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ACTIVE SEABED SCOUR PROTECTION RESEARCH

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ABSTRACT: The article presents the results of active shields carried out in a wave tunnel at the Institute of Hydraulic Engineering of the Polish Academy of Sciences. Qualitative results allow to state that active shields (1: 10 scale models) lead to: a reduction in the speed of bottom water jets, reduction of hydrodynamic pressure acting on the wall (behind the shield) and showed the ability to absorb the wave energy (called reduction of the reflectivity). This confirms (according to the author) the need for testing of susceptible engineering solutions (instead classic rigid ones), as it better adapts to the nature of vortices in gas and liquid flows. Up to now, in hydro-engineering, fascine mattresses have been used as solutions ensuring some kind of system susceptibility, but the solution proposed by author below, may combine their advantages and liquidate their drawbacks. The active scour protection was designed and patented by author.

Keywords: wind turbines, offshore structures, scour protection.

1. INTRODUCTION

In the immediate vicinity of hydro-engineering constructions located on the sandy seabed, there trim and bumps will occur which are named as seabed erosion or scour phenomenon. Uncontrolled erosion around the structure may result in the loss of stability, which in turn may lead to failure and / or construction disaster. In order to protect the building against erosion, preventive measures are applied. Most often, the construction foundation is encapsulated with stone overhead, i.e. a rigid construction body obtained from solid rock breaks (mostly stones). The use of stone overlay causes that the bottom erosion is formed at the end of the overhead structure and not in the vicinity of the foundation. Uncontrolled erosion processes at the end of the overhead can lead to loss of stability and consequent failure / construction disaster. In its intention, an innovative solution - the so-called active covers - they are to act as a stone bedrock, but do not cause erosion at the ends of the covers. Theoretically, active covers can cover the foundations of the structure directly for example: piles, gravitational foundations and system enclosing the port quays or indirectly: filling just the critical places in a classic stone coating, of an underwater threshold or wave breaker.

1.1. Seabed scour phenomenon

"Erosion and bumps are created near port breakwaters, breakwaters directing (a type of breakwaters built in estuaries of rivers or canals), heads of breakwaters, shore breakwaters with an uprated or sunken crown, underwater thresholds, shore bands, pipelines and supporting structures for offshore wind farms. It is estimated that the formation of uncontrolled trims is the most frequent reason for the occurrence of breakdowns and construction disasters. Even a small reduction in the geometry of the created trims and bumps is a desirable direction for the development of new technologies in water engineering." In the immediate vicinity of each structure located in the river, in the sea or in the zone of the surf, scour will be created. These internally shaped caverns arise because of an increase of speed of the local water flow in the immediate vicinity of the structure, whereby the grain of sand flows up and will be transported to an area where the water flow rate is lower than the critical value.

2. STRUCTURE OF TESTED SCOUR PROTECTIONS

Active covers consist of an EPDM membrane, filled with balls and water. The spherical elements move freely within the bag of the EPDM rubber membrane, flexibly and dynamically adjusting the shape of the bag to the current wave / current pressure field.

2.1. The laboratory tests

The aim of the research conducted in the IBW PAN wave channel, was to perform hydraulic measurements to determine the impact of active shields on erosion and reconstruction of the seabed in the vicinity of the pile's hydrotechnical structures and port quays. In case of vertical breakwater walls covered by the active shield, the wave reflectance value was measured. The models were made in 1:10 scale, ensuring proper reproduction of hydrodynamic conditions. The models were placed in a separate section of the wave channel together with a set of measuring devices, including: probe sets for determining free water surface elevation changes, ADV speedometer for spotting water velocity vector, a set of pressure sensors, and a specially designed device for mapping the changes bathymetry. The measurements carried out allowed to determine the impact of active shields on the reconstruction of the seabed around and under the tested structures and allowed to determine changes in hydrodynamic conditions caused by the presence of active shields.

2.2. Susceptibility in nature and human engineering

One can observe interesting solutions of nature and sometimes human engineering in the field of construction of given systems actively reacting to acoustic, aero and hydrodynamic excitations. For example:
- active wings tested in NASA (2015) allow for better adjustment of the wing geometry to changing flow conditions.
Owls wings are covered with very thick layer of fluffy and airtight feathers, thanks to which they perfectly suppress all turbulence and are

the quietest birds silently hunting at night. Their excellent volatile properties also result from relatively large wings compared to the small body, which allows them to soar at lower speeds.

- active sharks or dolphins skin layers allows them to adjust its geometry to the water vortices that are formed, leading to their extinction.

-The flies flying in the air, actually swim in it like in water (due to the ratio of their size and weight to air viscosity) using vortexes to balance their weight and repel them. We use the analogous phenomenon managing with vortexes by sailing a dinghy with one oar working on the eights trajectory (in polish, so-called "bączkowanie").

-So the same effects of pushing away from vortices (as opposed to combating them), we use while swimming in the pool. When the hands meet the increasing resistance of water from the vortex, the swimmer moves them gently into the adjacent clean area. In the course of speeding up by the swimmer, better effects are achieved by minimizing fast movements and loosening the body muscles that are not working (at the moment), because it allows you to increase the surface pushing the water, and also reduces the vortices excited by the flow around the rigid body.

3. DESCRIPTION OF SCALED MEASUREMENTS

The measurements were carried out for two research tasks:

• the influence of active covers on the reconstruction of the seabed in the vicinity of the pile construction,

• the influence of active shields on the reconstruction of the seabed in the vicinity of the vertical-water quay and the determination of the reflectance.

"Parameters of generated regular waves have been selected on the basis of natural conditions corresponding to medium and stormy wave conditions in the 1: 10 scale:

• Medium conditions, natural scale: water depth h = 4 m, wave height H = 1 m, wave period T = 3.2 s, wavelength L = 15 m;

• medium conditions, laboratory scale: water depth h = 0.4 m, wave height H = 0.1 m, wave period T = 1.0 s, wavelength L = 1.5 m;

• Storm conditions, natural scale: water depth h = 4 m, wave height H = 1.5 m, wave period T = 7.9 s, wavelength L = 47 m;

• Storm conditions, laboratory scale: water depth h = 0.4 m, wave height H = 0.15 m, wave period T = 2.5 s, wavelength L = 4.7 m."

Interestingly, when scaling, the "T" wave periods were not subject to linear scaling as was the case for other parameters: heights and wavelengths.

"One hour of waving in laboratory conditions corresponds to three hours of waving in natural conditions. Analogously, two hours of research in the Canal corresponds to about six hours of waving in natural conditions. The adopted periods are considered representative of hydrodynamic events in the southern Baltic.

The dimensions of the analyzed models of hydrotechnical structures were as follows:

• Pile construction

- natural conditions: pile diameter 1 m, rigid guard with base diameter 4 m and height 0, 5 m;
- laboratory conditions: pile diameter 0.1 m, rigid guard with base diameter 0.4 m and height 0.05 m;
- laboratory conditions: pile diameter 0.1 m, active cover with base diameter 0.4 m and height 0.05 m;

• Vertical-side quay

- natural conditions: water depth 4 m, simple vertical wall;
- laboratory conditions: water depth 0.4 m, simple vertical wall;
- natural conditions: active cover with rectangular triangle cross-section, height 6 m, base length 4 m.
- laboratory conditions: active cover with a rectangular triangle cross-section, height 0.6 m, base length 0.4 m.

Studies of bathymetric changes were carried out before and after the wave test in the foreground and behind the construction. Difficult testing of bathymetry (bottom profile) under covers due to deformations occurring during the lifting of the covers caused great difficulty. For this reason, they were made only for the conical shell of the pile. For the studies of bathymetric changes, the duration of the measurement series was set at 1 and 2 h.

For the transmission and reflection coefficient tests, the duration of the measurement series was 60 s for medium conditions and 150 s for storm conditions. Measurements of the components of the speed of motion of water particles were made using an ADV speedometer."

4. ACTIVE COVER INFLUENCE ON THE SEABED BEHAVIOUR AROUND THE PALE STRUCTURE

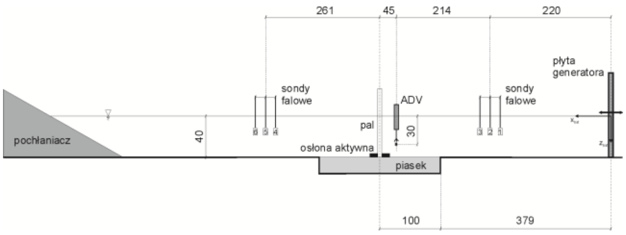

Fig.1 Scheme of the measurement stand with the spacing of measuring devices where the pile with the rigid and active shield was tested. During the research, the bottom of the tunnel had to be raised by the height of the sand box. Ultimately, in the future IBW PAN will try to suspend bathtub to the bottom from outside of the tunnel

„In the case of medium wave conditions (for both types of shields) there were no changes in bathymetry both in the area before and behind the pile cover. The changes were registered only in very close vicinity of the shields and under them. The results for the rigid sheath indicate the scouring around the perimeter of the sheath and slight erosion propagating to the core of the pile from the side of the wave. On the other hand, the results for the active cover indicate the bottom's accumulation around the circumference of the enclosure, in particular from the side of the wave.

In the case of storm conditions (for both types of shields) strong erosion was observed in the foreground and accumulation behind shields and more importantly, strong erosion was found under the rigid cover, which resulted in the cover falling by more than 1 cm". This means that during storm conditions, a wave height of 1.5 m caused at the bottom (at a depth of 4m) rinsing the sand around the perimeter of the cover and gradual displacement of sand from under the center of the sheath to its periphery.

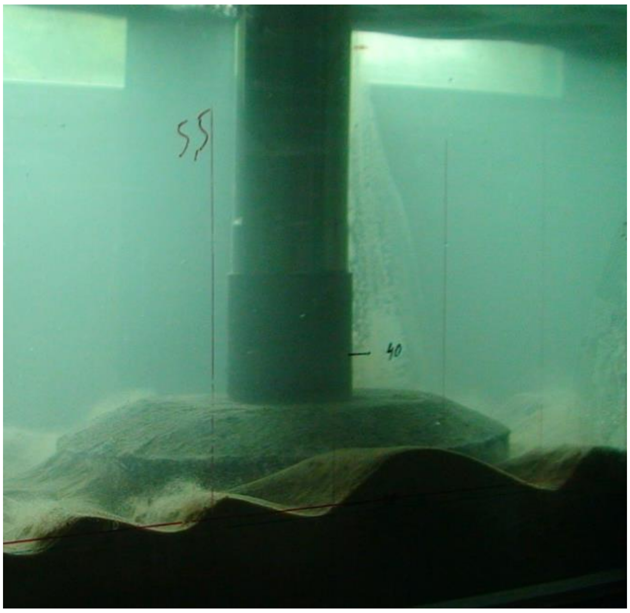

Fig. 2 Rigid pile guard placed on the sandy bottom in the wave channel. The concrete cone simulates, for example, the geometry of the rubble bed protection

The results for the active cover showed a limitation of the sludge leaching process to the formation of only small local depressions. And the observed phenomenon (as the report says) may be fluctuating or random. The real nature of the phenomenon could be confirmed by numerous research series.

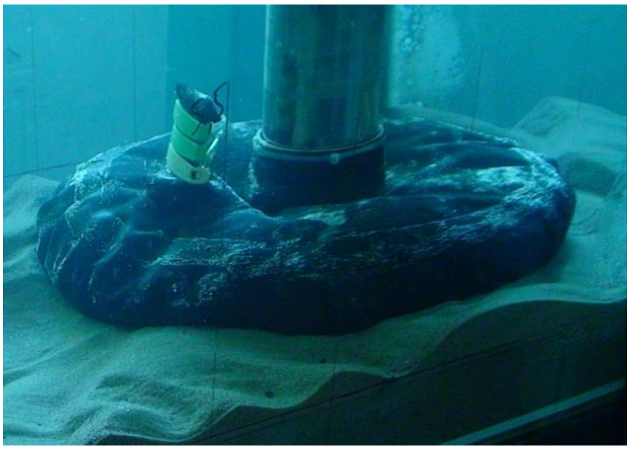

Fig. 3 The active pile guard is made of a 6 mm thick EPDM membrane. The crimped ball dispenser and the water inlet are visible. During the correct examination, the cover is filled with crutches and water under a slight overpressure. So that the shell retains the features of a resilient body absorbing the energy of small still not reinforced with hard surfaces of vortices

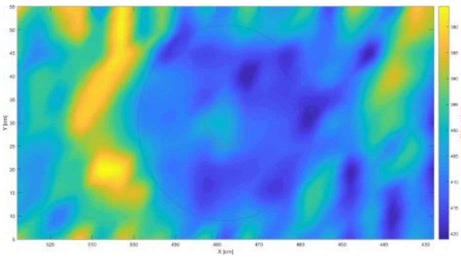

Fig. 4 Bathymetry in the vicinity of the pile with a rigid cover after a two-hour storm waving. Strong blackouts prove significant damage to the bottom under the concrete cover

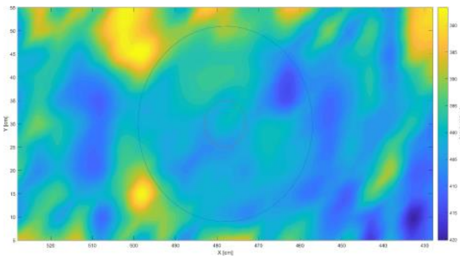

Fig. 5 Bathymetry in the vicinity of the pile with an active shield after a two-hour storm waving. Local bottom flushing was found, which appeared and disappeared at various places within two hours of the study

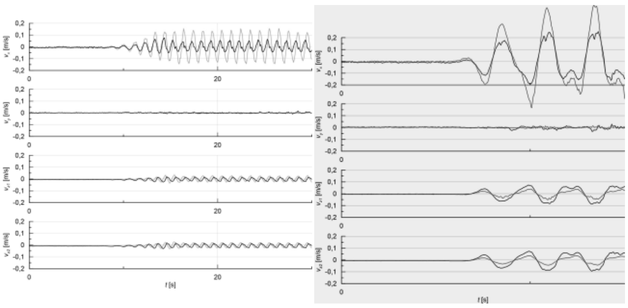

Fig. 6 Graph shows the changes in the components of the velocity vector of water molecules in time (0.05 m above the sandy bottom) for medium wave conditions with active cover around the pile. The lighter color presents analogous values for the rigid structure (vx - horizontal component parallel to the axis of the wave channel, vy - horizontal component perpendicular to the axis of the wave channel, vz1 / 2 - vertical component)

5. COEFFICIENT OF THE REFLECTION AND ACTIVE COVER INFLUENCE ON THE SEABED BEHAVIOUR AROUND THE VERTICAL WHARF

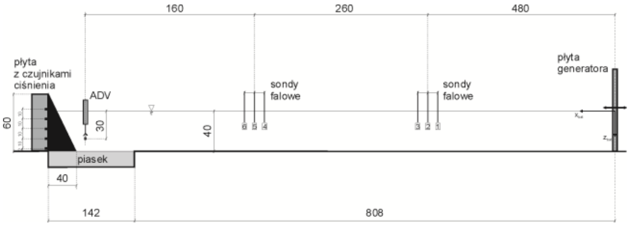

Fig. 7 Schematically presented measuring stand for the vertical-wall quay structure with an active shield. Between the cover and the wall, pressure sensors are visible. In the case of comparative tests, a vertical wall without a cover was tested

From the principles of hydromechanics (Refs 1, 2) it is known that the wave approaching to the waterfront vertical structure will be reflected, which in turn leads to interference of the incident and reflected waves. After a short time of established conditions, a standing wave is created. The wave amplitude and velocity of water particles may increase then even twice. The standing waves in their knots have horizontal movement of water molecules and in the peaks and valleys vertical. In intermediate areas, the movement of water particles has a transient direction (about 45°). "The indicator used to assess the quench suppression capability is the reflection coefficient, which is determined based on the height of the approach wave and the reflected wave.
Reflection coefficients for the wharf without and with active shielding, for medium wave conditions were KR = 0.76 and KR = 0.41, respectively ". This means that the sheath significantly improved the wave conditions for medium waves - reducing the reflection coefficient by nearly 50%. However, for storm waves (relatively long ones), the reduction of the reflected wave was, unfortunately, negligible. The reason for this behavior is most likely the small shield mobility generated during the reflection of the long wave. Such a wave is characterized by a relatively large distance between peaks and valleys (L=4.5m). Thus large distances between sucking and pushing actions, acting on the front wall of the vulnerable cover and stretched in time impact cannot excite a short (0.4 m) cover so that it effectively absorbs the the wave energy. Probably long formations (with a length l> 0.3L) of active shields will be excited.

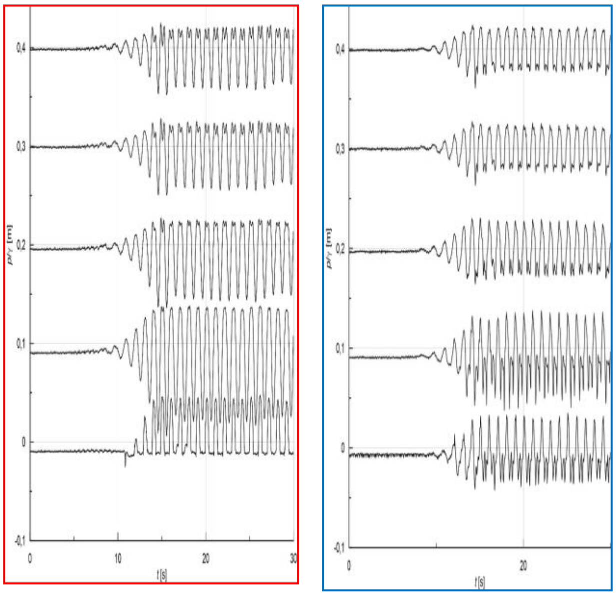

Fig.8. The diagrams show changes in hydrodynamic pressure for storm wave conditions (in meters of water column) for sensors located adequately from the bottom of the channel: 0.02 m (upper graph); 0.12 m; 0.22 m; 0.32 m; 0.42 m (bottom graph) To the left, the rigid cover chart, to the right the active shield.

"The hydrodynamic pressure measurements exerted on the wharf wall has confirmed also the positive influence of the active cover on the vertical wall.
For medium storm conditions, its reduction amounted to approx. 30% (for sensors installed under the water surface).
For storm wave conditions, a pressure reduction of approx. 20% was visible for the three lowest-lying sensors. In the case of the highest sensor, a vacuum generation for the wharf with an active shield was observed ".

6. CRITICAL COMMENTS FROM THE CONDUCTED STUDIES. RECOMMENDATIONS FOR FURTHER PROCEEDINGS

The research carried out in the IBW PAN wave channel made it possible to conduct qualitative observations of the analyzed phenomenon, as wave parameters were scaled according to the similarity of free-flow mirrors, with the dominant effect of the own weight, regulated by the Freund's number. The sediment transport difficult to calibrate was not scaled. "Due to the complexity of the process and the ambiguity of laboratory methods, quantitative studies of sediment transport in the IBW PAN wave channel would require a separate, advanced methodology of the work" and in particular the construction of models on such a scale that the prototype structures tested would be larger. "In the case of positive results of tests carried out in a large wave channel (which are missing in Poland), the next stage of research should be to conduct the observation of the functioning of active shields in nature".
According to the report in Poland, underwater submarine structures will be most commonly used in the coming years. The construction of an active cover type for this purpose may positively affect the effectiveness of sea coast protection (Ref. 3).
Analyzing the weaknesses of the tested solution, it was stated that "technical refinement requires determining the method of fixing the active cover to the seabed or to the structure.
The laboratory and technical refinement requires determining the strength of the sheathing of the active cover for wave shock. The use of rubber type plating requires tensile testing and fatigue testing of the material (UV, ice, frost resistance and mechanical damage) "etc..
In future studies, it is also worth taking into account the combined effect of wave and sea current on the work of the active cover.

7. ACKNOWLEDGEMENTS

In this type of atypical research, people who see the solution's potential and grant financial resources are extremely important. In the case of this project, the supporting unit from the "Incubator +" project was the Technology Transfer Center in the persons of Dr J. Firlej and J. Pietrzak.
Innovative research, far from classic solutions, requires research teams that are open to new and able to engage their knowledge and reputation in new areas. Luckily, such a team was built at the Institute of IBW PAS in Gdańsk and the report (photos and schemes) were prepared by: P. Szmytkiewicz, M. Paprota, B. Hedzielski, D. Majewski, J. Malicki, W. Sulisz. The text quoted from the report was enclosed in quotes.
Rubber covers were built by a talented specialist in the rubber modeling Mr. W. Włodarczyk.

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