9. WATER PRESSURE FLUCTUATION AROUND A SUBMERGED BREAKWATER

Lechoslaw G. BIERAWSKI¹ and Shiro MAENO²

¹ Doctoral Course Student, Graduated School of Natural Science and Technology, Okayama University, Okayama, Japan, lbier@cc.okayama-u.ac.jp
² Dr. of Eng., Assoc. Professor, Dept. of Environmental and Civil Eng., Okayama University, 700-8530 Tsushima-Naka, Okayama, Japan, ph. 0862518151, fax 0862518257, maeno@cc.okayama-u.ac.jp

A laboratory small-scale experiment is conducted in order to investigate the water pressure fluctuation in the wave field over a submerged rubble breakwater as well as in the sandy bed beneath it. The permeable and impermeable but flexible cases are considered. The water and pore water pressure fluctuation characteristics are clarified and the difference between these two distinct cases was described. The interaction between wave and the submerged breakwater is analyzed. As the main result of the study, the water exchange process is proved to be a crucial factor of wave propagation inside a highly permeable porous medium.

Keywords: permeable submerged breakwater, water pressure fluctuation, water exchange process

1 INTRODUCTION

Despite of the large number of studies to be done on the submerged breakwaters (e.g. Ahrens, (1987, 1989), van der Meer (1987, 1990) van der Meer and Piłarczyk (1990,1995), there are still many questions left to answer. The destructions still to happen and those indicated by H.Ouemaraci (1994) remind us about the imperfections constantly. In order to update the understanding of the ruination reasons and also searching for new design methods, we investigated the wave induced pore water pressure fluctuation inside the reef breakwater as well as the water pressure in its vicinity (over the slopes and inside the bed below the structure), respectively, to obtain a better understanding the phenomena and the interactions to take place at such structures. We assume that the water exchange process (the velocity fraction) between the porous structure and the wave field plays a significant role in the wave propagation inside the structure and the sandy bed. The comparison of the results from the permeable cases and the impermeable cases provides good verification for this expectation and confirms our assumption. Additionally the zones of the highest risk of devastation are identified and pointed out.

2 OUTLINE OF THE EXPERIMENT

The laboratory experiment was carried out in a wave tank of 1400 cm in length, and 60 cm in width. The tank was equipped in a computer controlled wave generator, and a sponge slope wave attenuator to reduce the wave reflection effects. However, to minimize potential interferences, several waves at the beginning of the experiment were taken into account. The examined model is shown in
The experimental model

Fig. 1. The examined model arrangement

Photo. 1 The experimental model

Fig. 2. The pressure gauge layout

Table. 1. Experimental case naming convention

<table>
<thead>
<tr>
<th>Overtopping</th>
<th>Permeable Case</th>
<th>Impermeable Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>the crest at SWL</td>
<td>Case 1P</td>
<td>Case 1I</td>
</tr>
<tr>
<td>Case 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>crest 15 cm below SWL</td>
<td>Case 2P</td>
<td>Case 2I</td>
</tr>
<tr>
<td>Case 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>crest 30 cm below SWL</td>
<td>Case 3P</td>
<td>Case 1I</td>
</tr>
<tr>
<td>Case 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1 and Photo 1. It consists of sandy bed: 300 cm long, and 40 cm high, and a breakwater. The breakwater has steep slopes 1:2. The structure crest is of 30 cm in height and 30 cm in length. It was made of small stones that the mean diameter was \( d_{50} = 15 \text{ mm} \) and the porosity coefficient \( n \approx 0.35 \). The structure was designed according to the procedure given by Van der Meer (1987), and Van der Meer and Pilarczyk (1995). The sandy bed was made of the highly saturated Toyoura sand. Its parameters are: the median diameter \( d_{50} = 0.25 \text{ mm} \), the specific gravity \( G_s = 2.65 \text{ g/cm}^3 \). The sand was put into the pit and vibrated to obtain the specific homogenous characteristic: the porosity coefficient \( n \approx 0.4 \) and the permeability coefficient \( k = 1.2 \times 10^{-2} \text{ cm/s} \). The height of the sandy bed is 40 cm.

The whole experiment consisted of six different cases: three of them for the permeable breakwater and the remaining three for the impermeable structure. As the impermeable membrane a single layer of soft plastic foil was applied in order to eliminate only the water exchange process between the structure and neither the sandy nor the wave field. It was placed at about three – four centimeters below the breakwater surface, covered by 2 – 3 layers of the stones to impose a load (against the uplift forces) and keep the surface rough. The membrane was fixed tightly at the bed level, but at the other edges tiny interstices were left to enable pressure compensation and the original structure elasticity. The dashed line in Fig. 1 indicates its arrangement. The impermeable structure was deaerated to maintain the characteristics of pressure propagation in the highly saturated rubble mound. By these means we obtained an impermeable but elastic structure with exactly the same roughness coefficient. The case naming convention is presented in Table 1. Both the impermeable and permeable cases (marked as “I” and “P” in the order mentioned) were examined in three different water depth conditions: with the crest at the still water level (1), with the crest 15 cm below the SWL (2), and with the crest 30 cm below the SWL (3) respectively. Combinations of the above numbers, in parentheses, and the letters together signify the particular experimental cases.
The model was equipped in 37 points that the fluctuation from the hydrostatic pressure was measured. Their outlay is provided in Fig.2. In Case 2 and 3 the water pressure was measured in the points marked from 1A to 8A, placed 1 cm over the breakwater surface, whilst in Case 1 at points 1A, 2A, 3A, 6A, 7A, and 8A. The difference comes from that, in Case 1, points 4A and 5A were located over the SWL, so the measuring was impossible. The pore water pressure was gauged in 29 points signed from ‘B’ to ‘G’. In the impermeable case, the pore water pressure was not measured in the ‘B’ points. We were not able to gauge in these points because they were covered by the impermeable membrane. Wave height was measured by two wave meters. One of them was located over the breakwater toe (over point 1a) and the other right behind the breakwater (over point 8a). The waves used during the experiment had the period of $T = 2$ s. Their height was set to the largest but not causing any significant destruction of the structure during experiment. Namely, at 30 cm depth (Case 1) it was about 6 cm, at 45 cm (Case 2) 9 cm, and at 60 cm (Case 3) 20 cm.

3 RESULTS AND DISCUSSION

As mentioned before, the experiment was conducted for six different cases. The results for all of them reveal similar general properties. For the sake of conciseness only the clearest examples will be presented and described in the text. The scope of the study was the pore water fluctuations around submerged breakwater. Therefore the wave field will not be discussed here much. The waves were breaking during passing over the breakwater crest in all cases. The highest wave is measured in point 3A over the seaward slope in Case 3P. The approaching waves become steep here to subsequently break down. In the other cases the largest water pressure fluctuations over the breakwater surface and inside the porous medium were in the area near to point 3A or point 4A which is located near the seaward edge of the breakwater crest. Fig.3 illustrates the statement well by comparison of the pore water fluctuations at the points located close to the breakwater surface. It is in full agreement to the statements by Hudson (1959) or van der Meer (1987) that the area of the highest risk of devastation is located around the crest, especially on the seaward side.

Fig.4 shows the pore pressure wave propagation in Case 1P, measured along Vertical 3 (at points 3A, 3B, 3C, 3E, and 3F). Point 3A was located in water so it is supposed to be closely related to the wave profile. The attenuation and the phase lag between point 3E and point 3F differs significantly from these between points 3B and 3C. It is because the pairs of points are in the sandy bed and inside the rubble mound respectively. The distinction is caused by the difference in the hydraulic permeability coefficients of the fine Toyoura sand and the stones of $d_{50} = 15$ mm to be expressed by the mean diameter and the porosity ratio.

In order to consider the significance of the structure permeability on the pressure fluctuation in the vicinity of the breakwater an impermeable membrane was inserted into the mound. The fluctuations at point 4A are almost the same, independently on the breakwater type (measured in Cases 2 and 3 only). A general distinction of the permeable from the impermeable case can be obtained by analyzing Fig.5 and Fig.6. The largest difference is noticeable at points 4C and 4D. In the impermeable case the
graphs of these points are almost the same. Neither the phase lag nor the wave attenuation is noticeable. All points surrounded by the impermeable membrane show very similar instantaneous pore pressure rates and in fact any phase lag between them cannot be distinguished clearly. It means that the stone framework filled with water wrapped together in “the sack” behaves like a uniform, solid unit. Additionally, the presence of the membrane has attenuating effect, because the fluctuations transmitted to the bed are considerably smaller comparing to the adequate permeable case. The energy coming from the water particle velocity is transferred to the stones, reflected or dissipated. Definitely, considering these example graphs it can be stated that the pressure fluctuations are transmitted by moving water particles throughout porous permeable media. Moreover, by preventing water exchange process we reduced the movement of water inside the closed area.

In figures from Fig.7 to Fig.17 the model cross-section with the pressure distributions for both the permeable and impermeable cases under: the rising state of the free surface, the wave crest, the lowering state of the free surface, and the wave through are shown in the order mentioned. The unity of the points surrounded by the membrane is here very pronounced. Relatively large distances between the measuring points decrease the graphs reality. It is easy to notice especially in the impermeable case. The structure disable water from going through it, still it is flexible, so some variation in pore water pressure was noticeable there. The membrane as a barrier is supposed to transfer the energy of moving water particles and in result to rapidly change the pore pressure. During the experiment, in the impermeable cases, the crest was being totally destroyed. Fig.14 provides a visualization of the phenomenon. The large pressure gradient, between the point in water and the pressure inside the breakwater, was the cause of the crest devastation. The stones were moved by the waves and sliding down over the membrane. Here the foil was also an artificial shear line. However in these graphs the change is not shown, because it spreads on a quite a distance – between two adjacent measuring points. In future experiments the measuring point densification will be taken into account as crucial for the result reliability. It is pronounced that in the sandy bed in the permeable case the pore pressure gradients are always not very far from horizontal. In the other cases the gradient becomes vertical under the wave crest and trough. The interaction between the structures and the sandy bed differed much. It is quite pronounced in Fig.12. The area below the rubble mound toe, inside the circle, is the second place of a high hazard to the structure. The pore pressure gradient oriented upward can be a reason for sandy bed scouring from the vicinity of the toe and subsequently for the mound collapse. In the permeable case, Fig.11, the change of the pressure takes place on larger distance which is to say that the gradients are lesser. In these view the permeable structure is safer.
4 CONCLUSIONS

The pore pressure fluctuations, inside a reef breakwater and over its surface as well as in the sandy bed below it were investigated experimentally. The main conclusion of the present study is that the water exchange process is substantial for the phenomena taking place inside a rubble structure under wave attacks. Elimination of the flow through the breakwater using the membrane significantly changes the pore pressure distribution, what should be understood as a huge difference in the wave propagation inside it as well as in the sandy bed beneath it. The original structure seems to be safer than the one equipped in the impermeable layer. Therefore changes in permeability characteristics of structures caused by plugging the pores for example by sand particles might by a cause for the offshore toe scouring.

Any of the following phenomena occurred inside the impermeable structure: neither the phase lag nor the wave attenuation. It means that the lack of the water particles movement, relative to the solid grains, is responsible for the phenomena. The impermeable structure not only protected the sandy bed located below it from large pore pressure gradients caused by passing waves but also attenuated the wave to transmit to the bottom. However an area of large gradients appeared right below the offshore toe. Moreover, the crest of the rubble mound was destroyed. The wave propagation characteristics were different for the permeable mound and for the sandy bed, what indicates the dependency on the water conductivity properties of the material. In this experiment, the influence of the breakwater permeability on the wave attenuation seems to be minor. Only the ability to reflect the approaching waves varied, especially for the case of the largest relative height. The significance of any changes in breakwater characteristics becomes larger with the freeboard ratio becoming close to zero.

In the present paper the significant role of the water exchange process in the pressure propagation inside a porous media was clarified. To get full view on the effect of the water exchange process at submerged breakwaters the studies should be continued to include its influence on the wave field.

REFERENCES