POAC'17
Busan, KOREA

Proceedings of the 24th International Conference on
Port and Ocean Engineering under Arctic Conditions
June 11-16, 2017, Busan, Korea

Automated Monitoring System of Planned Position of Arctic Quay Walls

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ABSTRACT

In current practice of construction projects Arctic offshore pier may be deviations from the planned situation building structures as during the construction phase and during operation. In winter period there is a powerful influence ice loads, measuring and control that with traditional method of surveying extremely difficult. The objective of this research is to automate monitoring procedure of building structures. Article suggests a new method and apparatus for automated health monitoring of construction elements of geotechnical engineering structures of maritime transport in the Arctic port piers. Maritime port located on the Arctic shelf is exposed to difficult environmental impact, the study and the characteristics of which are not fully understood. High freight load, a limited period of use in the summer navigation, the lack of scientific support for the project, all this lead to the need to perform regular observations of engineering.

KEY WORDS: Arctic port pier; Quay walls; Monitoring system; Technical state.

INTRODUCTION

Many Arctic offshore piers have a popular structure as quay walls construction, because it is easier and faster than building of gravitational structures, which is more difficult to deliver bulky and heavy construction materials. Sheet piling (or pipe piling) installation in permafrost and Arctic conditions is also challenging, but it is still easier than building of large gravitational structures. Coastal structures are experienced high loads from naval cargo. In recent years, there is the problem of structural integrity of harbor. It becomes more important question in connection with various environmental constraints and extreme phenomena such as typhoon or collision of the vessel. Common failures such as deformation of quay wall or its movement affect the stability of whole structure. Local faults affect the structural stability of entire structure and may cause the total destruction or restrict performance. Therefore, the integrity monitoring of the existing sheet piling structures is absolutely necessary.

Currently, structural technology of the technical condition monitoring of building constructions

is actively developed. Existing inclination control devices have some drawbacks, the main of them is the high cost and secrecy of data processing technology. Also, most of measuring systems don't allow to determine spatial structure of individual elements of situation as part of whole buildings complex, those, they don't have a linked network structure for processing and analyzing data about change the geometric parameters.

Metzger, Hutchinson and Kwiatkowski (2014) proposed the measurement system for berthing parameters of marine vessel, it's the most complete and perfect system, but it requires a special connection with berthing ships. Lee and Kim (2015) reviewed the water level influence on the vibration characteristics of gravitational structures by analyzing of the modal parameters.

Van der Linden, Emami-Naeini, Kosut, Sedarat and Lynch (2011) describes an analysis to determine optimal placement of inclinometers for deformations evaluating of operated bridge, examines the results of model tests, but definitive conclusions about optimal structure of sensor network cannot be moved to a random construction structure.

Ichii, Kitade, Kawano and Taguchi (2014) discuss cases of port facilities worsening. Method is used for monitoring of the state of backfill sheet pile quay wall which is the main structural component of construction. It was found that as a result of corrosion interlocks discontinuity of some of sheet piles occurs and as a result, fine particles of backfill are washed out, which is a serious problem that must be considered in order to maintain security of the harbor wall. According to the results of numerical simulation with using the finite element method (FEM) in the dynamic analysis was formulated the deformation changes acting in pier. The results of analysis were compared with results of direct measurements in natural conditions.

METHODOLOGY AND APPARATUS

In this study we suggested a structural method for measuring of local deformations (angles of inclination) to assess the technical condition of quay wall construction. We have proposed a multiple analysis of variance design line cordon berth. To achieve this goal, the following approaches were implemented. On first phase we developed a simplified structural model of the sheet pile wall, which has a kinematic degree of freedom, at the expense of the formulated structure for measuring of network planning provisions which, in turn, corresponds to a set of sensors. On second phase we make the algorithm is based on the identification and use of the obtained inclination angle measurement sheet pile wall elements. This makes it possible to formulate a more accurate model by additional analysis of the elastic properties and structural rigidity of the quay wall. On third phase, the forecast of technical condition of sheet pile wall design with the refinement of the damping parameters was obtained as a result of in-situ measurements. At each stage it is possible to take into account additional parameters that determine the arctic conditions, if possible to fix instrumental observations.

Network sensor implementation can continuously monitor technical condition of building structure in automatic mode, which will reduce the cost of engineering staff. It is important for the Arctic port facilities under a long winter period, when surveying is complicated because of the severe winter conditions. With this system, continuous monitoring of quay walls parameters can be in real-time. Developed project of monitoring system is presented in this article and demonstrates the usefulness of automated system. The article provides reasonable scheme for installation of measurement sensors and examples of data obtained from test measurements.

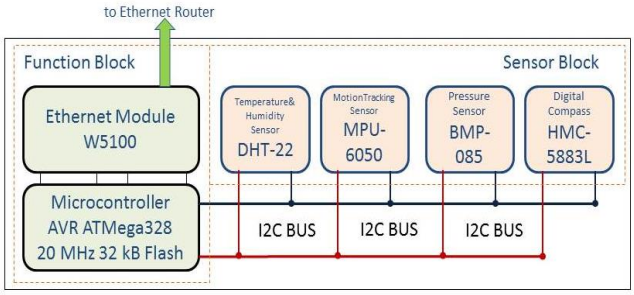


Figure 1. Structural diagram of the sensor for controlling of the inclination angle of the structural element of quay walls

The developed sensor is arranged in a sealed housing from non-magnetic material (aluminum cast alloy) inside which is a three-axis accelerometer, gyroscope and magnetometer (compass). Each of sensing axes of accelerometer is collinear of magnetometer axis and gyroscope axis. Temperature, humidity and barometric atmospheric pressure sensors are additionally installed in the device, these sensor allow to adjust correcting the measuring data depending of meteorological conditions. A detailed diagram is shown in fig.1, which discloses a composition of all components. The developed sensor has a standard network interface and can be connected via a router to Internet for next data transfer to server. Technical characteristics of server for receiving and collecting data are minimal, can be used as a local or remote server. Photo of the developed sensor is shown in fig.2.

Figure 2. Photography of measuring sensor of automated system for control of planned position

Developed automated system identifies hazardous angular displacements of sheet pile wall in real time and storing all data about deformation on special remote server, which is important information for further calculations and evaluation of safety of operation on berth. Developed equipment includes a microcontroller AVR ATmega328 and some measuring sensors, which accurately detect angular deflection of structural elements. One measurement module contains a micromechanical accelerometer, magnetic compass, temperature sensor, humidity and atmospheric pressure, together they provide objective information about majority of phenomena that affect on structure of pier.

THE MAIN TASKS FOR USE OF DEVELOPED MONITORING SYSTEM FOR MARITIME TRANSPORT PORT'S PIERS IN ARCTIC

Most of the regulations and rules suggest that offshore facilities are potentially dangerous as technical constructions. Then, for designs of high hazard class it is recommended to use the automated monitoring system. This article discusses the berths with varying depth at the quay wall. However, for arctic conditions (shift method of work) and a long period of people absence on facility, requirements for the regulations execution for conducting of periodic inspections of technical condition is almost impossible, and due diligence requires significant capital expenditures. Similar conditions correspond to stationary and gravity platforms on the Arctic shelf.

The scientific methodology for organization of the system for continuous automated monitoring of some operation on hydraulic structures of water transport, which interact with the environment was proposed (Garibin and Ol'khovik, 2015; Oleynik, Makshanov and Marley, 2015) and now we're developed the new strategy for the technical state monitoring is a series of elaborated structural schemes for automation of measurements. The essence of proposed deterministic model for assessing of technical state of arctic port pier is disclosed in that form: "The automated monitoring of the technical state" - "The complex model of assessment of the technical state" - "The predictive model".

New developed model allows providing the safety of operation of the hydraulic structures already on a completely new practical level and gives the qualitative prediction on the predetermined time period, i.e. fully implementing of the concept of the life-cycle analysis. The methods of joint inclinometric and dynamic instrumental observations are offered new integrated approach that in complex implement for quay walls monitoring and give a possibility in future to get safe and justified information about the technical state.

MODEL OF THE TECHNICAL STATE ASSESSMENT

We used the standard approach for evaluating of technical condition - the calculation of stress-strain state under load and natural factors. For this we considered the classic type of revetment structure form tongue with anker system and distribution belt. For the stress-strain state calculations we used the software GeoWall (freeware demo version from www.geo-soft.ru) and some own research model. The results are present in fig.3, 4.

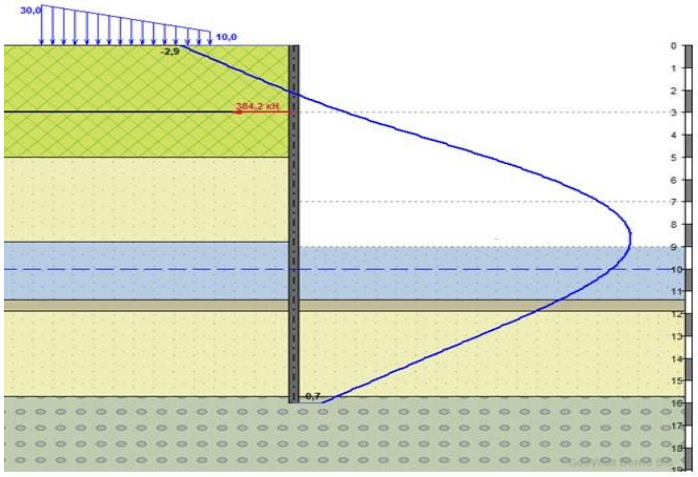


Figure 3. Design of sheet pile quay wall with one horizontal anchor

The simulated displacement and deformation of quay walls can be calculated with sufficient accuracy by using software (GeoWall or other) – in fig.3. Further, it is possible to determine the parameters of critical strain as a deviation in plane of geometrical dimensions or wall angle from horizontal (fig.4). Also, the calculated displacement and deformation in the mathematical model can be defined for the exact values of the stress-strain state. Then, all measurements obtained from the proposed equipment (fig.1, 2) as a result of long-time monitoring can be interpreted as the variable load on the building structure of sheet pile wall.

Thus, the relationship can be established for controlled planned position of berthing wall with various load and environmental factors in the form of constant monitoring of technical condition. That is especially important for the Arctic designs construction, which is impossible for periodic inspections due to adverse weather conditions and the absence of special service personnel.

CALCULATION MODEL

The bending profile (fig.4) of sheet pile wall for most of load corresponds to the quadratic parabola with zero angle of rotation in the base soil.

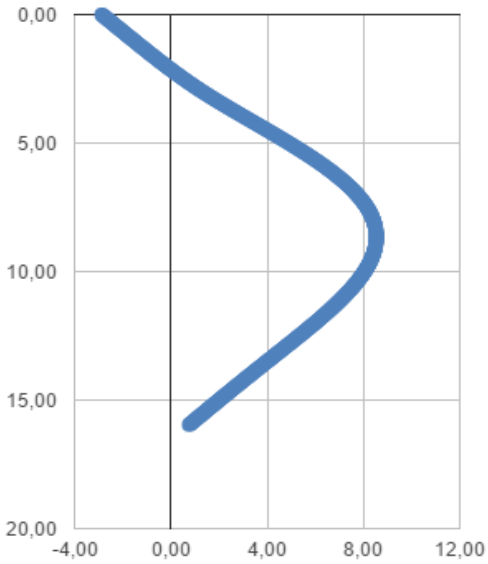
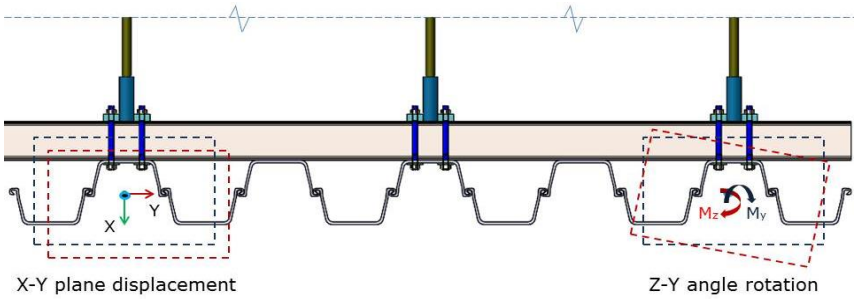


Figure 4. Calculation of the horizontal displacement of sheet pile wall

Also, power of marine ships which alone maneuver in water area is constantly increasing. That is cause of destruction of shore protection structures in ports. To evaluate the effects of using empirical methods and periodic inspections, Abramowicz-Gerigk (2014) proposed some ways of automatic identification of degradation processes of shore protection. However, these methods are based on measurement of ship propeller jets velocities and have some limitation.

Network from the measurements sensors are mounted at top of well head harbor wall have full control of displacements and rotations, as shown in Figure 5. Movement in X-Y plane (planned situation) is in Fig. 5(a) or rotation in Y-Z plane is in fig. 5(b). For this purpose, data from accelerometer and magnetic field sensor used in the automated monitoring system of technical state.



a) b)

Figure 5. The scheme for measuring the angular deviation of sheet pile wall.
a) Displacement through parallel shift in horizontal plane;
b) Displacement through rotate or bend deformation in vertical plane

We have developed software, which analyzes incoming data from sensor network. Data updating is provided every minute that is sufficient. The signal system is realized depending on the angle of deformation, for example: 0÷1 ° – a normal state, 1÷2 ° – warning, 2÷3 ° – danger. Such control allows estimating loadings more precisely at cargo operation of pier, including processes of freights unloading in various pier zones.

На рисунке 6 представлены тестовые измерения для угла отклонения sheet pile wall of небольшого грузового причала (протяженность около 100 метров) в зимний период в Санкт-Петербурге, метеорологические условия были максимально приближены к арктическим (отрицательная температура, лед в акватории). В условиях швартовки и отхода судна (буксира) были зафиксированы небольшие отклонения от вертикальной оси (с 22 по 55 минуту), что подтверждает работоспособность разработанной системы мониторинга.

Figure 6 shows the test measurements for the angle of deflection of sheet pile wall of a small cargo quay (about 100 meters long) in winter period in St. Petersburg, meteorological conditions were as close as possible to the Arctic (negative temperature, ice in the water area).

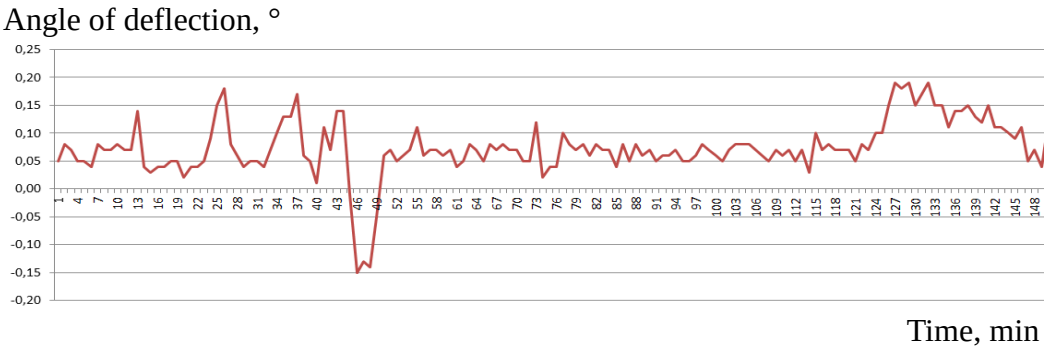


Figure 6. Results of monitoring (measurements) of local deflection of sheet pile wall in X-Y displacement

CONCLUSIONS

Continuous geodetic monitoring of planned position of elements of berthing constructions is an indispensable condition for their safe operation, it belongs also to the Arctic ports with severe climatic conditions and the minimum personnel during the winter period.

In perspective the developed automatic monitoring system allows to solve some problems with

definition of current technical condition of an arctic quay walls. Applied algorithm detects the slightest position deviations within 0.15 angle degrees, which is sufficient to detect significant deviations of planned position of quay wall.

The developed monitoring system can be applied together with other control systems, for example, with control system described by Ruggeri, Segato and Scarpelli (2013) where the technique for a tension control in anchor devices is presented. Also, as some application is control of vessel mooring on a wall, the sufficient mathematical apparatus for similar calculations is presented (Liu, Wang and Zhu, 2015; Sato and Tabata, 2009), it can be confirmed with data directly from a network of sensors installed on a quay wall.

Sharapov, Shkhinek and Delvalls (2015) proposed technology that due to heating of the inner site of the sheet pile wall allows to significantly reduce the ice load on the design of pier and remove ice accumulations. Lack of this technology is high electricity consumption. Joint use of our monitoring system and heating system can provide smooth energy consumption due to regulation of its consumption only at the necessary moment when there is a significant force impact on the anchor tractions and the quay wall.

Wrangborg, Marchenko & Murashkin (2015) in research cycle during the winter season 2013 and 2014 using Geokon Earth Pressure cells, fiber optics and water pressure sensors (Sinitsyn, A. (2012) used 3D Scanner) made measurements on both the inside and outside of one of the open cofferdams supporting the quay. The systematic studies of ice impacts proposed by them are unique, but the complexity of the equipment will not allow the introduction of these methods for mass use. Автоматизированная система мониторинга, разрабатываемая нами, обладает большей универсальностью, поскольку выполнена на основе единого сенсора, также имеет преимущество за счет низкой стоимости конечного продукта. The automated monitoring system which is being developed by us is more versatile, because it is based on a single sensor. It also has the advantage of low cost of the final product.

In future articles we will discuss the details of use of the developed monitoring system of the quay walls state.

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