Analysis on the present situation of the whole life cycle monitoring technology of standing pile wharf

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Abstract. The standing pile wharf long-term service in abominable natural conditions, it is easy to be damaged and may affect the structure safety of wharf. There are some hidden dangers in traditional testing methods. Therefore, it is very important to establish a set of whole life cycle monitoring system for wharf structure. This paper discusses the application status of monitoring technology in domestic and foreign engineering, discusses the components of the whole life monitoring system of high pile wharf and makes a brief analysis of its mechanism, focusing on the detailed discussion of the sensor module. The selection and arrangement of all kinds of sensors are discussed, and a new idea of sediment thickness monitoring is put forward. Then in light of the current research status of the monitoring system for the whole life surface of the high-pile wharf, the author puts forward some suggestions.

1. Preface
Zhejiang Province is rich in port resources, with a total of 6714 kilometers of mainland and island coastlines. By the end of 2017, there are 1084 port berths in the coastal area of the province, including 235 berths bigger than 10000-tons. Most of the coastal ports in Zhejiang Province are built on soft soil foundation, and most of them are wharf of precast reinforced concrete slab with beam on piles. The wharf is made up of pile; pile cap; crossbeam; longeron; slab and berthing member. It has the characteristics of light structure, good wave mitigation effect, poor durability and so on [1].

The standing pile wharf is a kind of open type wharfs. Its durability is not as good as gravity quay-wall, and its adaptability to overload is poor, then it is prone to lateral displacement and cracking. The wharf often serves under the harsh natural environment, and is faced with a series of problems such as chloride ion erosion, corrosion of the steel bar, impact of the ship, erosion of wave sputtering, nonstandard use, etc. The security of the wharf structure is a big problem. The traditional wharf detection is to invite the relevant inspection units to carry out the manual inspection periodically or not. Because there is no relevant mandatory standard to standardize the detection frequency, the frequency of the operation mode is lower. There are some hidden dangers in the structure health of wharf. Therefore, it is necessary to set up a real-time monitoring system covering the whole life cycle of wharf to monitor the health and safety of wharf. Based on the relevant domestic and foreign literature in recent years, this paper will discuss and analyze the whole life cycle monitoring technology of wharf.

2. Research status of health monitoring at home and abroad
Structural health monitoring of wharf refers to obtaining real-time data such as stress and strain by using
sensors arranged inside or outside the wharf, analyzing structural characteristics of wharf, and assessing whether there is structural damage and hidden danger of safety. Structural health monitoring technology is the first to carry out load monitoring, and then with the development of structural engineering towards high-level and complex, the content of monitoring gradually develops to damage location detection and structural safety assessment [2]. The essence of structural health monitoring is to detect the damage of engineering structure, which can be divided into local method and integral method [3]. Structural health monitoring was applied and developed rapidly in bridge structures in the 1980s, and it was gradually applied to super-high-rise buildings, reservoir dams and tunnels. Tsing ma Bridge in Hong Kong is equipped with a monitoring system based on GPS technology, which can collect data and display three-dimensional displacement in real-time. It can monitor the deformation of bridge in real-time [4]. The Shanghai Tower uses a real-time data acquisition system composed of more than 400 sensors to monitor the super-high-rise building through the analysis of data such as settlement, wind load and dip angle [5]. The monitoring system of Lijiaxia Hydropower Station is more adequate, including displacement monitoring, stress-strain monitoring, seepage monitoring, etc [6]. The Tianxin Tunnel in Yuxi, uses embedded FBG sensors to realize real-time strain monitoring of the secondary lining of the tunnel [7].

However, the research on wharf structure monitoring is rare, and few of them are used in practical engineering. In 2011, Zhu Tong, from Dalian University of Technology, install sensors at a 300000 DWT oil harbor in Dalian Port. They collected stress-strain data during berthing of large ships and in the case of huge wind and waves to monitor the structural health of the wharf [8]. In 2015, Chen Jing and Zhang Hanlin set up a set of structural health monitoring system by analyzing the displacement, strain and other data of the structural health monitoring system [9]. In 2018, Huang Hongbao, from Tianjin Research Institute For Water Transport Engineering, set up a set of health monitoring system at a general wharf in Nanjiang Port area of Tianjin Port. Unlike in the past, the sensors are placed in the concrete structure during the construction phase [10].

There are many famous ports abroad, including the Dutch port of Armstrong, the port of Rotterdam, the port of Yokohama, and the port of Singapore. Sydney Port in Australia, Barcelona Port in Spain, Hamburg Port in Germany and so on. But there's not much research on them. In 1999, Dr. Ranga studied the crack width monitoring of hydraulic structures and applied the results to design guidance [11]. In 2002, Dr. Mufui installed a whole life monitoring system on Hill wharf, which is the first time that grating fiber sensor has been used in structural health monitoring of high pile wharf [12]. Det Grosso reported on the results of his fiber optic sensors in the Italian port of Genoa, at 3rd international conference on structure health monitoring & intelligent infrastructure [13].

3. The whole life cycle monitoring system
The whole life cycle monitoring system is generally composed of sensor module, data transmission module, data analysis and safety assessment module and so on. The sensor module is mainly responsible for converting the data received by various types of sensors into optical signals or electrical signals. The data transmission module is mainly responsible for automatically collecting the converted signals of the sensor and transmitting the signals to the rear processing base station. The data analysis and safety assessment module mainly analyzes and processes all kinds of data to determine whether there are hidden dangers in the structure.

3.1. The sensor module
The sensors can be divided into temperature sensor, humidity sensor, displacement sensor, stress sensor, chloride sensor [14]. The standing pile wharf will encounter concrete local cracking, concrete damage, displacement and so on in the process of operation. Analysis of its damage principle, can be divided into the following reasons: ship impingement; steel bar corrosion; overload operation; Sediment below wharf [15]. In view of the above damage mechanism, displacement sensor, stress sensor, chloride sensor and so on are generally used in the whole life cycle monitoring system of standing pile wharf for real-time monitoring.
Sensor is the most important and initial part of the monitoring system, and its durability and reliability are very important. Most of the traditional resistive and semi-conductive sensors are metal materials, which are prone to corrosion and other damage under the harsh natural conditions of seaports, and it is difficult to meet the requirements of the whole life cycle monitoring system. In recent years, the rapid development and application of fiber optic sensors provide a new choice for the whole life cycle monitoring system. At present, the fiber Bragg grating (FBG) sensor and the distributed Brillouin optical fiber sensing are commonly used in engineering. The results show that the low temperature of -40°C will not affect the service life of FBG sensor, while the reliability of FBG sensor can be maintained for 25 years at 80°C [16]. Unfortunately, the current research on durability and reliability of FBG sensors is the result of single environmental impact. The research on durability and reliability of FBG sensors under multi-environmental effects has yet to be carried out. The brillouin optical time domain reflectometer (BOTDR) is widely used in engineering monitoring at present, which has advantages of small size, high anti-interference and strong sensitivity [17,18].

3.1.1. Selection and placement of displacement sensors. The displacement sensor can be used to monitor the whole displacement and the displacement of the local member. The whole monitoring can be divided into vertical and horizontal according to the direction of displacement. The local monitoring can be used to monitor the relative displacement between the pile cap and the longitudinal beam between the face plate and the longitudinal beam. The BOTDR sensor has the characteristics of high precision and high sensitivity, and the main material of ordinary single-mode fiber is silica, which can be placed directly on the surface of the structure after reasonable packaging.

The BOTDR sensor can be packaged in FRP form, and in this way the BOTDR sensor has high tensile strength and corrosion resistance [19]. The sensor is fixed on the pile cap, the longitudinal beam and the panel by the fixed-point method, and the local displacement is monitored by the fiber-optic deformation between the two points. In order to monitor the whole displacement, it is necessary to lay the fiber directly on the surface of the structure. This method can ensure that the deformation of the fiber is consistent with the deformation of the whole structure, so that the overall displacement can be monitored [20]. Then we can do further research on the arrangement and bonding mode of Brillouin fiber.

3.1.2. Selection and placement of stress sensors. The stress sensor can be used to monitor whether there is any abnormal behavior such as overload on the wharf surface, and it can also be used to monitor the stress change of the ship during berthing or even accidental impact. It can also be used to monitor the change of pile foundation stress during sediment deposition under the wharf. The stress fatigue limit sensing life of FBG sensor has been studied by Shuyue step of Chongqing Jiaotong University. The experiment shows that the sensor can withstand about 132 million times of pressure fatigue test [21], which is enough to meet the requirement of life monitoring.

The layout of stress sensors should be embedded in the prefabricated panels, ship-leaning components, prefabricated pipe piles and other components. FBG sensors first use epoxy resin to paint the first layer to reduce the impact of the sensor. The sensor is protected from moisture and decay, then the sensor and transmission cable are pasted on the steel bar by epoxy resin, and wire mesh is added to the outside of the FBG sensor in order to reduce the damage to the sensor when the concrete is poured and vibrated [7,8,22]. Next, the layout of the stress sensor can be further optimized. At present, there is little research on this field [23,24]. More sensors are deployed in sensitive and critical parts to increase the reliability of monitoring system, and less sensors are deployed at non-important nodes to reduce the cost of reduction.

3.1.3. Selection and placement of chloride ion sensors. Corrosion of steel bar is an important cause of damage to marine concrete soil in port, and chloride ion sensor can monitor the concentration of chloride ion in concrete, and then judge whether it will cause corrosion of steel bar [25]. Currently available chloride sensor can be divided into optical fiber chloride sensor and Ag/AgCl electrode type chloride ion
sensor. The optical fiber chloride sensor can not continuously reflect the concentration change of chloride ion around it, and when the concentration of chloride ion changes repeatedly, the sensor will fail. The electrode type chloride ion sensor can continuously and real-time measure the change of chloride ion concentration in the surrounding medium, and can be used in concrete chloride ionization. Subconcentration monitoring [26].

3.1.4. Assumption of monitoring sediment thickness. Sediment deposition may cause the pile foundation to bear a large bending moment and cause the concrete pipe pile to crack and destroy. Therefore, the structural health of the pile foundation can be analyzed by monitoring the sediment deposition thickness. At present, there are few researches on the monitoring of sediment thickness at home and abroad, so the author puts forward a theoretical monitoring method of sediment deposition thickness.

The principle of this monitoring method is to use the principle of static water pressure and the principle of gravity stress distribution of soil mass and calculate the approximate sediment deposition thickness of this point by using the data of stress sensor and the calculation of water level height. The preliminary idea is as follows: a horizontal platform is set up on the pile foundation at the height 20-30 cm of the designed mud surface, the optical fiber strain sensor is arranged on the platform, and then a water level monitoring instrument is arranged at the pile foundation at the designed water level. At present, this is only a theoretical possibility, and further in-depth research needs to be carried out.

3.2. Data transfer module
The data transmission module mainly transmits the optical signal and electric signal generated by the sensor to the rear processing base station through the cable or wireless transmission equipment through the signal collector. Data transmission is divided into wired transmission and wireless transmission. Cable transmission requires the installation of cables, which can be connected to the monitoring cable to transmit the data to the rear processing system. At present, most wharves can realize the full coverage of monitoring, so it is feasible to transmit data by cable of monitoring system, and it is more reliable than wireless transmission. Wireless transmission is characterized by good expansibility, easy equipment maintenance and easy interference with transmission signals.

By using the data transmission module, the relevant staff do not need to go to the site to receive the data, but can monitor the site monitoring data in real time through the network at the management base station in the back side. The design life of the whole life monitoring system is long. The wireless network transmission needs to pay the network cost to the network operator all the time. The wired cable is recommended for data transmission.

3.3. Data analysis and security assessment module
The data analysis and safety assessment module is composed of a high-performance calculator and a system for wharf health monitoring. At present, this kind of system has been developed by scholars based on various platforms. The principle of life monitoring of wharf is to build three-dimensional model of wharf by using the data of design drawings, BIM technology [27], finite element analysis software [28], etc. Then, the actual data obtained by the sensor are compared with the relevant standard values. The method of structure analysis, probability analysis, fuzzy analytic hierarchy process [29] and grey comprehensive evaluation method are used to compare and analyze the actual data obtained by the sensor [30] and other methods to assess the structural health of wharf and to make risk early warning. The safety assessment system will automatically judge the safety situation of the terminal. And when necessary, send the relevant parameters to the terminal users of the engineers and technicians.

4. Conclusions and recommendations
In this paper, the whole life cycle monitoring technology is briefly summarized, the failure mechanism of the standing pile wharf is analyzed briefly, the application status of the whole life monitoring technology in domestic and foreign projects is described, and the components of the whole life cycle monitoring system of the high pile wharf are briefly described. This paper expounds the characteristics
of each component, emphatically introduces the sensor module, discusses the selection and arrangement of all kinds of sensors, and puts forward a new type of monitoring assumption for sediment deposition thickness. Based on all kinds of sensors and analysis system, the whole life surface monitoring system of standing pile wharf can evaluate the safety and health of standing pile wharf by monitoring the data of stress, displacement and chloride ion movement of core components of standing pile wharf, then make an early warning of the risk.

The research on the whole life monitoring system of high pile wharf is still in the initial stage. According to this situation, the following suggestions are put forward:

- The real-time monitoring technology of bridges and dams has been relatively mature and has a good effect in the engineering practice. We should draw on the experience of relevant disciplines and construct a set of theoretical system suitable for the monitoring of the whole life surface of high-pile wharf.
- Combined with the principle of full-life surface monitoring and damage mechanism of standing pile wharf, this paper analyzes the easily damaged parts and key structural nodes of wharf, optimizes the location and arrangement of sensors, and obtains better monitoring results with a small amount of resources.
- With the strong wind, wave and corrosive natural environment of seaport, the study of durability and reliability of the sensor is strengthened, and the research of the new type sensor is speeded up.

References
[1] Han L 2008 Port Hydraulic Structure (Beijing, China: China Communications Publishing & Media Management Co. Ltd)
[2] Yuan S F 2007 Structural Health Monitoring (Beijing, China: National Defense Industry Press)
[3] Housner G W et al 1997 Structural control: Past, present, and future J. Eng. Mech. 123 897-971
[4] Chen X 2002 Real-time GPS bridge deformation Monitoring system in Qingma traffic control area of Hong Kong Transpworld 2002 35-6
[5] Su J Z, Xia Y, Chen L et al 2013 Long-term structural performance monitoring system for the Shanghai Tower J Civil Struct. ealth Monit. 3 49-61
[6] Li J, Lu S H and Guo C 2005 Automatic monitoring system of the dam safety of Lijiaxia hydropower station Water Power 31 63-4
[7] Guan Y Y, Li C, Cai Z C et al 2014 Monitoring research of fiber Bragg grating strain sensors embedded in tunnel secondary lining Opt. Tech. 40 547-50
[8] Zhu T, Liu X Q, Zhou J 2011 Health monitor of berthing piers of cylinder caissons based on fiber grating sensing technology Port Waterway Eng. 2011 156-62
[9] Chen J and Zhang H L 2015 Research on key techniques of Wharf structural health monitoring China Water Transport 2015 53-5
[10] Huang H B and Liu H B 2018 Tianjin construction of wharf life-span health monitoring system China Communications News 2018-8-28
[11] Ranga R A V and Sundaravadivelu R 1999 A knowledge based expert system for design of berthing structures Ocean Eng. 26 653-73
[12] Tennyson R C, Mufti A A, Rizkalla S et al 2001 Structural health monitoring of innovative bridges in Canada with fiber optic sensors Smart Mater. Struct. 10 560
[13] Det Grosso A, Lanata F, Brunetti G and Pieracci A 2007 Structural health monitoring of harbor piers Proc. 3rd Int. Conf. Structure Health Monitoring & Intelligent Infrastructure: Structural Health Monitoring & Intelligent Infrastructure (Vancouver, Canada)
[14] Hu H, Ye L and Tian H 2017 Review of detection indexes analysis and application of high-pile wharf's structural health J. Zhejiang Institute of Communications 2017 23-6
[15] Sun Y X and Ran C G 2005 Brief introduction of structural damage mechanism and health monitoring technology of high-pile wharf Hydrogeol. Engi. Geol. 32 110-2
[16] Zhang W 2016 Key technology for reliability of fiber bragg grating strain sensing system...
Li X H and Huang Y H 2018 Application of distributed optical fiber monitoring technology in health monitoring of civil structures Sci. Technol. Vision 2018 208-9

Wei D R, Zhao H C, Qin Y T et al 2005 Development of distributed optical fiber monitoring technology in China Guizhou Water Power 19 7-9

Fuhe J P 2010 Full-scale distributed monitoring technology of optical fiber brillouin and its applications in civil engineering (Harbin, China: Harbin Institute of Technology)

Shi B, Xu H Z, Zhang D et al 2004 Feasibility study on application of botdr to health monitoring for large infrastructure engineering Chin J. Rock Mech. Eng. 23 493

Shu Y J, Wu J, Zhou S L et al 2017 Evaluation method of ultimate sensing life for stress fatigued FBG strain sensors Acta Photonica Sinica 47 1-6

Zhao X F 2011 Experimental research on the fiber corrosion sensor based on distributed Brillouin optical time domain reflection technique J. Optoe. Laser 2011 333-7

Feng J 2017 Selection and implementation of pile foundation strain monitoring position in health monitoring system of high pile wharf China Water Transport 2017 165-7

Zhang X, Wang P, Xing J C et al 2013 Optimal placement of sensor for health monitoring of high-piled wharf structures Port Waterway Eng. 2013 80-4

Wu Y M and Gu B 2010 On durability of concrete for marine pile pier J. Guangzhou Marit. Univ. 18 11-3

Gao X J, Yang Y Z and Deng H W 2010 Real time monitoring technology for chloride ion penetration process into concrete Archit. Technol. 41 41-4

Chen J, Yang K, Ma R X et al 2018 BIM technology in the application of piled wharf monitoring research Ship Electro. Eng. 38 13-16, 67

Liu X X and Zhang Y 2016 Safety assessment of piled wharf under ship impact force Port Waterway Eng. 2016 55-9

Wang X J, Qin L and Chen Y 2010 Harbor safety evaluation system in the three georges reservoir region J. Chongqing Jiaotong Univ. (Nat. Sci.) 29 628-31

Xu X J and Luan S G 2008 Grey multi- hierarchical comprehensive evaluation on existing pile wharf's durability grade J. Waterway Harbor 2008 97-101