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Innovative Project of Propellers and Thrusters Jet Loads during Ship Berthing Monitoring System

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ABSTRACT: The growing number of large high powered vessels operated in shallow water ports is the reason that port authorities and terminal operators are interested in online monitoring of loads generated by vessels during manoeuvers close to hydrotechnical constructions. The test version of the loads measurement system based on the mobile laboratory and commercial version of monitoring system based on the cloud technology are presented in the paper.

1 INTRODUCTION

Safety of port manoeuvres of large self-manoeuvring vessels in confined areas of port docks is related to the available steering forces generated on the hull.

The powerful propulsion and steering devices produce high energy thrust streams which are beneficial for ship handling but at the same time can cause seabed scouring and damage of hydrotechnical constructions (Blaaauw et al., 1978; Blokland et al., 1996)). The assumed loads from vessels are included in requirements of civil engineering codes (BAW Code, 2010), guidelines (PIANC, 2015; Reccomendations of the Committee for Waterfront Structures Harbours and Waterways EAU, 2012, 2015) and modern safety based approach to design taking into account operation of the vessel and structure (Gerigk, 2015 a; Sntos et a., 2015; Taraszkiewicz et. al, 2015).

The problem of ship induced strong water currents is the most important in shallow water conditions (Skupień et al., 2014; Jachowski, 2008) and strong weather conditions close to the limits of port weather window.

To prevent the scouring and damage of seabed protection systems port authorities limit the use of power of main propulsion units up to 25% - 40% of the maximum power. In the operational practice the limits are mainly related to berthing and unberthing operations at the selected quay walls.

The power of bow thrusters of self-manoeuvring vessels in most cases is not limited in the operational guidelines for port constructions. They have smaller impact than main propellers however they can have a destructive influence. In Antwerp and Rotterdam the allowable design values are assumed less than 100 % of maximum available.

The design and operational requirement for ferries and ro-ro vessels is the ability of crabbing under lateral wind of 7 B. The widely used industry practice is to install bow and stern thrusters with power of 0.5 – 0.96 kW per square meter of the windage area. Therefore the power of the most widely used bow thrusters is usually in the range of 800 kW to 1500 kW. They are installed in different combinations of two or more devices, very often as twin bow thrusters of the same power and dimensions.

The large container ships which normally use tug boats assistance in narrow docks in many situations support the manoeuvres using their own bow thrusters and propellers. VLCS and ULCS (very large and ultra large container ships) with capacity 8000 - 21000 TEU (twenty-foot equivalent unit) with 300 to 400 m length overall are equipped with several units of 2000 kW - 3500 kW.

The power of auxiliary steering devices is growing. The largest bow thruster made for a cruise vessel has the power of 5500 kW (Wartsila, 2016). The highest velocities of bow thruster jets are in the range of 4 - 5 m/s.

The violation of permissible jet velocity limits results in the emergence of destructive loads. Their severity depends on the jet velocities and time of the impact. The extent of damage is related to the type of seabed protection (Lam et al., 2011; Nakamura et al., 2011).

The most susceptible to damage are the systems ensuring a soft bottom effect, made of geotextile mattresses – geotextile bags filled with sand and tied with each other on their edges with ropes. Even after a single violation of limits this construction should be inspected because the next violation of the allowed limits is usually followed by the destruction of much bigger area of the seabed protection. The immediate repair of a few damaged elements decreases the total maintenance costs.

The periodical inspections are carried out by 3D imaging and scanning, experienced divers or specially designed AUV (autonomous underwater vehicle) (Gerigk, 2015 b). The usual time between consecutive inspections of seabed protections is six months to one year therefore the main goal of the project presented in the paper is to solve the existed problem of loads monitoring in real time and warning the personnel responsible for berth operation about the exceedance of permissible loads.

2 INDIRECT METHOD OF MEASUREMENT OF THRUST STREAMS VELOCITIES OVER THE SEABED

The maximum velocity over the seabed can be calculated using German or Dutch method (PIANC 2015). These empirical methods are developed both for main propellers and thrusters.

In case of bow thruster induced loads the empirical formula (1) for the maximum velocity over the seabed in front of the quay wall recommended by German method is as follows:

$$U_{\text{max-seabed}} / U_0 = \alpha \cdot 1.9 \left(\frac{L}{D_p} \right)^{-1.0} \tag{1}$$

where: U_0 – is the efflux velocity at the bow thruster outlet opening, α - is the correction factor of a value between 0 and 1 for values L/Dp in the range between 3 and 8, and it is dependent on the ratio of distance L [m] (distance between the thruster opening and wall surface) to the bow thruster propeller diameter Dp and vertical distance z [m] between the propeller axis and seabed surface, in other cases α should be assumed as 1 (Fig.1) (PIANC, 2015).

The maximum flow velocity over the seabed calculated according to the Dutch method is given in the form of equation (2):

$$U_{\text{max-seabed}} / U_0 = 2.8 \left(\frac{z+L}{D_p} \right)^{-1.0} \tag{2}$$

Both German and Dutch methods are the complete design procedures. The formulas (1) and (2) should be used respectively to the chosen method. Both can give almost the same results for sea-going vessels when bow thrusters are situated about a ship breadth from the quay wall.

In the case of full bodied box-shaped hull forms in which the bow thruster tunnel outlets are situated close to the quay wall the velocities calculated by German method are about twice bigger than calculated by Dutch method.

The most widely used formula to calculate the efflux velocity is presented in equation (3).

$$U_0 = 1.15 \cdot \left(\frac{P_d}{\rho_w \cdot D_{BT}^2} \right)^{1/3} \tag{3}$$

where: P_d – is the bow thruster generated power [W], ρ_w - is the water density [kg/m3], D_{BT} - is the bow thruster propeller diameter [m].

The calculations allow determining the maximum seabed velocities and can be used as basic information when decisions of necessary monitoring are made.

The straight measurement of loads on the surface of a bottom protection cannot be done due to the possible damage of measuring instruments.

The idea of indirect method of measurement in case of thrusters is based on the previous investigations presented by Römisch (1975).

The kinetic energy of the bow thruster jet is converted into pressure on the quay wall (figure 1). The conversion of the kinetic energy of a thrust stream into the pressure takes place over 0.3 L distance from the wall surface. The maximum stagnation pressure on the wall is in front of bow thruster outlet opening where the jet velocity is equal to zero.

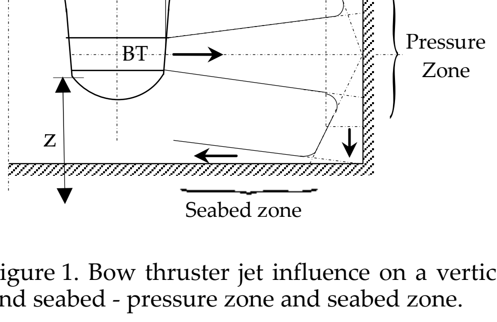

Figure 1. Bow thruster jet influence on a vertical tight wall and seabed - pressure zone and seabed zone.

The change of direction of the flow on the quay wall results with the free surface deformation and flow formation over the seabed. The decrease of flow velocity due to the change of flow direction along the wall to the seabed can be assumed as negligible (Römisch, 1975). The velocity over the seabed is equal to the velocity on the quay wall therefore the measurement of total pressure values on the quay wall and calculation of related velocities allows for the prediction of velocities in the seabed zone.

The prediction of flow velocities over the seabed generated by propellers is also based on the measurements of dynamic pressure on the berth wall. In this case the relationship between pressure on the quay wall and thrust stream velocity over the seabed is obtained from CFD simulation.

The relationship between the dynamic pressure values and flow velocity can be expressed by formula (3) giving the results close to Bernoulli equation with the percentage error less than 5% (Abramowicz-Gerigk et al., 2018).

$$p = 471.2 \cdot v^2 + 8.8 \cdot v \qquad (3)$$

where: p [Pa] – is the dynamic pressure, v [m/s] is the flow velocity.

The indirect method of measurements of bow thrusters wash over the seabed before it is implemented in the target online monitoring system has been tested using the measuring system operated from the mobile laboratory in the van car (Abramowicz-Gerigk et al., 2014; 2018).

The results of CFD modelling and measurements allow determining the proper parameters of the system, number and location of sensors on the quay wall.

3 ONLINE MONITORING OF THRUST STREAMS VELOCITIES OVER THE SEABED NEAR A QUAY WALL

The idea of the online monitoring system of thrust streams velocities over the seabed is presented in figure 2:

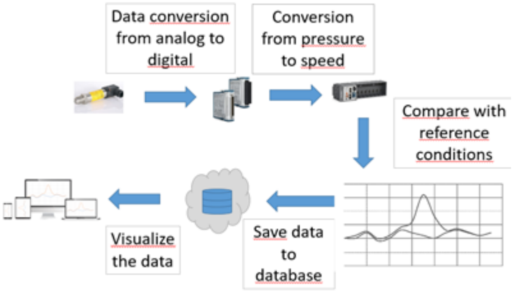

Figure 2. Online monitoring of thrust streams velocities over the seabed.

The data are collected from the sensors positioned on the quay wall and results of the initial calculations are sent over the internet, using the modem connected to the main unit, to the “cloud”, which is a collection of services (software and hardware).

Then the data is furtherly processed with usage of connected resources. It may consist of multiple physical servers, additional processors or other hardware parts. This allows scaling the resources depending on the number of installations or the amount of the data to process.

The target monitoring system should be tailor made. The basic design assumptions are the type of a quay wall construction and expected position of maximum loads generated by propellers and thrusters during operations performed by vessels.

The example of the measuring module of the system designed for the ferry terminal in Port of Gdynia for propellers loads monitoring is presented in figure 3.

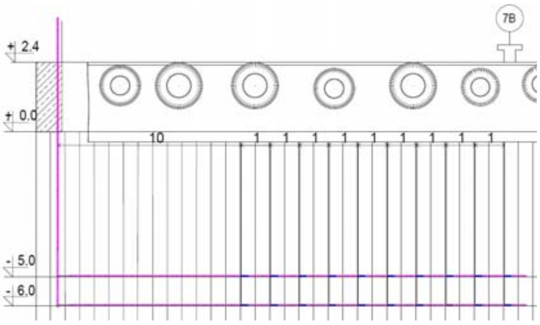

Figure 3. Position of pressure sensors on the quay wall in ferry terminal in Port of Gdynia.

The example in figure 3 presents the installation on the Larssen sheet piling type quay wall dedicated to measurements of propeller thrust streams in the exposed area near the terminal ramp.

4 DATA COLLECTION AND ANALYSIS

The process of data collection and analysis is presented in figure 4.

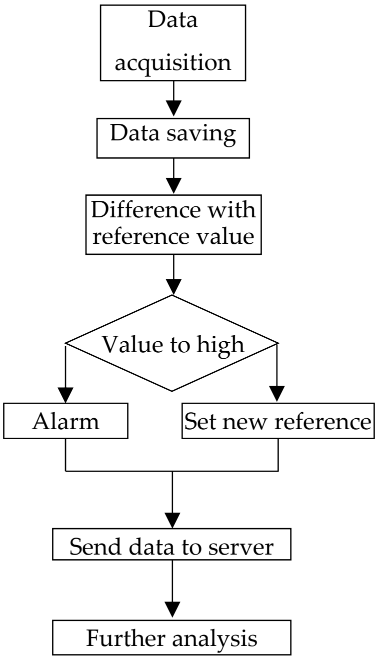

Figure 4. Process of data collection and analysis.

The main elements of the system are piezoresistive pressure sensors, providing basic data for further processing.

The analogue data collected as a total value of pressure acting on the sensor membrane is converted to a digital form with usage of the analog-to-digital converter. Information in this form can be further processed and compared with the mathematical model.

The results are stored in local database and sent with the GSM modem to main server. Then the data can be shown to the user with help of the internet application and HTTP protocol.

The data received from the measuring system is stored on a hard drive or multiple drives, which increases safety of the data.

When the connected resources (RAM, CPU, Hard drives) are not enough powerful, more processing power can be added to the system with minimal downtime.

The "cloud" solution simplifies further development of supplementary elements – data presentation on a website through scaling the number of virtual servers or allowing the access to the raw data for a specific user.

It is also possible to run servers in multiple physical locations to minimalize the time the user has to wait to view the data. The "cloud" solution allows decentralizing the storage and processing modules to minimalize the influence of one to another.

The reference pressure value for the system should be checked at least every 5 minutes, taking the measurements and comparing it with the maximum limit and previous reference measurement.

If the measured value is lower, it becomes the new reference. If it is higher the alarm is set on and the reference value is not changed.

Comparing the difference between measurement and the reference the damage of the quay will be detected if the limit is exceeded for the assumed time (e.g. 2 seconds) and it can be assumed as an average value of the measurement.

The system takes a measurement with 5 Hz frequency.

The measurement data consists of:

- pressure value,
- difference between taken pressure and the reference pressure value,
- state of the alarm.

An electronic diagram of the measuring system is presented in figure 5.

The measurement and reference value is saved with a proper timestamp.

The system should send the data to main server using the direct contact with database or FTP.

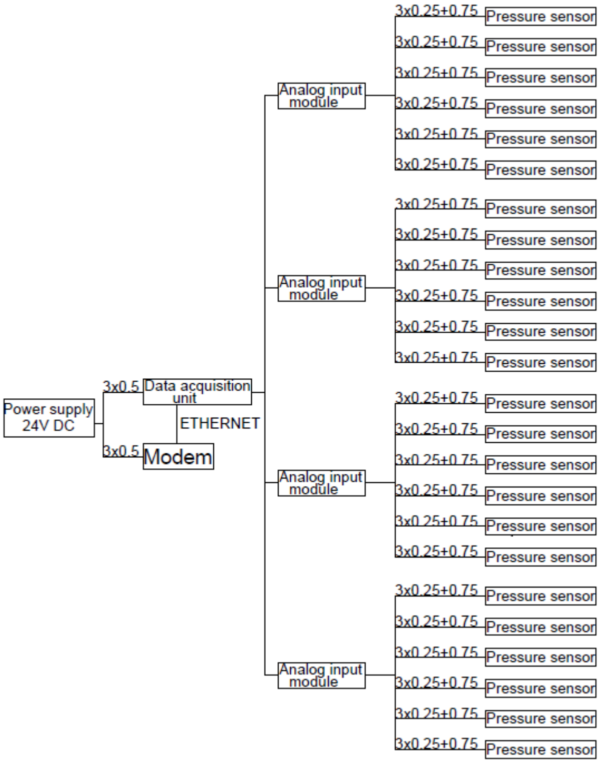

Figure 5. Electronic diagram of the measuring system.

The local data should be stored for the assumed time e.g. 7 days. 5 measurements x 60 seconds x 60 minutes x 24 hours x 7 days is 3024000 recordings. For 24 sensors and 4 bytes for single precision number it gives 290304000 bytes, ~280 MB for the measurements.

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The data that was sent to server can be used in further analysis – for example to determine how many times the alarm is set on in selected time range, the frequency of the measurements being too high or the time of the day in which most alarms are set on.

5 CONCLUSIONS

The presented system for monitoring loads induced by ships on the seabed close to the quay wall during berthing and unberthing manoeuvres is the solution of decreasing maintenance costs of terminals. It was initially dedicated to ferry terminals however the open system architecture allows to adapt it to different berths, ship types and special requirements of port authorities. The first conclusions from the real time monitoring carried out within the project are expected in July 2019.

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