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Abstract - **A key element of simulating wave behaviour around man-made structures, e.g. piers or harbour walls is to understand the likely dominance of reflection or diffraction effects. Related to this is the selection of an appropriate reflection/absorption coefficient. There is little information in the literature regarding the values of reflection coefficients in piled structures and little published research work in the last decade specifically relating to the reflection/absorption coefficient. In this work, several sensitivity tests were conducted to better understand the behaviour of the ARTEMIS model and its response to different structures and the imposed reflection coefficient, to infer the most appropriate reflection coefficient to be used in piled structures. A theoretical arbitrary domain (200 m x 100 m) has been used to carry out a series of tests which consider various scenarios, including different types of structures: 1 wall (100m long); 2 walls (40m long and 20m spaced); 2 walls with a larger gap between them (30m long and 40m spaced); 3 walls (20m long and 20m spaced); 1 row of 21 piles (1m in diameter and 5m spaced); 1 row of 11 larger piles (2m in diameter and 10m spaced); 4 rows of 21 piles (1m in diameter and 5m spaced). For the wall simulations the chosen reflection coefficient was 0.85, and for the piles, reflection coefficients of 0.65, 0.95 and 1.0 have also been used. The transmission of wave energy was analysed for each case.**

Results from the various test cases show how a system dominated by reflection (walls) gradually becomes more dominated by diffraction (piles). Qualitatively, the piles show little reflection effects and patterns of energy distribution are relatively insensitive to the reflection coefficient. From a quantitative analysis and taking into account the few experimental observations available in literature, a reflection coefficient between 0.95 and 1.0 should be appropriate for piled structures where the pile spacing is about 5 times the diameter.

I. Introduction

A key task in simulating wave behaviour around man-made structures is determining the appropriate reflection/ absorption coefficients to apply. Walls reflect most wave energy whilst wave behaviour around piled piers is quite different, and an appropriate reflection/absorption coefficient is needed in the transition zone between the two effects. There is little information in the literature regarding values of reflection coefficients in piled structures and minimal published research work in the last decade specifically relating to the reflection/absorption coefficient. We aim to examine the sensitivity of the coefficient in the transition between reflection and diffraction.

The value used for the reflection coefficient is a critical parameter in ARTEMIS modelling, i.e. the ability of a solid boundary to reflect wave energy. This coefficient can be set in the model between a value of one (perfect reflector – no absorption of wave energy) and a value of zero where all energy is absorbed at the solid boundary [1]; each structure is considered as a boundary. Theoretically, the effect of using a reflection coefficient of 1 for a solid boundary (no absorption of energy) means that no attenuation of waves occurs as they pass through that boundary. A reflection coefficient near 0 has the opposite effect, and each contact of waves with the boundary absorbs energy such that after propagating through several solid boundaries almost all the wave energy was absorbed. In this work, several sensitivity tests were conducted to better understand the behaviour of the ARTEMIS model and its response to different types of structures and the imposed reflection coefficient. This helps addressing questions such as when does diffraction from a structure dominate over reflection.

Research carried out at the Field Research Facility (FRF) at the US Army Corp of Engineers, Duck, North Carolina, during the last decade, shows some of the difficulties in determining the correct values for reflection, or absorption, of wave energy by piled structures. The facility at Duck includes a shore-normal jetty which extends from the shoreline, for 561m into water with depth of ~6m. The jetty features two lines of support piles and the pile diameter is 0.85m. The FRF facility has hosted much coastal research during the last 20 years and provides comprehensive datasets of waves being attenuated by the jetty structure. [2] used FRF data to compare the performance of two wave models (CGWave and SWAN) under storm conditions. Both models are less complex than ARTEMIS, although as a phase resolving model CGWave is closest to ARTEMIS and bases mesh density on wavelength (minimum 10 nodes per wavelength), whereas SWAN, a spectral energy model, is closest in type to TOMAWAC and uses an orthogonal, 8m grid based on bathymetry. A feature of the FRF Jetty is a distinct bathymetric "low" under the structure and whilst design details are not known, would suggest significant local erosion (scour) has occurred due to turbulence generated by the piles emerging from the seabed. Due to the specific working of each model (CGWave includes a reflection/diffraction effect but SWAN does not), direct comparison of the mechanisms leading to wave attenuation was not possible. [2] concludes that the pier piles had little effect to block propagating waves and that the effects seen on the wave field were due to the bathymetric "trench" under the jetty. Work performed by [3] presents transmission coefficients for closely spaced lines of piles. Even when the gap is 0.2 times the pile diameter, their results show a transmission coefficient (ratio of transmitted to incident wave height) of 80% or more. Flume tests carried out by [4] on a 4 x 4 array of piles with spacing 2 times the pile diameter gave transmission coefficients of 90-95%.

II. METHOD

In order to better understand the behaviour of the ARTEMIS model and address the issues of wave reflection compared to diffraction, a series of theoretical tests were conducted, which included response to reflection coefficient. The ARTEMIS model aims to simulate, reflection, diffraction, refraction and wave-wave interactions. A theoretical arbitrary domain (200m x 100m) has been used, with a flat bathymetry-eliminating refraction effects- (-5m in all the domain). Monodirectional random waves with a peak period of 6s, wave direction of 180° and incident wave height of 0.5m have been applied at the southern boundary; waves are able to freely leave the domain. Bed friction is constant across the domain, using the formulation of Putnam and Johnson. These conditions, using the intermediate depth wave formulation, correspond to a wavelength of 38m. The incident wave energy for these scenarios was 306.5J/m^2.

Various scenarios have been considered in the domain, including different structures: 1 wall (100m long); 2 walls (40m long and 20m spaced); 2 walls with a larger gap between them (30m long and 40m spaced); 3 walls (20m long and 20m spaced); 1 row of 21 piles (1m in diameter and 5m spaced); 1 row of 11 larger piles (2m in diameter and 10m spaced); 4 rows of 21 piles (1m in diameter and 5m spaced). A reflection coefficient of 0.85 was selected for the wall cases, although for the scenarios with the piles, the reflection coefficients of 0.65, 0.95 and 1.0 have also been considered (a sub set are shown here).

III. RESULTS

Fig. 1 presents the wave energy for a solid wall, using a reflection coefficient of 0.85. It shows how reflected waves interact with the oncoming waves travelling in different directions, combining their energy and forming interference patterns. This results in regions where increases occur in wave height where the waves combine, alternating with regions of decreased wave height where they cancel out (standing waves). At the end of the wall is a region of diffraction with increased energy at the edge.

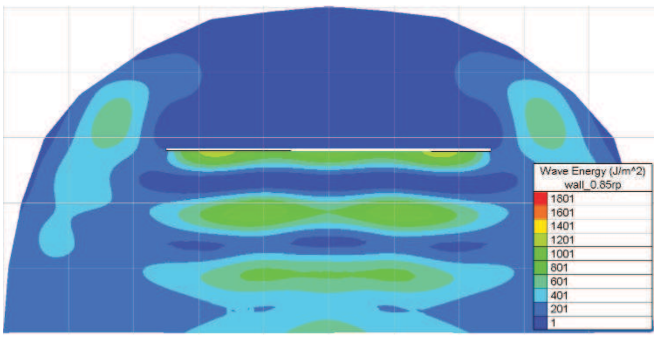

Figure 1. *Wave Energy: Solid wall case; reflection coefficient 0.85. Incident wave from South.*

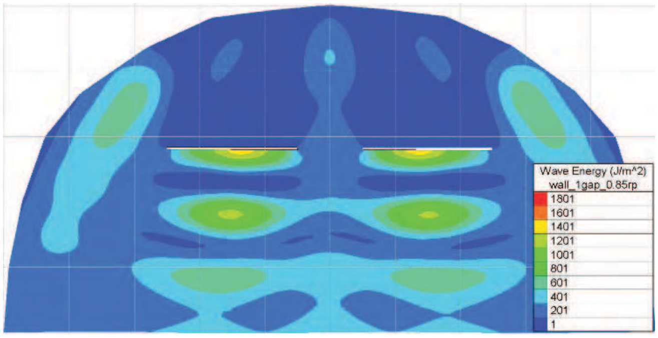

Figure 2. *Wave Energy: 2 Walls 40m long and 20m gap. Reflection coefficient 0.85.*

The wave energy for the scenario using 2 walls is represented in Fig. 2, where the standing waves are still evident in front of the walls, but to a reduced extent. There is some limited passage of energy through the gap between the walls. In Fig. 3, for the three wall simulation, a significant increase in wave energy is observed directly in front of the walls. Away from the walls, the maximum energy is aligned with the gaps. There is greater energy propagating behind the wall with diffracted waves interacting to produce zones of high energy. Fig. 4 shows the wave height and direction associated with the single wall; limited diffraction can be seen around the edges of the wall. In the three wall case (Fig. 5) diffraction is greater and leads to wave-wave interaction increasing wave height behind the walls. In all of these cases, the reflected waves have increased in energy in front of the structure.

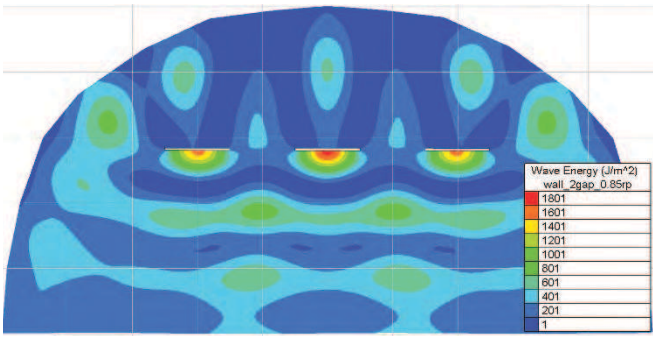

Figure 3. *Wave Energy: 3 Walls 20m long and 20m gap. Reflection coefficient 0.85.*

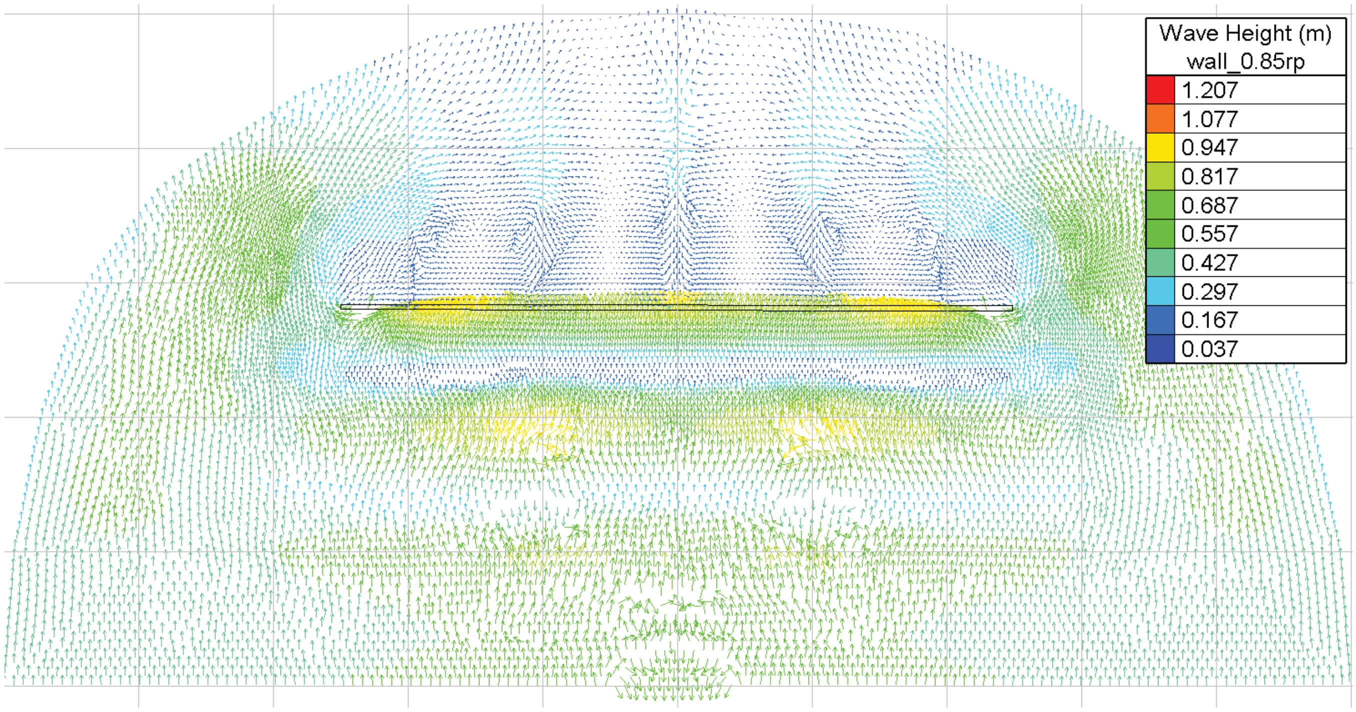

Figure 4. *Wave Height (colour scale) and direction arrows for single wall. Reflection coefficient 0.85.*

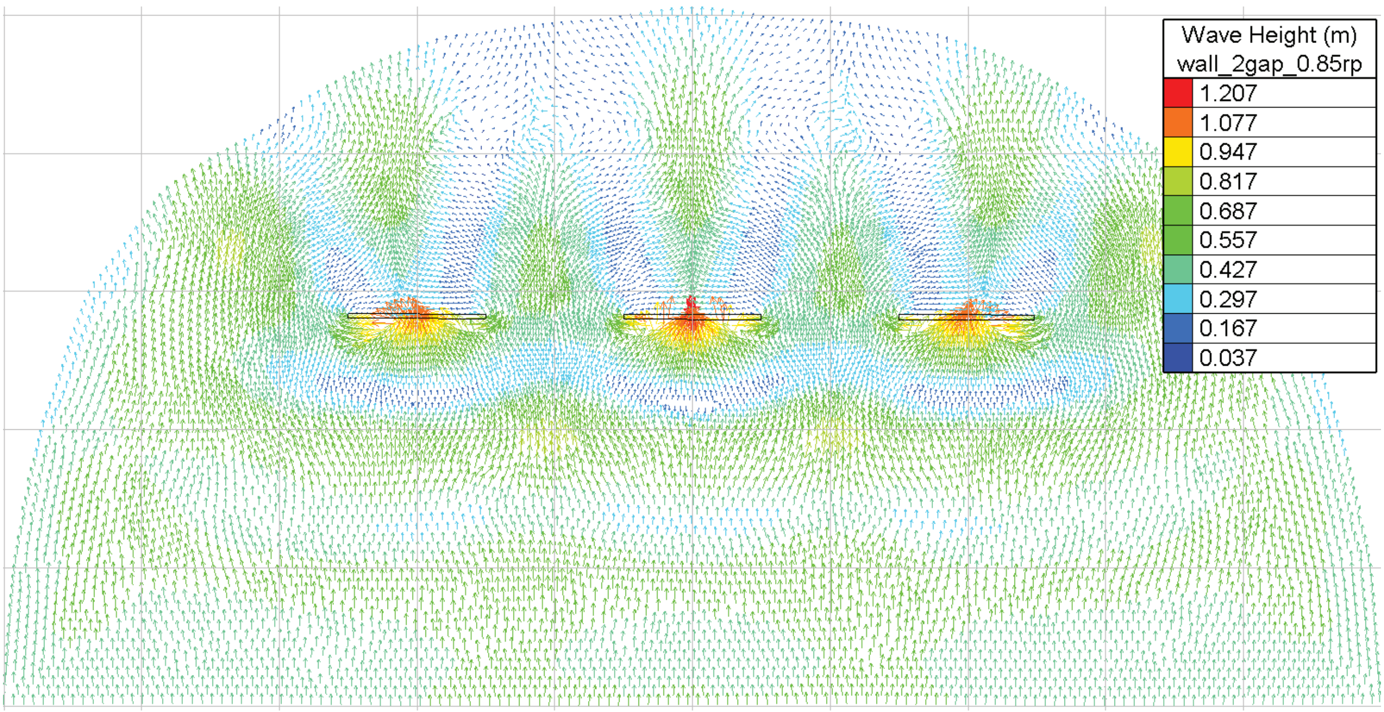

Figure 5. *Wave Height (colour scale) and direction arrows for three 20m walls spaced 20m. Reflection coefficient 0.85.*

Considering densely piled structures, Fig. 6 shows the effect of a single row of piles, while Fig. 7 presents the effect of the multiple layers of piles. The effects of reflection are almost unnoticeable; there is an increase in wave height behind the structure where diffracted waves interact with decreased wave height at the edge of the piles. There is little difference between the 1 row or 4 row simulations. In the transition from the walls (Fig. 5) to the piles configuration (Fig. 6), it is possible to see a substantially lower impact of the piles on the wave height either in front of the piles or behind them.

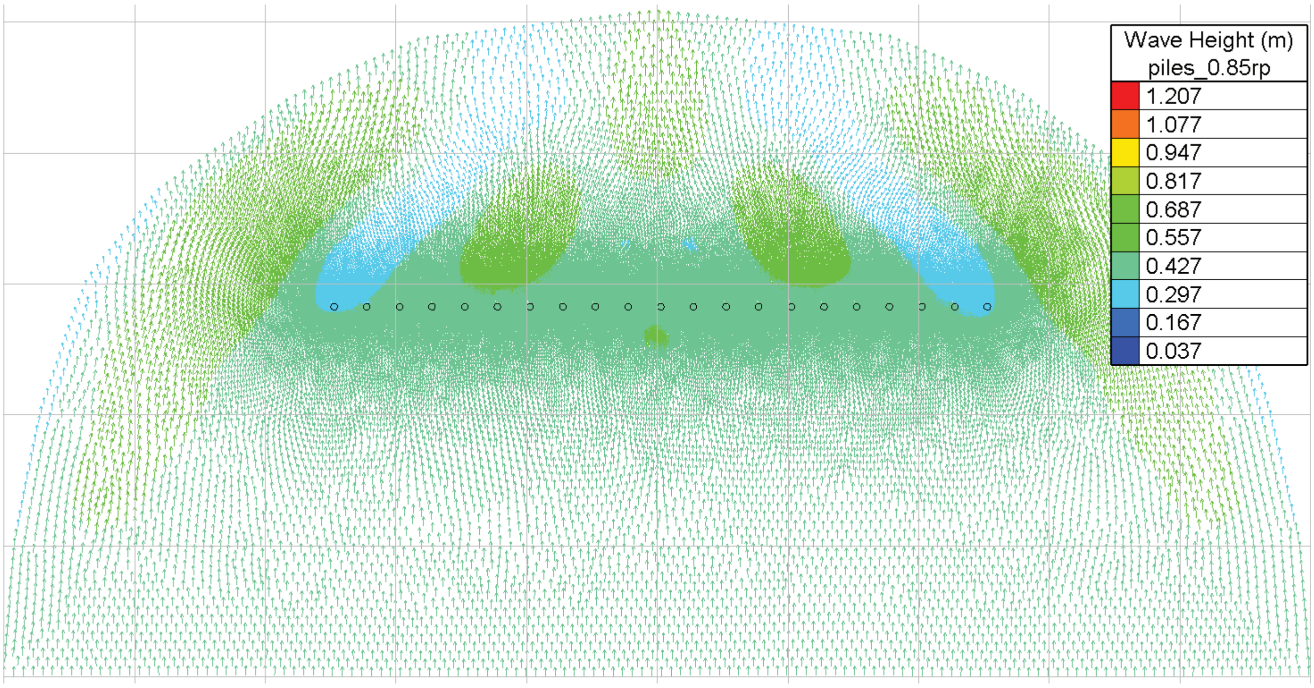

Figure 6. *Wave Height (colour scale) and direction arrows for a piled structure of 1 row of 1m diameter piles with 5m spaces. Reflection coefficient 0.85.*

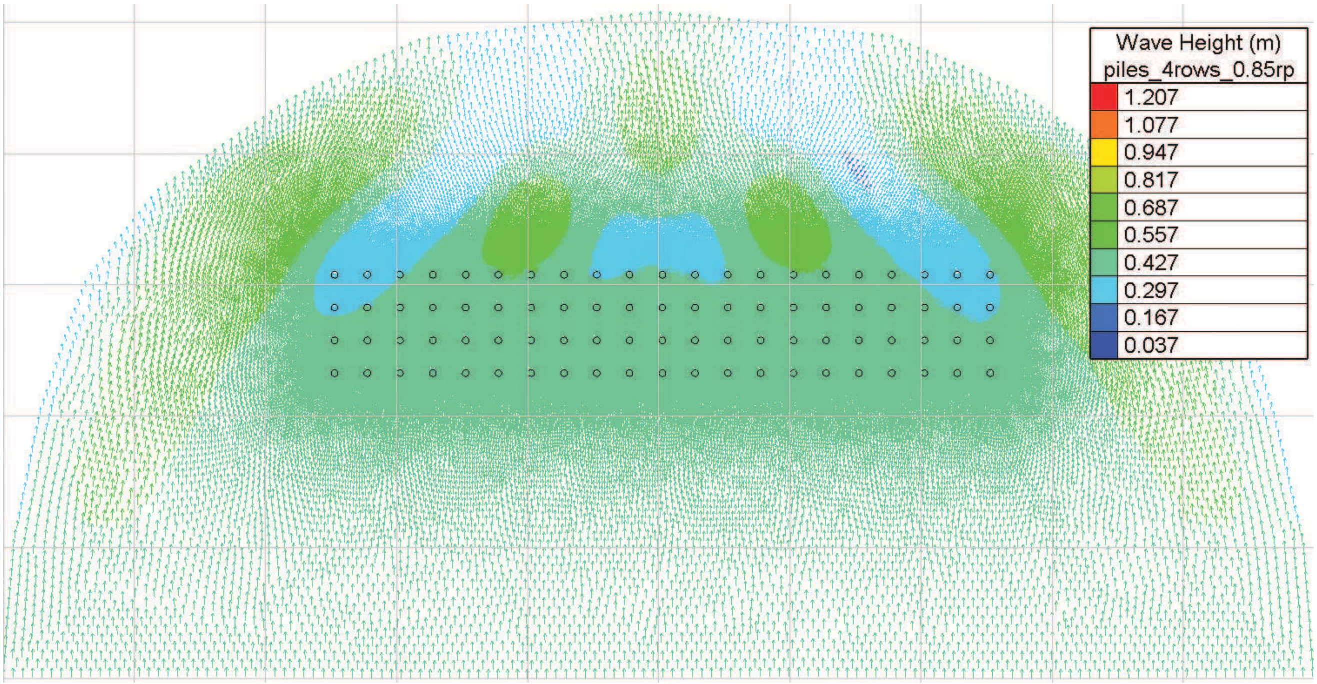

Figure 7. *Wave Height (colour scale) and direction arrows for densely piled structures of 4 rows 1m diameter piles with 5m spaces. Reflection coefficient 0.85.*

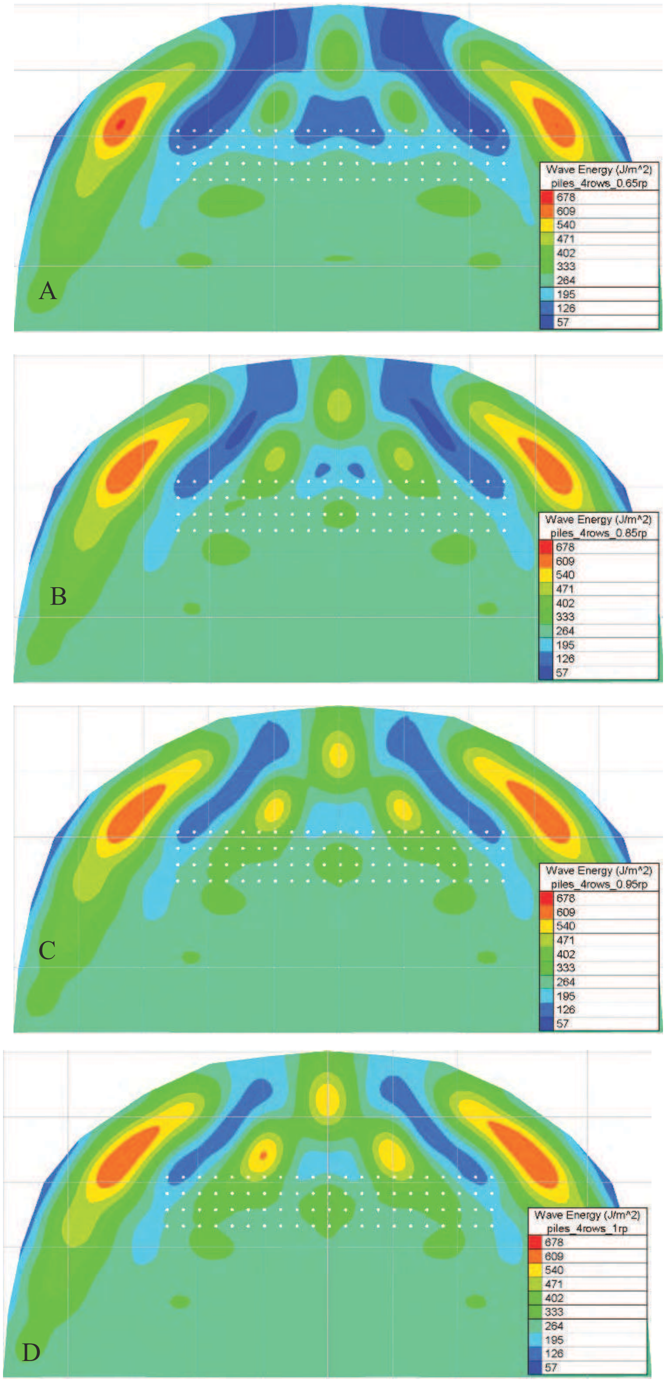

Figure 8. *Wave Energy from simulations on four rows of piles, for different reflection coefficients: A) 0.65, B) 0.85, C) 0.95, D) 1.0 (a perfect reflector).*

Fig. 8 presents the wave energy for the simulations using 4 rows of piles. The effect of changing the reflection coefficient, from 0.65 (A) to a perfect reflector (D), is shown in this figure. Evident is the relatively little difference between the scenarios, in qualitative terms, presenting similar patterns. Some of those external patterns might be related to boundary effects. Either side of the piles are zones of increased wave energy, and behind the piles (North) are zones of decreased energy. The exact amount of reduction does vary between each scenario (see the quantitative analysis in Table 1). At the scale presented, there is little difference between the scenarios in the wave energy in front of the piles.

With a reflection coefficient of 1.0 it is actually expected some evidence of waves reflected from the piles, leading to increases in wave energy on the incident side and a small reduction in wave energy transmitted.

Table 1 presents the maximum percentage decrease in wave energy behind the obstacle (considering the piles scenarios with 1 row and with 4 rows), for the various reflection coefficients investigated. Some of those percentages are referred to a small localized region. As expected, when increasing the reflection coefficient, the effect of the piles is less pronounced.

TABLE 1 PERCENTAGE DECREASE IN WAVE ENERGY BEHIND THE PILE ROWS FOR DIFFERENT REFLECTION COEFFICIENTS

Reflection coefficient	% decrease	
	piles_1row	piles_4rows
0.65	63.1	81.4
0.85	56.6	66.4
0.95	53.6	56.9
1	52.7	52.0

IV. SUMMARY

In this work, the response of Artemis model to structures with different geometry and by imposing a range of reflection coefficients has been investigated. The physical structures considered in the study were walls and piles, configured in different ways, and the reflection coefficients were 0.65, 0.85, 0.95 and 1.0. The simulations demonstrate the progression from a system dominated by reflection (i.e. walls) to that where diffraction is the dominant aspect (i.e. piles) and when reflection itself is of relatively low importance. As the solid structure becomes smaller, the effect of reflection become less significant and diffraction becomes the dominant effect. As a consequence, the wave transformation imposed by the structure takes place differently, resulting in piles having a smaller impact. Although a qualitative analysis shows small changes in the wave energy patterns, a quantitative assessment presents localized differences in the maximum percentage decrease in wave energy behind the piles, for the various reflection coefficients. Based on these numerical results and considering the few experimental observations available in literature, a reflection coefficient between 0.95 and 1.0 should be appropriate for piled structures with a pile spacing about 5 times the diameter, representing near perfect reflection. As a result, high transmission of wave energy will take place and the piles have little effect on the transmission of the waves through the structure.

ACKNOWLEDGEMENT

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