optimization of fiber systems and the design of special fibers for specific communications applications. Generally, it is made of a silica glass or polymer plastic that carries light along its fiber length. The two basic fiber types are produced from variations in the material composition of the core. In the step-index fiber, the refractive index is uniform throughout the core and undergoes abrupt change (or step) at the cladding boundary. In a graded-index fiber, the core refractive index decreases as a function of the radial distance from the center of the fiber. Those fibers can be further categorized into single- and multimode classes. They have a core radius ranging from 8 to 12 μm and 50 to 100 μm while a cladding region ranges from 125 until 400 μm, respectively (see Fig. 6). It means that the core is surrounded by a cladding with slightly lower index number. Because of the core refractive index is larger than the cladding refractive index, the electromagnetic energy at optical frequencies is allowed to propagate along the fiber waveguide through the mechanism called as total internal reflections (TIR) at the core-cladding interface. Single-mode fiber (SMF) can only support one mode of propagation, whereas multimode fiber (MMF) can support hundreds of modes.

Figure 5. Simplified schematic of structural health monitoring and management system. Adapted from C. Chang (Principal Investigator), Fiber Optic Smart Structures for Monitoring and Managing the Health of Transportation Infrastructures, Final Report METRANS Project 09-13, April 2010, pp. 1-26. Adapted with permission.

Figure 6. Popular Optical Fiber Core/Cladding Diameter Ratios. Adapted from M. Curran and B. Shirk, Basics of Fiber Optics, Amphenol Fiber Systems International, TX, USA. Adapted with permission.
Optical fiber has many advantages over copper wire (see Table 1) including [12, 16]:

- **Long Distance Transmission:** Compared to copper wires, optical fibers having lower transmission losses. The consequences are data can be sent over longer distances, thereby reducing the number of intermediate repeaters which are needed to boost and restore signals in long spans. This reduction in equipment and components will therefore decrease the system cost and complexity.

- **Increased bandwidth:** The high signal bandwidth channel of optical fibers provides a significant greater information of carrying capacity. Typical bandwidths for multimode fibers (MMFs) are between 200 and 600 MHz-km and >10GHz-km for single-mode fibers (SMFs). Typical values for electrical conductors are from 10 to 25 (with unit of MHz-km).

- **Immunity to Electromagnetic/Radio Frequency Interference:** An especially important feature of an optical fiber relates to the fact that it is a dielectric material, which means it conducts no electricity and emits no radiation. This also makes optical fibers immune to the electromagnetic interference effects which are seeing commonly in copper wires.

- **Decreased cost, size, and weight:** They are easier to install, require less duct space, are lighter 10 to 15 times, and lower cost if compared to copper conductors of equivalent signal carrying capacity.

- **Lower losses:** Optical fiber has lower attenuation loss of signal intensity (higher performance) than copper conductors, allowing longer cable runs with fewer amplifiers or repeaters.

- **Enhanced Safety:** Fiber optics do not emit sparks or cause short circuits (conduct no electricity), which is important in explosive gas or flammable environments. Fiber optic cables do not have any metal conductors; consequently, they do not pose any shock hazard inherently in copper cables.

- **Increased Signal Security:** Fiber optic systems do not emit RF signals, therefore they are difficult to tap into without being detected. This feature is in contrast to copper wires where electrical signals potentially could be tapped off easily.

| Parameters                  | Coaxial Cable | Fiber Optic Cable (MMF) | Fiber Optic Cable (SMF) |
|-----------------------------|---------------|-------------------------|-------------------------|
| Representation of distance bandwidth products | 100 MHz Km | 500 MHz Km | 100,000+ MHz Km |
| Attenuation/Km @ 1 GHz | > 45 dB | 1 dB | 0.2 dB |
| Cable cost ($/m)            | $ $ $ $ $ $ | $ | $ |
| Data security               | Low | Excellent | Excellent |
| EMI immunity                | OK | Excellent | Excellent |

Optical fiber sensor can convert light rays into electronic signals. They facilitate transmission of light over long distances and at higher bandwidths (data rates) even without additional amplification rather than other form of medium communications. They are sensitive to any parameter which can modify the intensity, frequency, polarization, or phase of light traveling through the fiber. One of the features of optical fiber sensor is its ability to measure the changes from one or more light beams. The change is most often based on the alterations to the intensity of light. They can work either on the single point method or through a distribution of points (multi-channel). Through the single point method, a sole phase change is needed to activate the sensor. In terms of distribution concept, the sensor is reactive along with series of sensors or single fiber optic array.[8, 11]

In general, there are at least five characteristics of high performance smart sensory technology to replace traditional sensors in order to be effective and reliable in monitoring some important key parameters such as pressure, temperature, corrosion, crack formation, vibration, humidity, chemical measurements, and etc. Those five characteristics are as follow: (1) optical sensor should have a reliable (long-term and sharp) accuracy, (2) it is benefited where the commercial price of the sensor should be in a reasonable cost (affordable), (3) they should be small in size and weight (compact), especially for embedded installation, (4) The serviceability of the sensor should be long-lived (durable), and (5) they should be easy to be run and time consumed for retrieving data should be close to real-time measurement. It seems that fiber-optic sensor (FOS) technology is suitable to fulfill such those characteristics, which using optical fiber either as the sensing element (it is called as “intrinsic sensors”) or as a means of relaying signals from a remote sensor to the electronic devices that process the signals (“extrinsic sensors”). Comparison of the two types is given in Table 2 [8].

Fiber-optic sensor (FOS) technology can be classified into four main categories based on intensity, phase, wavelength, and polarization modulation. While another classification is based on the application type such as physical, chemical, or biomedical sensors. Both above classifications are mostly in the form of continuously
distributed or quasi-distributed systems. Also exists another classification based on their sensing capabilities such as intrinsic and extrinsic sensors (see Table 2 for comparison) where these sensors are based on modulation or demodulation and these sensors could be physical, chemical, or biomedical. Finally, their classification can be based on the type of mountings, either surface or embedded, where the sensors can be called as intrinsic or extrinsic ones [8].

| Table. 2. Comparison of extrinsic and intrinsic optical fiber sensors |
|-------------------------------------------------|
| **Extrinsic** | **Intrinsic** |
| Applications-temperature, pressure, liquid level and flow | Applications-rotation, acceleration, strain, acoustic pressure, and vibration |
| Less sensitive | More sensitive |
| Easily multiplexed | Tougher to multiplex |
| Ingress/egress connection problems | Reduces connection problems |
| Easier to use | More elaborate signal demodulation |
| Less expensive | More expensive |

3. Selected Applications of Fiber-Optic Sensors

Typically, structural health monitoring system is composed of a network of sensors that measure some parameters relevant to the state of the structure and its environment. For transportation and civil infrastructures such as bridges, roads, tunnels, dams, geosurfaces, power plants, high-rise buildings and historical monuments, the most relevant parameters are: physical quantities (position/displacement, deformations, strains, forces, pressures, accelerations, and vibrations), chemical quantities (humidity, pH, and chlorine concentration), and environmental quantities (air temperature, wind speed and direction, irradiation, precipitation, snow accumulation, water levels and flow, and pollutant concentration). Although conventional sensors based on mechanical and/or electrical transducers were able to measure most of those parameters, but fiber optic sensors technologies [14] have made a significant transition and progress to replace traditional ones. Recently, this innovative technology is now sufficiently mature for a routine use and offers superior performance compared to the conventional ones in terms of an improved quality of measurements, a better reliability, a possibility of replacing manual readings and operator judgment with automatic measurements, and also an easier installation and maintenance and a lower life-time cost. Among FOS applications to all civil infrastructures, bridges are probably the most frequently reported ones. A review state-of-the art of FOS technology for bridge monitoring has been reported by Casas and Cruz in 2003. Therefore, in the following subsection, a review on optical sensor applications for transportation and civil structure health monitoring systems that have reached an industrial level with commercial products or at the stage of advanced field trials/simulations will be provided [15, 17].

3.1 Interferometric Sensors

Interferometric sensors called “Michelson Interferometric Sensors (MIS)” consists of two fibers which one of those fibers is used for reference fiber and the other is used for sensing parameter. Any deformation in a transportation infrastructure will cause the length difference of the two fibers. The interference between the two reflected light beams produces interference fringes. The shift of the fringe is an indirect measurement of the deformation strain. The fiber optic sensor based on Michelson interferometer is usually a long-gauge sensor for deformation strain measurement with a resolution in the range of micrometers. Figure 7 is the optical fiber sensor experimental set up. Inficor multimode fiber was used in this experiment. Light coming out from the light source (LED, λ=635 nm) was coupled into a 50/50 fibre splitter. One arm of the fibre splitter was connected to the modulated fibre and the other one to the reference fibre. Light detected by both light detectors (D1 & D2) were recorded and processed by a computer which has been programmed to calculate the transmission coefficient (T). The maximum value of T is either 100 or 1.
SOFO interferometric sensors are the most successful low coherent interferometric sensors for SHM, which have been reported being successfully deployed in more than hundreds of structures so far, including bridges, buildings, oil pipes, tunnels, piles, historical monuments, and dams. In contrast with Michelson interferometric sensors, SOFO interferometric sensors are long-gauge sensors. The sensor consists of a pair of single-mode fibers installed in the structure to be monitored. One of the fibers, called the measurement fiber, is in mechanical contact with the host structure, while the other, the reference fiber, is placed loose near the measurement fiber. All deformations of the structure will then result in a change of the length difference between these two fibers, while a temperature change will affect both fibers identically. The functional principle of SOFO system is schematized in Fig. 8. The SOFO system is based on a low coherence double Michelson interferometer in tandem configuration. In principle, a Michelson interferometer splits the amplitude of a light wave into two components which propagate along different paths. When the two components are recombined, interference will occur which can be observed with a detector. SOFO system is categorized as a fiber optic deformation sensor that can give useful information both during the construction phase and in long term [19].

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**Figure 7.** Optical fiber attenuator is used to adjust light intensity in the reference arm, $I_{\text{ref}}$. Adapted from A. Marzuki et al., *Intensity Modulated Fiber Sensor Configuration Equipped with a Variable Fiber Optic Attenuator*, SDIWC, 2014, ISBN: 978-0-9891305-4-7, pp. 205-208. Adapted with permission.

**Figure 8.** Setup of the SOFO system reading unit as displacement sensors. Adapted from D. Inaudi, N. Casanova, G. Steinmann, J.-F. Mathier, and G. Martinola, *SOFO: Tunnel Monitoring with Fiber Optic Sensors*, Conference on Reducing Risk in Tunnel Design and Construction, 7-8 Dec. 1998, Basel Switzerland. Adapted with permission.
3.2 Intensity Modulation or Distributed Sensors

Working principle of intensity modulated or distributed sensor is based on the modulation of light intensity or amplitude in optical fiber. This kind of sensor is the simplest one as only a source (such as laser) and an optical detector (such as photodiode) are required as main components, that is depicted in Figure 9 below. This research paper explained that experiment was conducted by measuring detector’s output voltage every 5 μm displacement of the mirror away from the sensing port [21]. Detector’s output voltage then will be converted to be the laser’s light power. The conversion is done by varying the light power from laser, which is can be done by putting a pair of polarizer between laser and detector and then changing its polarization angle. The slope which is given by light power versus detector’s output voltage plot is the conversion factor. Advantages of these sensors are simple implementation, low cost, signal multiplexing, and ability to perform as real distributed sensors. Its main application is for fault finding and attenuation monitoring in optical networks [8].

![Figure 9](image.png)

**Figure 9.** Setup experiment of fiber optic displacement sensor. Adapted from Samian et al., *THEORETICAL AND EXPERIMENTAL STUDY OF FIBER-OPTIC DISPLACEMENT SENSOR USING MULTIMODE FIBER COUPLER*, Journal of Optoelectronics and Biomedical Materials, Vol. 1, Issue 3, September 2009, pp. 303–308. Adapted with permission.

Currently, two major distributed sensing methodologies are used in optical time domain reflectometry (OTDR): one is using Rayleigh & Fresnel scattering and the other is by Brillouin scattering. Rayleigh and Fresnel scattering are used in OTDR for sensing structural perturbations. Actually, it is not necessary to study on the scattering phenomena in detail like what we did before [22-24] as this method works only in simple light scattering principle. Based on the light scattering in the optical fiber, the distributed fiber-optic sensor is capable of continuously monitoring major structural parameters and has high spatial resolution in the order of a few centimeters; hence, it allows structure engineers to measure structural parameters in an entire infrastructure system for design verification, damage, and reliability assessments [7]. For example, the OTDR relies on the reflection of light that has been launched into a fiber from an amplitude-modulated and pulse source. By using the backscattering light [25], it is still possible to obtain the value of light intensity along the whole fiber, by measuring the time of flight of the returned pulses. In this way, it is possible to detect losses in the fiber and to locate these losses with quite good spatial resolution. Although distributed sensors have a great potential applications in civil engineering, they also having certain limitations such as insufficient resolution, weak detectable signal, and cumbersome demodulation system.

Brillouin scattering sensors have shown an interesting potential for distributed strain and temperature monitoring. Brillouin scattering is the result of the interaction between optical and sound waves in optical fibers. Thermally excited acoustic waves (phonons particle) produce a periodic modulation of the refractive index. It occurs when light propagating in the fiber is diffracted backward by the moving grating, giving rise toa frequency-shifted component by a phenomenon similar to Doppler shift. The process is called spontaneous Brillouin scattering (SBS). The main challenge in using SBS for sensing applications resides in the extremely low level of detected signal. This requires sophisticated signal processing and relatively long integration times. A commercial system based on
SBS is available from ANDO company [15]. Distributed sensors like Brillouin scattering based are also kind effective intrinsic sensors because they were used to detect strain and temperature over larger distances of about 20-30 kilometers in the past. Currently, Brillouin optical time domain reflectometry (BOTDR) offers a measurement distance of 30 km up to 200 km. Its spatial resolution is from 1 m to 4 m.

The last distributed sensor methodology is added and introduced here is Raman optical time domain reflectometry (ROTDR) based on Raman scattering phenomena. ROTDR is based on the Raman scattering where both Stokes and anti-Stokes components are generated. The intensity ratio between these two components can provide temperature information at any given point along the fiber link as the fiber link itself works as the sensing medium. Since the amplitude of the Stokes components is not temperature dependent, ROTDR is only capable of measuring the temperature rather than the strain with a resolution of 0.2 °C. The sensing distance is normally limited to approximately 8 kilometers with a spatial resolution of 1 m. ROTDR and BOTDR are employed for distributed sensing applications over the past few years. Their operation mechanisms are based on the non-linearities characteristics of optical fibers, where additional spectral components are generated. These additional spectral components are affected by external environmental parameters. Thus, evaluating the spectral content in an appropriate way can determine the changes in external measurands.[26]

3.3 Grating-based Sensors

Fiber Bragg Grating (FBG) is an optical filtering device that reflects light of a specific wavelength and is present within the core of an optical fiber waveguide. The wavelength of light that is reflected depends on the spacing of a periodic variation or modulation of the refractive index that is present within the fiber core. This grating structure acts as a band-rejection optical filter passing all wavelengths of light that are not in resonance with it and reflecting wavelengths that satisfy the Bragg condition of the core index modulation. Fiber Bragg Grating (FBG) technology is one of the most popular choices of optical fiber sensors for strain or temperature measurements due to their simple manufacturing process and relatively strong reflected signal produced (see Fig. 10 below).

![Figure 10. Schematic diagram of an FBG having an index modulation of spacing $\Lambda_G$ inside a single-mode optical fiber](source)

Adapted from S. J. Mihailov, *Fiber Bragg Grating Sensors for Harsh Environments*, Sensors, Vol. 12, pp. 1898-1918; doi:10.3390/s120201898, 2012. Adapted with permission.

The main interest when using Bragg gratings resides in their multiplexing potential. Many gratings can be written in the same fiber at different locations and tuned to reflect at different wavelengths. This situation allows the measurement of strain at different places along a fiber using a single cable. Typically, 4 to 16 gratings can be measured on a single fiber line. It has to be noticed that since the gratings have to share the spectrum of the source used to illuminate them, there is a trade-off between the number of grating and the dynamic range of the measurements on each of them. Fiber Bragg gratings can be used to replace the conventional strain gauges and installed by gluing them on metals and other smooth surfaces. With adequate packaging, they can also be used to measure strains in concrete over basis length of typically 100 mm [27]. In addition to the widespread applications in temperature and straining sensings, FBG sensors have found applications for measurements of acoustic/ultrasonic signals or damage and crack monitoring [26, 28, 29].
The failure of concrete structures usually starts with cracks [17]. The damage condition of a concrete structure can be assessed through the monitoring of cracks. Non-destructive evaluation techniques, such as visual inspection, radiography, ultrasonics, and acoustic emission have been developed for damage detection; however, all of them have common limitation that continuous assessment of cracks cannot be made in situ during the service of structures. Fiber optic crack sensors developed recently have provided a good solution to this problem. In this type of applications, FBG sensors replace the conventional piezoelectric (PZT) sensors in order to pick up the ultrasonic/acoustic waves by reducing the complexity of wiring issue. FBG sensors have been deployed in a large quantity by utilizing their multiplexing capability, low cost, compact size, and good linearity. Therefore, they can achieve a full-scale monitoring. These characteristics are some of the most competitive advantages of FBG sensors over traditional PZT sensors and other types of fiber optic sensors. Currently, FBG sensors have become as the major leading technology in fiber optic sensor technologies.

3.4 Microbending Sensors

It is obvious that there are two kind of bending sensors: macro- and micro-bending. But here, the explanation is focused only on microbending sensors. The microbending sensor is one of the earliest fiber-optic measurement approaches, having been demonstrated by Fields and Cole since 1980s for acoustic measurements. Besides, typical applications include sensing of pressure [30], and force [31].

The geometry of a sensing region of a microbend sensor is shown in Figure 11. The sensing region consists of two corrugated plates. The corrugations are cylindrical rods with fixed diameters. The fiber is pressed between these plates by applying different forces to the top plate. Optical fiber passes through these corrugated plates. The sensor comprises of a certain length of fiber which is placed between two rigid plates having an optimum corrugation profile so that the fiber experiences multiple bends. Both ends of the fiber inside the sensor are relaxed to keep away elastic factors of the fiber. $\Lambda$ is the mechanical periodicity (deformer tooth spacing), $l_s$ is the corrugation size (thickness of the spacer material between the deformer plates) and cylindrical rods are the corrugations (bendings).

![Microbend Sensor](image)

**Figure 11.** Geometry of the sensing region. Adapted from H.S. Efendioglu, T. Yildirim, and K. Fidanboylu, *Prediction of Force Measurements of a Microbend Sensor Based on an Artificial Neural Network*, Sensors, Vol. 9, pp. 7167-7176; doi:10.3390/s90907167, 2009. Adapted with permission.

To understand the behavior of microbending optical fiber sensors, experiments have been conducted. Those experiments examined the principles of microbending in optical fiber as load sensor and detected the power loss caused by the pressure, so-called Weight in Motion (WIM) System [32, 33]. The expected results of investigation is to know the potential of optical fiber sensor for static and dynamic loads. The results of static and dynamic test show the good linearity and small error. It indicates that optical fiber sensor has a potential to be applied in WIM system. Intensity modulation caused by microbending losses in multimode fibers can be used as a transduction mechanism for detecting some environmental changes. For multimode fiber sensors, modulation during measurement of any property like pressure can be reflected in the form of a microbending loss modulation, moving fiber modulation or an absorbing layer modulation. Due to the microbending induced losses, the lower order guided modes are converted to higher order modes and eventually lost by radiation into the outer layers.
resulting in a reduction of the optical intensity coming out of the fiber. Such sensors are appropriate for civil engineering structures especially in embeddable composites like reinforced concrete material. In this situation, reinforcing fibers in the composite structures act as natural bending loss sites for the optical fiber. Combination of multiple microbend (multimode) sensors can build a sensor array for the quasi-distributed sensing application in local monitoring section especially for strain or deformation along the structures, while OTDR can be used for investigation of each sensor unit conveniently. By connecting with multiplexed sensing processing schemes, this sensor array could find some applications in real-time monitoring and damage detection of large and critical engineering structures in the future [8, 17, 19].

4. Conclusion and Future Research
A brief analysis of preliminary and feasibility study regarding fiber-optic sensors application for structural health monitoring of transportation infrastructures has been presented. In fact, until now the majority of structural monitoring sensors used in Indonesia for long span bridge health monitoring systems are still based on the traditional transducer technology. This situation will cause deficiency in providing adequate accuracy and long-term stability. Therefore, fiber optic sensor (FOS) emerges as the cost-effective and innovative technology with high accuracy and sensitivity in order to solve this problem. However, their infrastructure are commonly large, long span, and will serve for a very long time, so durable and reliable sensors are becoming the foundation of successful and meaningful health monitoring systems. FOS system is being used and will be widely used in various key civil structures, including buildings, piles, bridges, pipelines, tunnels, adams, soil excavation. Additionally, they can be used for various core materials like concrete, steel or composites used in civil engineering. Fiber-optic sensor technology for the SHM system is still not widely accepted and applied for transportation infrastructures in Indonesia. Therefore, many tasks are still needed to be done in the future. In accordance to other countries, our focus might be shifted from measurements in strain, intensity, deformation, and temperature to other key structural parameters monitoring applications such as corrosion, crack formation, vibration, and humidity. Moreover, the fiber-optic sensors can also be used not only to assess the condition of the structure by collecting the data, but also to respond to it with an accurate and a correct action afterwards.

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