PHYSICAL AND NUMERICAL MODELLING OF WAVE FIELD IN FRONT OF THE CONTAINER TERMINAL PEAR - PORT OF RIJEKA (ADRIATIC SEA)

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1. Introduction

The results of the performed research of wave characteristics in front of the Rijeka Port, after the planned execution of the Container Terminal Pier, are presented.

For further development and increase of the container traffic in Rijeka Port – Croatia (Fig. 1) it is necessary to create new operational areas. Marine construction works for Container Terminal Pier extends approximately 720 m in length along the coast line, having maximum breadth of approximately 180 m. Deck structure was designed as a monolith concrete plate, having sea-front crown at +4.05 masl. Supporting structure consisted of concrete caissons designed and arranged in number of rows (along the coastline) and columns (perpendicular to the coastline) to maintain structural integrity of the construction. In between caisson rows and columns, armor slope was designed to dissipate incident wave energy (Fig. 1).

The previously made wind-wave climate study for the deepwater area in front of the Container Terminal Pier resulted in the adoption of critical directions of waves with related spectral wave characteristics (Fig. 1). These deepwater wave spectra were used for boundary conditions in the physical and numerical models.

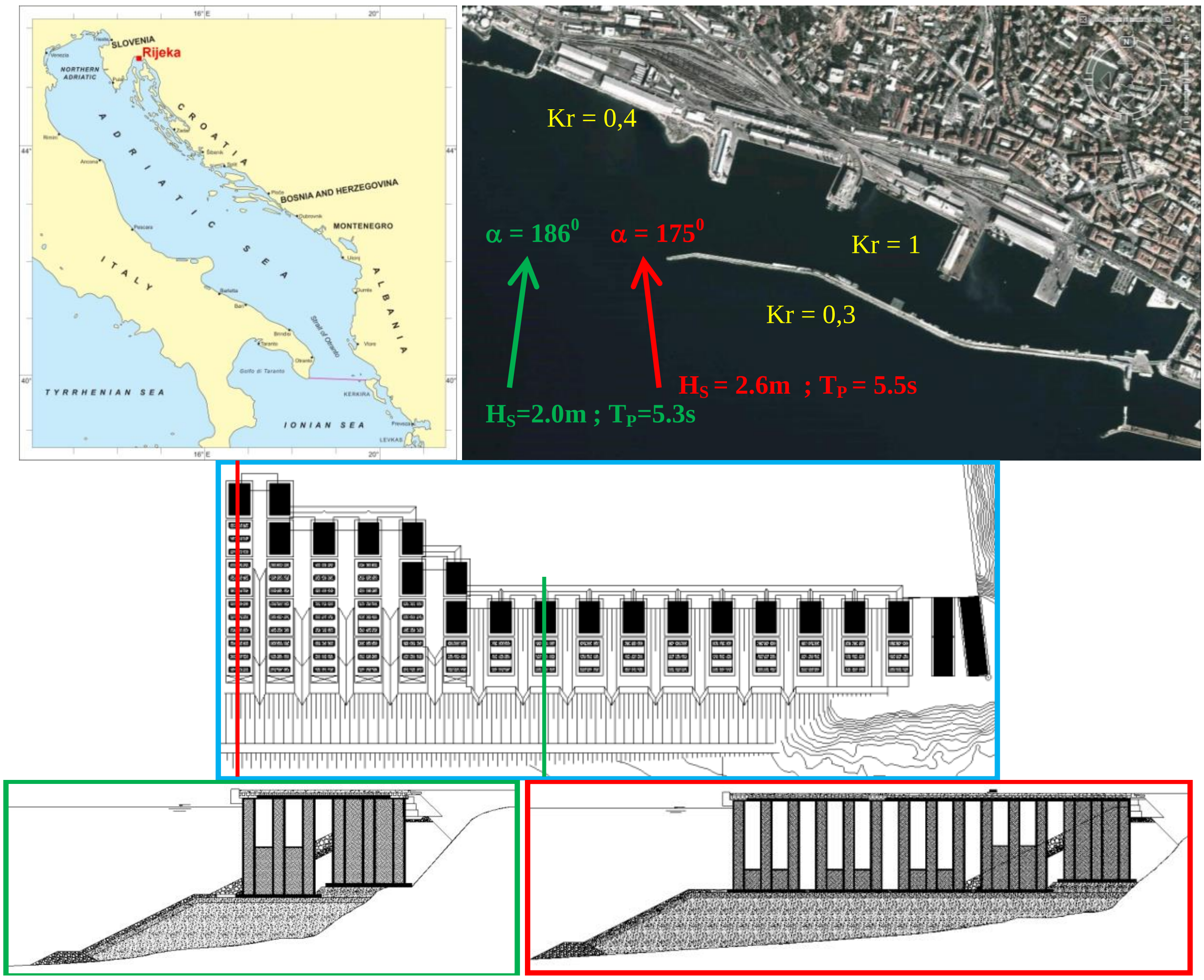

Figure 1. Map of the Adriatic sea (above left), wave climate in front of planed construction works (above right), plane (below left) and cross section (below right) of planed caisson construction

2. Methods

The research was done using numerical and physical modelling. Physical model (Figure 2) is built on the Froude's similarity criterion with the length scale 1:35. The tests are conducted in the basin facility equipped with the wave generator of the piston type (computer controlled, 6 m in length). Physical model includes geometry consisting of three longer pier structure columns (having five caisson rows) placed next to four shorter pier structure columns (having two caisson rows) without transition caisson columns (Fig. 2). The model is built out of waterproof plywood with deck partially modeled out of the transparent material.

Incident wave field was measured by two capacitive wave gauges (G01 and G02, Fig. 2). Wave field in front of the structure was measured by eight capacitive wave gauges, situated at the positions of the tunnels between caissons (G1, G3, G5, G7, Fig. 2) and in front of caissons (G2, G4, G6, G8, Fig. 2)

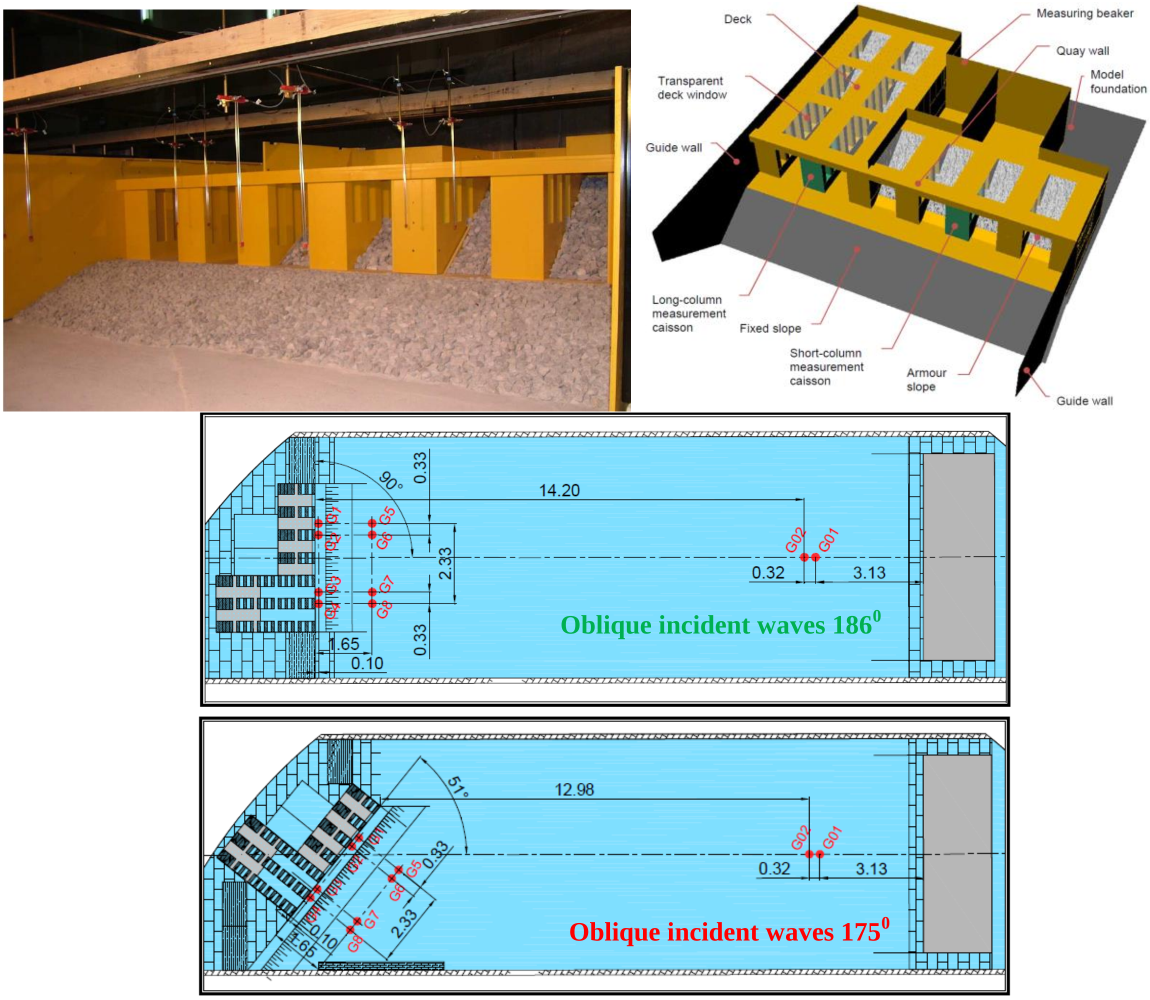

Figure 2. Physical model and recording equipment set-up within the testing basin

Reflection-transmission-dissipation properties of the caisson structure needed to be reproduced as faithfully as possible within numerical modelling of the wave deformation. Therefore, in the first step of the numerical analysis, numerical channel was modelled with the coverage and disposition of the same caisson structure section as in the physical model channel (Fig. 3). The values of the relevant parameters of the numerical model were varied until a satisfactory degree of similarity between the significant wave heights obtained by the physical and the numerical model was achieved. Following step refers to the numerical analysis of the wave deformation in a wider area of the Rijeka Port (Fig. 1), applying the same model parameterization.

The numerical model based on solving the Bousinesq equation in the time domain was used (DHI, 2013). Numerical channel was modelled that corresponds to the dimensions of the channel used in physical modelling, only in the full scale (Fig. 3). In the numerical channel the constant depth of d = 10 m was used. The condition of numerical stability determines the relation between the maximum allowable depth d_{max} and the adopted length of the shortest wave component L_{min} of the model spectrum (d_{max}/L_{min} = max 0.5). Accordingly, by taking that d = 10 m, it was possible to have model interpretation of the wave spectrum for wave components longer than L = 20 m, i.e. for the wave components with the periods longer than T_{min} = 3.58 s. An equidistant spatial grid of numerical nodes with an increment $\Delta x = \Delta y = 1$ m was used.

Description of the desired degree of reflection and/or dissipation of the wave energy in the spatial domain of the numerical model is achieved by using porosity layers with calibrated numerical coefficients (Fig. 3). The principal variables that were varied in the calibration procedure are porosity coefficient, coefficients of laminar and turbulent resistance, and the diameter of the solid particle of the porosity filling (Madsen, 1983).

On the wave generation line in the numerical channel (Fig. 3) the unidirectional wave spectrum was applied, as in the case of the tests performed on the physical model. On the wave generation lines in the numerical model of a wider water area (Fig. 1) the directional wave spectra were applied with dispersion of 30 deg.

The complex geometry of the planned caisson structure within the model of a wider area of Rijeka Port (Fig. 1, Fig. 5) was interpreted in the same way as in the numerical channel (Fig. 3). The spatial distribution of porosity layers with the related values in the planned project zone was adopted on the basis of the calibration process described previously.

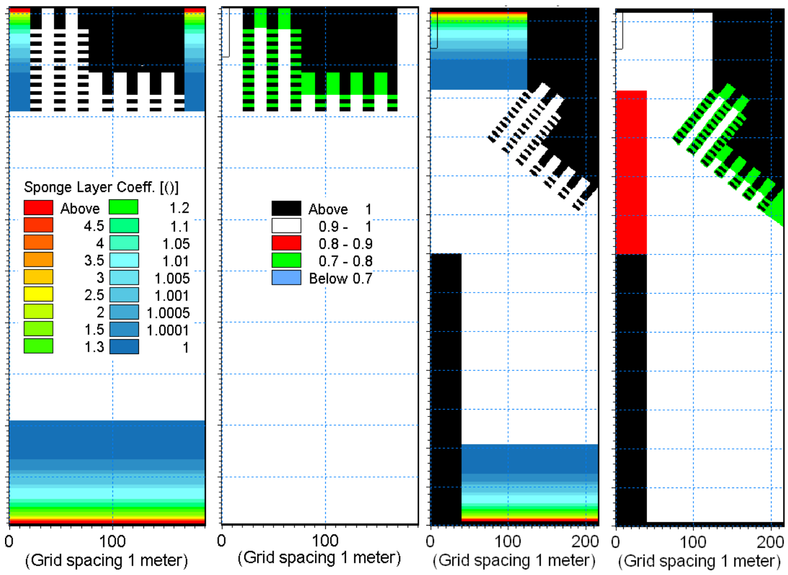

Fig 3. Spatial domains of numerical channels for incident wave directions 186^0 (left) and 175^0 (right) with positions of numerical sponge layers (b) and porosity layers

3. Results and discussion

On the basis of the analyses performed in the numerical channel, the resultant fields of significant wave heights H_S were obtained. Numerical fields of significant wave heights H_S provide continuous spatial information, whereas by the measurements on the physical model the H_S values were obtained only for the points at measuring positions (Fig. 2). The calibration of the numerical model was done on the basis of the measured values of H_S at measuring positions G1-G8 (Fig. 2) by varying the arrangement and the applied values of porosity layers in numerical model (Fig. 3). In the calibration process two statistical parameters were used in the assessment of acceptability, i.e. accuracy of the applied values of calibration coefficients. These were the average error (*AE*) and the root-mean-square error (*RMSE*) for variable H_S.

Comparison of the measured (physical model) and modelled (numerical channel) values of H_S at eight measuring positions (G1 – G8) for the case of incident wave direction 186^0 is given in figure 4. The fields of significant wave heights H_S, obtained by the model of wave deformation in a wider aquatory including Container Terminal pear, are presented in Figures 5 and 6. Reflection-dissipation characteristics of the coastline along the Container Terminal pear are described by model parameterization, adopting the relevant values in accordance with the previously performed calibration procedure.

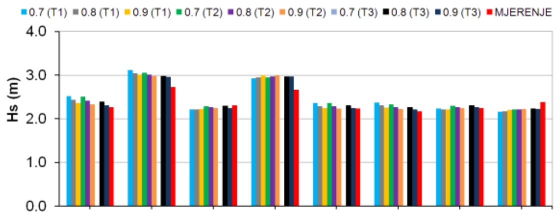

Figure 4. Measured (physical model) and modelled (numerical channel) values of H_S at eight measuring positions (G1 – G8) for the case of incident wave direction 186⁰

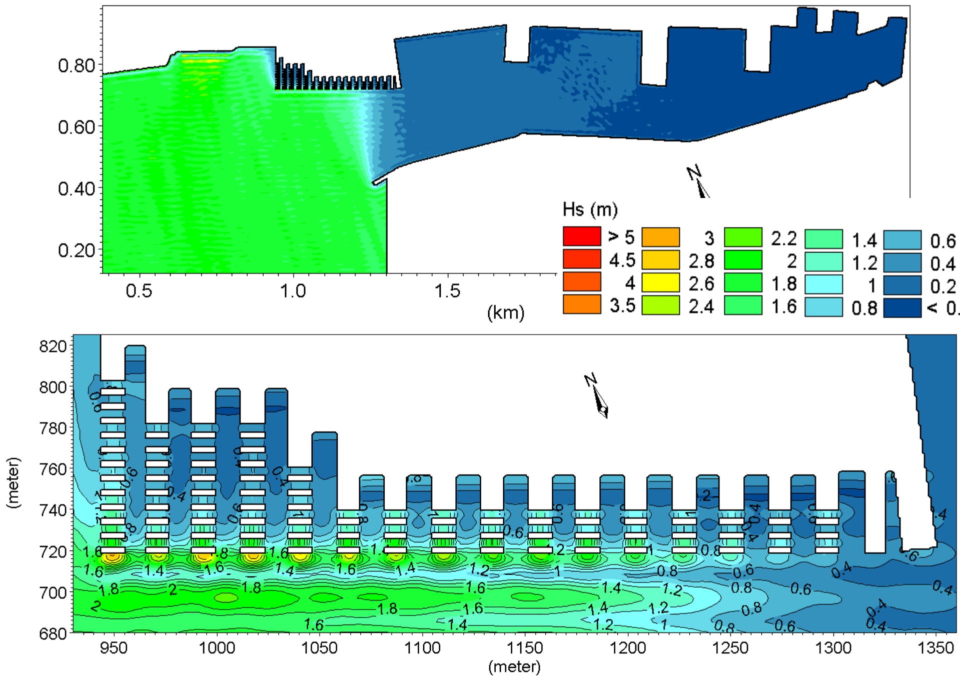

Figure 5. Fields of significant wave heights H_S (H_S= 2.0m ; T_P =5.3s at the boundary line) at incident wave direction 186⁰ for the planned condition of the coastline development

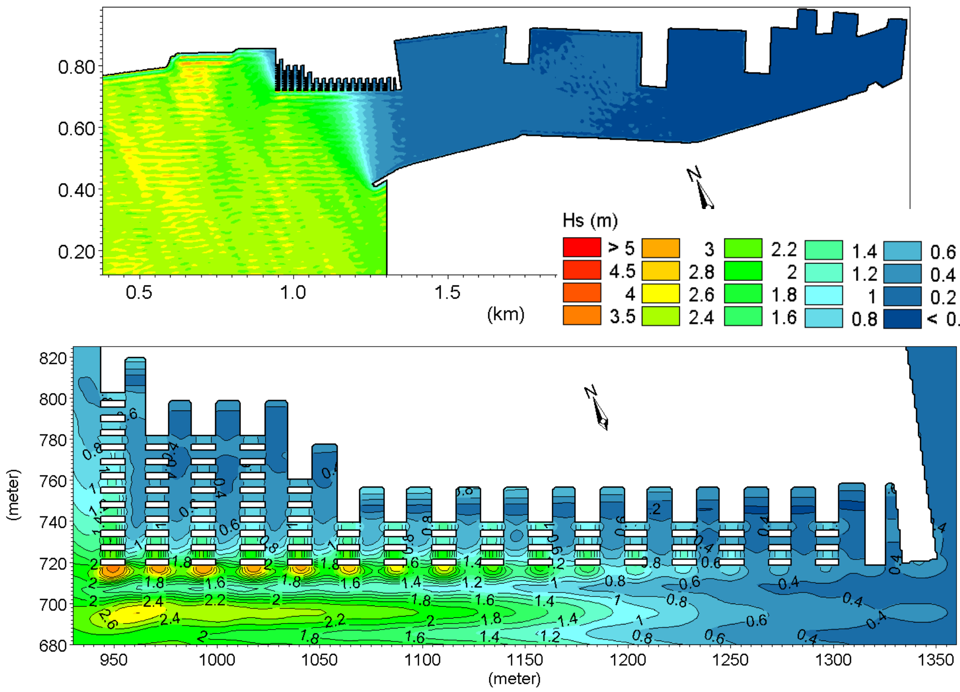

Figure 6. Fields of significant wave heights H_S (H_S= 2.6m ; T_P =5.5s at the boundary line) at incident wave direction 175⁰ for the planned condition of the coastline development

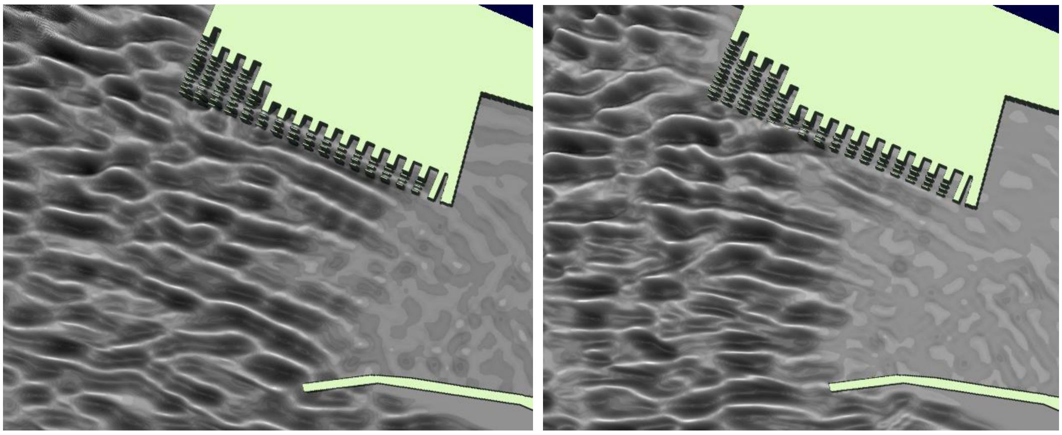

Figure 7. Instantaneous wave fields at incident wave directions 186^0 (left) and 175^0 right

4. Conclusions

The results of the performed research indicate highly inhomogeneous field of significant wave heights in front of the pier structure, as a result of the complex geometry of the planned structure and its reflective-dissipative characteristics. Such an inhomogeneous wave field can generate increased motion of a ship at berth and more intensive berth loads.

The largest wave heights occur on the very line of the planned coastline, especially in front of the structure caissons. In the cross-section parallel to the coastline at a distance of 10 m – 15 m from seawall, occurrence of continuous reduction in significant wave heights was found. At the cross-section through the field of significant wave heights at a distance of approximately 25 m from the seawall, repeated increase of significant wave heights was obtained, with less pronounced variation of the values along the cross-section. Since the eastern part of the planned structure coastline is partly under the influence, i.e. is protected by the main breakwater of the Rijeka Port, in this zone the significant wave heights were found to be lower than in the western part, especially in the case of 175^0 incident wave direction.

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