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A Fundamental Study for Real-Time Safety Evaluation System of Landing Pier Using FBG Sensor

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Abstract**—**A landing pier is subjected to safety assessment by visual inspection and design data, but it is difficult to check the damage in real-time. In this study, real - time damage detection and safety evaluation methods were studied. As a result of structural analysis of the arbitrary landing pier structure, the inflection point of deformation and moment occurred at 10%, 50%, and 90% of pile length. The critical value of Fiber Bragg Grating (FBG) sensor was set according to the safety factor, and the FBG sensor application method for real - time safety evaluation was derived.

Keywords**—**FBG sensor, harbor structure, maintenance, safety evaluation system.

I. Introduction

THE landing pier is a mooring facility composed of a main body of pier and a retaining wall behind it. The main body of the bridge is a port facility which is made of RC slab and beam as upper part and steel pipe or RC pile as base pile. More than 25% of the port facilities in Korea were developed in the 1960s and 1970s, and the deterioration of port facilities is rapidly progressing. As a part of the inspection and diagnosis by the Special Act on Safety Management of Public Facilities, the safety evaluation of port facilities is carried out; however, most of them are carried out through visual inspection of the diver. Therefore, it is accompanied with disadvantages such as subjective opinion of the investigator, securing the visibility of the diver and exposure to danger [1].

Nowadays, evaluation of the underwater structure becomes important, and researches on ROV or SONAR have been now in progress, but it is based on image survey. However, in actual water, there are barnacles or fish and shellfish attached to the surface of the structure, and it is difficult to grasp the damage of the structure. Therefore, this study analyzed the behavior of structures by attaching FBG sensors to the structures and conducted a basic study to evaluate real - time safety [2].

II. Theoretical Background

A. Safety Evaluation

In Korea, "Special Act on Safety Management of Public Facilities" was promulgated in 1995 and is managed by law. The landing pier structure also corresponds to the facility to be managed. The landing pier is made up of concrete decks, beams and column beams of upper structure, and steel pipes or concrete piles of underwater structure. The landing piers are similar to bridges that receive vertical loads, but they are structures that are subjected to lateral loads due to ship's berthing force, mooring force, tidal current, and waves.

In the landing pier structure, the ratio of the required strength to the design strength is considered according to the ultimate strength design method (USD), and the ratio of the actual stress and the allowable stress is considered in the steel member according to the working stress design method (WSD) as in (1), (2). The assessment is according to the criteria in Table I.

$$\text{Safety Factor in USD} = \frac{DesignStrength}{RequiredStrength} \tag{1}$$

$$\text{Safety Factor in WSD} = \frac{AllowableStress}{ActureStress} \tag{2}$$

TABLE I
SAFETY FACTOR BY STRUCTURE ANALYSIS

Marks	Grade	Safety Factor
a	5	more 1.0
c	3	more 0.9 ~ under 1.0
d	2	more 0.75 ~ under 0.9
e	1	under 0.75

Even in the case of a number of review sections, the safety evaluation index of each review section is regarded as one review item, and (3) is applied. The final safety evaluation index of the entire structure is shown in Table II

$$\text{Safety Assessment} = L + 0.3(H-L)\frac{\sum_{i=a}^{N-2} M_i}{5\times(N-2)}, (N>2) \tag{2}$$

$$= L + 0.3(H-L) \qquad , (N=2) \tag{3}$$

Here, N = number of safety examination items (structure review, activity, conduction, bearing capacity, etc.), L = Minimum of the rating of the review item, H = Maximum of the rating of the review item, Mi = Remaining values excluding the maximum and minimum values of the review item.

TABLE II
SAFETY EVALUATION STANDARD BY SAFETY ASSESSMENT INDEX

Marks	Safety Assessment Index
A	more 4.5 ~ under 5.0
B	more 3.5 ~ under 4.5
C	more 2.5 ~ under 3.5
D	more 1.5 ~ under 2.5
E	more 1.0 ~ under 1.5

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B. FBG Sensor

The principle of propagation of light in an optical fiber is the principle of total reflection that all light within a certain angle is reflected at the interface when light travels from a material with a high refractive index to a material with a low refractive index. The main component of optical fiber is made of silica glass. Its structure is composed of a core portion added germanium (Ge) which is for making refractive index slightly higher and a cladding portion for protecting the core portion as shown in Fig. 1 [5].

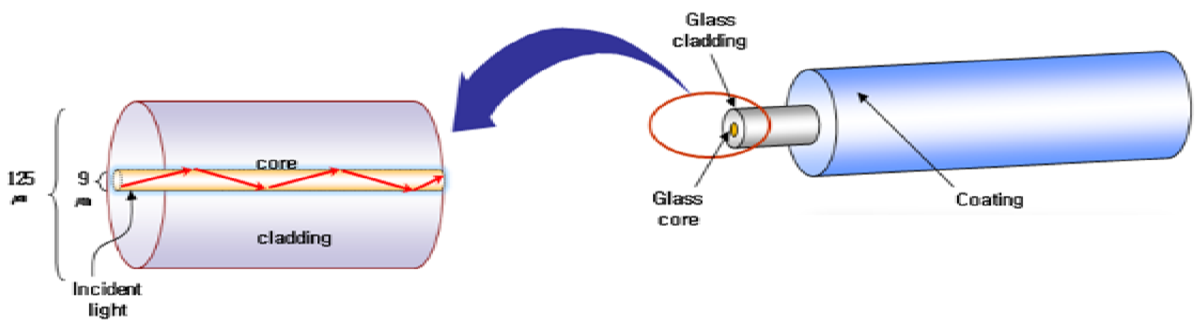


Fig. 1 Structure of FBG

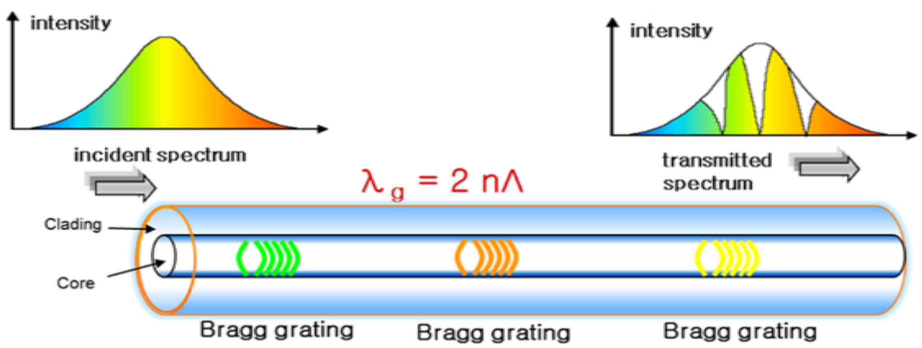


Fig. 2 Principle of FBG sensor

TABLE III
ANALYSIS PLAN

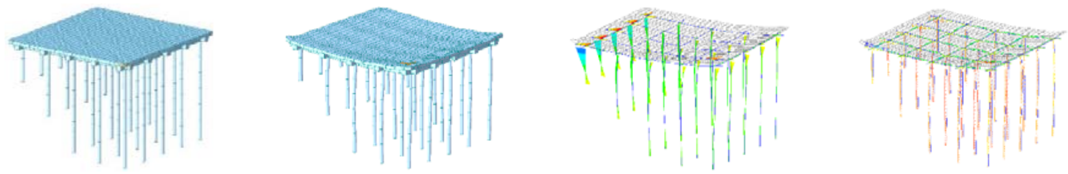
Name	Type of structure	Material	Standard	Allowable stress	Modulus of elasticity
OO Dock	Landing Pier	Reinforced concrete	fck = 28 MPa	fca = 11 MPa	Ec = 2.6986 × 105 MPa
		Steel pipe (SPS 490)	Φ = 609.6 mm, 711.2mm, t = 12 mm, 14 mm	fsa = 190 MPa	Es = 2.05 × 106 MPa

FBGs have been developed using the phenomenon that the index of refraction is slightly increased when the portion of the optical fiber core doped with germanium is exposed to light in the ultraviolet region. In this FBG, the reflection wavelength is changed depending on the interval of grating, and by using this principle, the FBG is packaged so that the wavelength value changes according to the change of specific physical quantity, and is used as the FBG sensor. The FBG sensor can be used semi-permanently compared with the electric sensor because there is no corrosion or loss caused by environment like humidity. Also, its stability is high since the FBG sensor can operate in extreme environment such as high temperature, low temperature, etc. Therefore, in this study, optical fiber sensor was applied because it should be installed in water.

III. Real-Time Safety Evaluation System

A. Real-Time Safety Evaluation System Method

The status evaluation consists of appearance examination and durability examination. Since the appearance examination is a qualitative evaluation, there is a disadvantage that the subjective opinion of evaluator is reflected, and there is a high possibility that the structure is damaged by the impact when the ship is docked. In this study, the load on real-time structure is calculated, and applying it to the review of pile allowance stress by using the strain generated on the pile according to the "Special Act on Safety Management of Public Facilities" manual. The OO port is a pier-type structure constructed in 2006, which is composed of 27.6 m × 28 m × 4BLOCK. The structure of the pier is made of reinforced concrete beams and slabs. The substructure is equipped with steel pipe files (φ609.6 × 12t (SPS490), φ711.2 × 14t (SPS490)). Table III shows the material properties. Structural analysis was performed by selecting one block of representative section and MIDAS CIVIL, which is widely used for structural analysis, was used as the analysis program [6].



(a) Modeling (b) Deformation (c) Bending moment (c) Axial force

Fig. 3 Static analysis result

In the OO port, the maximum deformation caused by the load acting on the pile such as wave is occurring in the middle part of the pile in the ocean direction. And the maximum deformation due to the load acting on the superstructure, such as the ship impact, occurs at the bottom of the pile at 10% of the pile length from the top. Considering the generation forces and deformation behaviors, it was found that the strain sensor should be attached to 10%, 50%, and 90% of the pile length from the top of the pile.

Composite stresses were investigated by using the allowable axial compressive stress without consideration of local buckling and the allowable stress for local buckling of circular steel pipe. The stress due to the axial force acting on pile and the stress due to the moment are shown in (4).

$$\frac{f_c}{f_{ca}} + \frac{f_b}{f_{ba}} \leq 1.0 \tag{4}$$

Here, fc is the stress for the axial load, and fb is the stress for the moment, which is generated by the horizontal force. Therefore, as shown in (5), fb can be divided into the bending stress fbd due to the fixed load and the upper load, and the bending stress fbl due to the external force.

$$\frac{f_c}{f_{ca}} + \frac{f_{bd}+f_{bl}}{f_{ba}} \leq 1.0 \tag{5}$$

The bending stress fbd due to the fixed load and the overburden load is the value obtained by structural analysis, and the real time stress can be obtained from the measured data by attaching the FBG strain sensor to the member of framework. So, as shown in Table IV, the critical strain value of each grade can be determined according to Table I [4].

TABLE IV
STRAIN RATE THRESHOLD ACCORDING TO SAFETY GRADE

Mark	Safety Factor	Strain threshold of fb1
a	more 1.0	-
c	more 0.9 ~ under 1.0	$\left[\left(1.000 - \frac{f_c}{f_{ca}}\right) \times f_{ba} - f_{bd}\right] \div E = \epsilon$
d	more 0.75 ~ under 0.9	$\left[\left(1.111 - \frac{f_c}{f_{ca}}\right) \times f_{ba} - f_{bd}\right] \div E = \epsilon$
e	under 0.75	$\left[\left(1.333 - \frac{f_c}{f_{ca}}\right) \times f_{ba} - f_{bd}\right] \div E = \epsilon$

B. Real-Time Safety Evaluation System Composition

Based on the structural analysis results, the safety evaluation of the file can obtain the real-time strain value from the installed FBG strain sensor. The installed FBG strain sensor can be transmitted to the server through the data logger. The server can calculate the stress change of the pile according to the input algorithm and can infer a real - time safety evaluation. This information can be checked in real time through the administrator's PC or smart phone, and immediate response and accident prevention are possible when the threshold of each member of framework is reached [3].

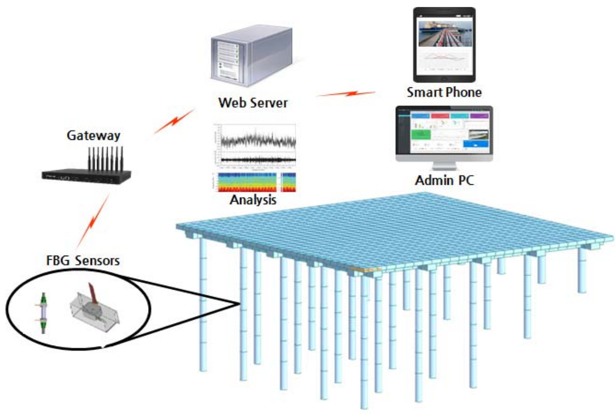


Fig. 4 Real-time safety evaluation system composition

IV. CONCLUSION

When performing the safety evaluation of port facilities, Diver input, a conventional method, is used to perform an underwater survey, and ROV or SONAR is used as an image based survey. However, it is difficult to grasp the damage of structures because of turbidity and environment. In this study, a real - time safety evaluation system was constructed using FBG sensor for safety evaluation of underwater pile. Structural analysis was carried out for arbitrary pier type structures. The maximum deformation caused by the load acting on the pile such as wave is occurring in the middle part of the pile in the ocean direction. And the maximum deformation due to the load acting on the superstructure, such as the ship impact, occurs at the bottom of the pile at 10% of the pile length from the top. Considering the generation forces and deformation behaviors, it was found that the strain sensor should be attached to 10%, 50%, and 90% of the pile length from the top of the pile. Depending on the results, the threshold value was set according to the safety evaluation grade in the section where the maximum deformation of the pile occurs. We constructed a system to evaluate the safety of underwater piles in real time by analyzing the data of FBG strain sensor of the section where the maximum deformation occurs. As a result, it is possible to check in real time through the administrator's PC or smart phone, and it is expected that immediate response and accident prevention will be possible when the threshold of each member of framework is reached. This study is a basic study, based on structural analysis for the axial force of the pile and for the horizontal force, the method of estimating the stress with the FBG strain sensor was used. Further research is required to provide accurate safety evaluation methods by measuring axial force and lateral force.

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