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HYDRO-GEOMORPHOLOGICAL PROCESSES IN THE TRANSITIONAL ROMANIAN BLACK SEA COAST, THEIR CONSEQUENCES ON THE MASTERPLAN FOR COASTAL PROTECTION IMPLEMENTATION

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Abstract. Under the actual anthropogenous disturbance induced to the many coastal processes over Romanian Black Sea coast, the littoral evolution at the sea-land interface, for a period of several decades, had registered some significant variation. The multi-annual survey of the shoreline evolution and beach profiles reveals the need to limit the activity in areas of the coastal zone and to set-up the priority for coastal protection/rehabilitation and management plans. The evaluation results over the evolution parameters variability of the Transitional Romanian Black Sea Coastal System, represented by the Navodari–Mamaia sector, shows that a significant coastal response process to climate changes/sea level rise trend, with an obvious influence on future development of natural environment, together with the socio-economic activities in coastal space. For erosion control, to restore natural environments in the mentioned coastal sector it was necessary to determine reasonable response of the shore to natural factors, in the complex built environment. Experimental researches on sand management along coastlines are extended in the several ongoing projects, and it is crucial for coastal planners to develop certain improved shore response models according with the EU policies on coastal conservation. Improved forecast models will assist them in the development of sustainable solution of coastal protection.

Keywords: coastal erosion, shoreline changes, master plan for coastal protection, coastal sustainability.

AIMS AND BACKGROUND

The main objective of the work is the study of the Mamaia beach short-term response under actions of the marine factors in the actual geomorphologic conditions (the sediment transport processes are developing in a context of a pocket beach/ geomorphologic littoral cell). The purpose of the work is achieved by applying certain coastal models, associated to fundamental hydrodynamic processes and to those of sediment transport, being very sensitive to the time and the scale of the issue in study.

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Estimating the growth and transformation of the wind waves when nearing to the coast is a critical component in most of coastal engineering projects, including prediction of the bathymetric changes/coast line, projecting or rehabilitation of some coastal structures, settling the navigation conditions and evaluation the natural evolution of bays and littoral beaches before or after certain establishments. Wave conveyance in the area next to the coast is influenced by a complex bathymetry, by currents generated by wind and waves, by water level variations and also by coastal structures existed.

For the purpose of this work, only one model of wave transformation has been selected, and this is so for reasons connected to the consistency of the steps taken during the numerical program development. Ultimately, the selection of one-wave model for this work has been oriented to the accuracy of the model in the prediction of the transformation of nearby coast waves. The accuracy of the model is necessary for evaluating the coastal response to different wave regimes, which induce different ways of sediment transportation along the coast. The selection of the model has taken into consideration the easiness of its employment and its utility in assisting the engineering analysis on the potential impact of different measures of coastal protection.

The analysis of the main characteristic and limitations, together with the basic hypotheses used in the enunciation of the models applied to wave transformation and breaking phenomena, has led to the selection of STWAVE model, as a spectral model, having a numerical scheme which results in the required accuracy with minimum calculation resources. STWAVE is superior to the capacity of calculating the main medium angles of the wave train, which are necessary as entrance data in modelling the rates of sediment transport. The performance of the sub-model of the incorporated wave height distribution[1], as well as that of the breaking sub-model which increases the model performance in the surf area counsel for STWAVE as the appropriate model in the operational approach on coastal engineering issues applied to the transitional Romanian Black Sea coast.

EXPERIMENTAL

The work encompasses the mapping, modelling and analysis of the coastal environment changes: wind, wave and sea-level regime, including sediment textures, coastal geomorphologic parameters, within 30 months, between March 2009 and November 2011.

Application to a wave transformation model, STWAVE (steady spectral wave model) developed by US Army Corps of Engineers (USACE – WES), being enunciated by Smith, Resio and Zundel[1], is related to the study of standing spectral wave transformation, based on a form of the equation of equilibrium of wave action developed by Jonsson[2]. Due to the fact that a wave spectrum is the result of the interaction between the spectrum of the wave energy and current coastal field, the model also includes sub-models for wave breaking and wave gradient near-shore. The model has certain assumptions made within its development: mild bottom slope and negligible wave reflection, homogeneous conditions of offshore waves, the steady-state wave regime, linear wave refraction and height due to depth decreasing, insignificant bottom friction and, linear shear stress.

General equations of the model are related to the wave dispersion relation which is given in the mobile reference system, moving along with the current, and the general equation for steady-state preserving of the wave spectral action along the wave radius is given by the Jonsson formula[2]. In this way, the density spectrum of wave action, which includes the current effect is preserved along the wave queue; when currents absent, the wave queues correspond to the wave orthogonals, and the density spectrum of the wave action is the density spectrum of the wave energy.

STWAVE is a numerical model with finite differences, based on a Cartesian grid. The lateral boundaries in the model may be specified as land or water by specifying the cell depths as positive (water) or negative (land). The numerical model is included in the NEMOS programme pack (**N**earshore**E**volution **Mo**del **S**ystem) of CEDAS (**C**oastal **E**ngineering **D**esign and **A**nalysis **S**ystem), being a commercial programme pack of CERC (Coastal Engineering Research Center), programmes which have friendly-use graphic interface.

Development of the numerical application of the model STWAVE for pocket beach represented by the Mamaia bay, where the port breakwaters may have a big influence on the wave field, with notable effects on the coast line. These propagation ways, respectively attenuation/intensification of the energy of the wave field in relation to the existence of navigation marine obstacles, were meant to be evidenced from the perspective of the mechanism of cumulative bathymetric changes, and also changes of the coast line in the transitional sector of the Mamaia bay, when significant events of the wave regime take place.

For the grid development, the most important component of most numerical applications, it was done according with the topographic/GPS and bathymetric data for the entire coastal sector, in Stereo 70/National projection coordinates for a similar actual, equilibrium bathymetry situation (after 1990's sand nourishment and sediment redistribution) from 2002. Once the domain settled, there were done the grid spacing and the extension of initialising domain grid of data on the free offshore boundary (by rotation to an appropriate azimuth). Geographical borders of the grid were settled after locating the 2 ports guarding the Mamaia bay. The grid cells had a 90 m spacing, that way the grid was spread on a rectangular area of 12 800/4000 m, in order to catch the coast line within the model, with 270° azimuth rotation (Fig. 1).

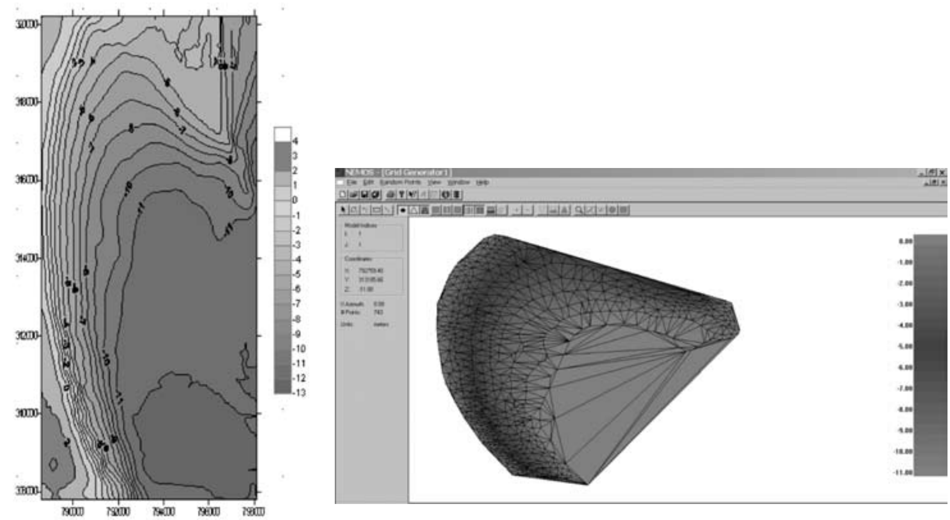

Fig. 1. Mamaia Bay – bathymetry, triangulation and grid development

The development of the wave spectrum for STWAVE was made using a 2nd degree numerical routine which creates a 2-dimensional spectrum for each event/specific wave condition (SPECGEN), by calculating the frequency and the directional dispersion of the wave energy spectrum based on wave significant parameters ($T_{1/3}$ and $H_{1/3}$). The frequency spectrum $S(f)$ is calculated using the relation of the Bretschneider–Mitsuyasu spectrum (f – frequency): where the significant wave period $T_{1/3}$ is estimated from the wave peak frequency: $T_{1/3} = 1/(1.05f_p)$, and $H_{1/3}$ is the significant wave height, defined as the mean of the highest one-third of waves in the wave records, and $T_{1/3}$ is the afferent period.

The wave data on the offshore boundary of the grid are generated through routine WISPH3, for transforming each and every offshore wave data (NetCDF format using a WWWL data editor). Development of statistical analysis on the wave field was made using the WWWL routine; by applying different filter/limiting criteria on the calm situations and on the selection of those significant events in respect to the coastal answer, boundary strips, wave parameters, in different changes of direction height and time interval.

RESULTS AND DISCUSSION

Aeolian and wave regime governs the surface currents formation. Also, it is induced the dune formations on the upper part of the beach, as an effect of the deflation.

For the analysed time period, 31 March 2009–8 November 2011, the biggest fervency for Constanta was registered from west direction, with 17.46% of the total cases, and the less represented was the south wind circulation with 8.34% of cases. For the generation of the 2D wave spectrum was used SPECGEN routine for representative data registered by visual observation 4 times per day at the Gloria platform, in offshore area.

Thus, from the total recorded offshore wave data, using WSAV routine, were saved 3 bands correspondent to situations of non-calm and significant impact for Mamaia shoreline general orientation – inducing long-shore sediment transport.

Developments on the wave statistics were made using WWWL routine, applying certain criteria for filtration, limitations and selections of significant event from calm situations, on different wave directions with consistent coastal response.

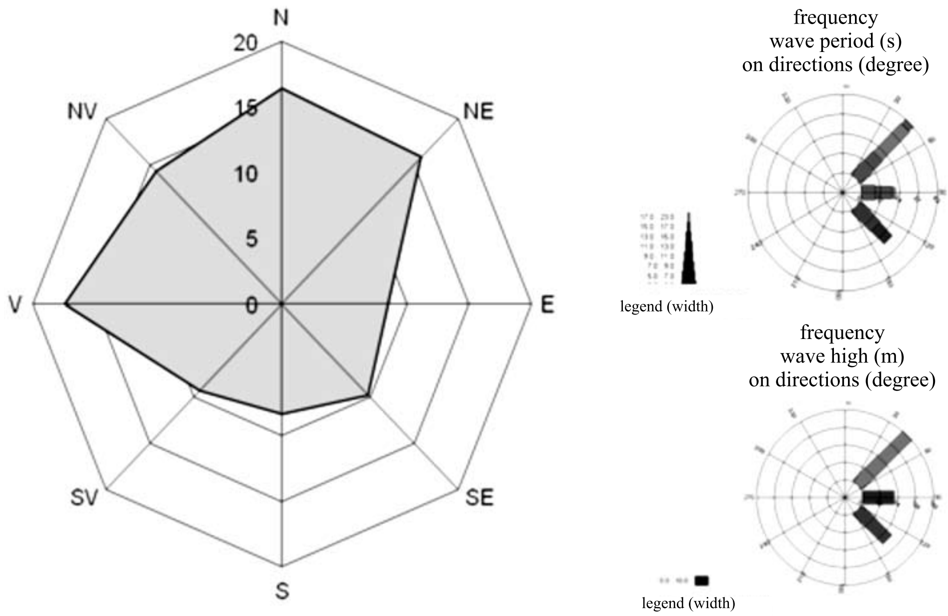

Fig. 2. Wind frequency for March 2009–November 2011; included figures (*a*) and (*b*) of the wave parameters frequencies on dominant directions with significant action in the Mamaia bay

Also, from wind regime analysis was quantified that it were favourable conditions for dune formations, when the wind speed was higher that 10 m/s, from N, NE, E and SE directions had a fervency of 39.4% (16% – 2009, 12% – 2010 and 11% – 2011).

Sea level. In the analysed period, including 1st of April to 15th of October 2011, the sea level had an averages value of 29.78 cm, and its variability encompasses maximum of 73.8 cm, in the interval of variation of 74.2 cm (11 February 2010, in conditions of an averaged wind speed of more than 20 km/h for a period of 5 days from N, E and NE directions, and 0.4 cm (14.10.200 – with averaged wind speed of 32 km/h from SV directions).

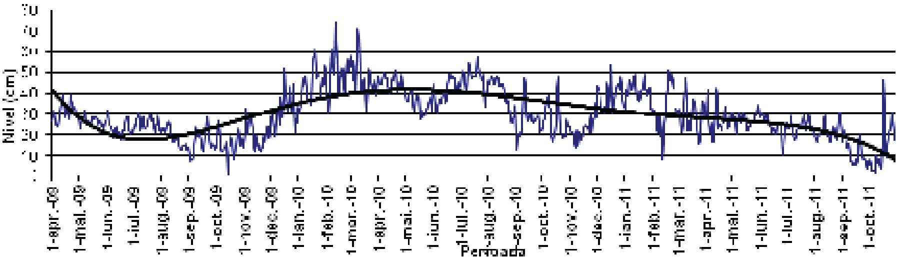

Fig. 3. Sealevel variability registered at the Constanta port gauging stations in the period of March 2009–October 2011

The highest levels were registered in winter time, in the months of February–March of 2010 (wind speed was higher than 15 km/h from NE, E and SE), August 2010 (consequence of historic Danube river discharge in the first half of June 2010) and also January–February 2011 (storm surges generated by wind speed around 30 km/h from NE and E directions).

Emerged beach changes in Navodari–Mamaia sector, at land–sea interface, from north to south, shows 3 characteristic subsectors: northern sector (from landmark MM3 to MM7, Navodari beach to North Mamaia beach, within sheltered area of the Midia port), where the processes of accretions are dominant in both seasons, central sector, northern sector of the Mamaia beach (from landmark MM9 to MM11, at north of detached parallel breakwaters), where it is dominant the effect of erosion, especially in cold season, and southern sector (from MM12 to MM18 landmark), where the erosional processes are diminished by beach protections solutions including levelling using bulldozers and reed fences installations.

Thus, at the end of cold seasons (in both case April 2009 and 2011) the dominant for the coastal processes were 43% erosion (29% weak erosion, 14% medium erosion), 29% relative equilibrium and 28% accretion (21% weak accretion, 7% strong accretion), and at the end of summer season (August 2009 and October 2011) it was 87% accretion and 13% relative equilibrium[3].

Results of STWAVE application to the Mamaia bay encompass the development of several running and visualisation using WMV routine (Wave Model Visualisation).

The dominant condition for the wave simulation within the Mamaia bay was determined from 3 directions of wave occurrence: NE and SE (2.26 m wave height, 12.5 s wave period, and $\theta = 42.59^{o}$ and 132.59^{o}) and also, the frontal exposure from E direction (2.32 m wave height, 12.5 s wave period, and $\theta = 90^{o}$) showing the influence of the port jetty and bathymetric gradients on the wave propagation. The calculated values on wave field transformations distributions were validated by wave recorded in a Mamaia hydrometric stations, moored at 11 m depth in front of the Rex hotel, and operated by Basin Administration of 'Romanian Waters'.

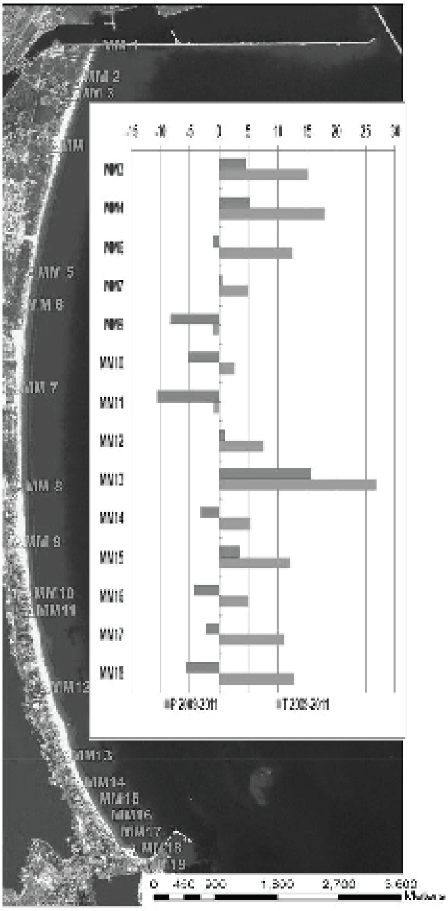

Fig. 4. Emerged beach changes within 2009–2011 time intervals

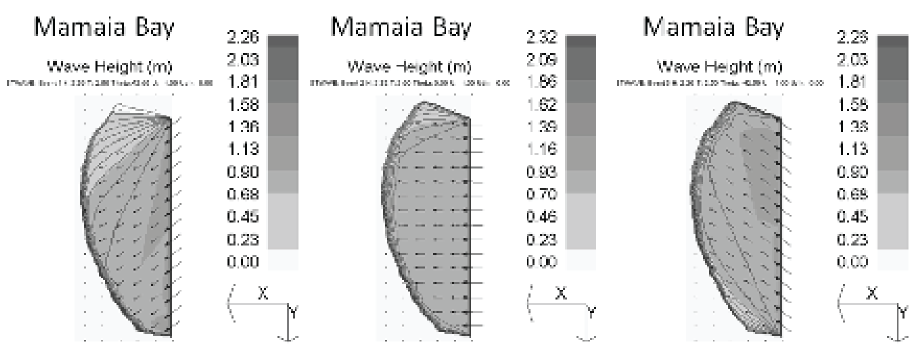

Fig. 5. Wave propagations from NE, E and SE directions (conturs show the wave heights, and vectors – the averaged wave directions)

It is revealed that STWAVE model is capable to evaluate the wave regime changes, induced by a pocket beach configuration as the Mamaia bay, but there are some limitations for sediment dynamic quantification due to the complex configurations of the built shore in the Mamaia southern sector, which induced several chronic erosional sites or vulnerable areas to erosion, at the extremities of the hydrotechnical works.

CONCLUSIONS

The emerged beach of Mamaia, at the end of cold season (April 2009 and 2011) had small width variations in the interval of –10.7 to + 15 m, and to the end of summer season (August 2009 and October 2011) it had rebuild with averaged value of 9.44 m, in the interval of variations from –1.1 to +26.8 m.

The submerged beach morphology is affected by the Midia port in the domain of small depths, from 1 to 4 m, as well to dipper areas, distance between isobaths in the range of 5 to 9 m being reduced to half from south to north sector.

For modelling of a wave processes dominated coastal beach the application of the STWAVE model can provide good results, including the diffraction processes[4], induced by the northern placed Midia port jetty.

Certain *recommendations for the actual Masterplan for coastal protection* can be outlined for its implementation generally adapted to regional environmental and socio-economic aspects, including the modern approach in the domain of the coastal ecologic, hydro-geomorphologic phenomena[5].

Even the version of Masterplan for protection was updated in 2011 by an international consortium drive by Halcrow Romania, from the version of 2005 founded by JICA (Japan International Cooperation Association)[6], to correspond especially to the new installed environmental conditions, it can be added that the estimations of the coastal response for the transitional Romanian Black Sea sector of Mamaia must be approached by continuations and extensions of coastal surveillance activities in the domain of a detailed high-resolution 3D modelling, built in a monitoring-modelling-management system.

Thus, the control of the coastal erosion and the environmental quality within the Mamaia bay, as combined result of the coastal natural and anthropogenic factors, will involve the knowledge of the geological, physical, and geomorphological impacts of the continuous modification of the marine hydrodynamics due to the new climate change evolution, and also, will require an appropriate response investigations strategies/methodologies in order to develop sustainable coastal protection and ecosystem rehabilitation. Such numerical model, built in the operational domain, will be the engine of an integrated forecasting system, which will provide a crucial understanding in the selection of the coastal protection and management solutions implementations.

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REFERENCES

1. J. M. SMITH, A. R. SHERLOCK, D. T. RESIO: STWAVE: Steady-state Spectral Wave Model. User's guide for STWAVE Version 3.0. ERDC/CHL SR-01-01, U.S. Army Engineer Research and Development Center, Vicksburg, MS, 2001.
2. I. G. JONSSON: Wave-current Interactions. The Sea. Ch. 3, Vol. 9, Part A (Eds B. LeMehaute, D. M. Banes). John Wiley & Sons, Inc., New York, 1990.
3. P. BRUUN: Sea-level Rise as a Cause of Shore Erosion. J. Waterways and Harbor Division, Proc. American Society of Civil Engineers, **88**, 117 (1962),
4. W. R. DALLY: An Overview of Coastal Surveying Technology Documenting Beach-Inlet Interaction. J. of Coastal Research, Special Issue, (18), 291 (1993).
5. D. M. BUSH, W. J. NEAL, R. S. YOUNG, O. H. PILKEY: Utilization of Geoindicators for Rapid Assessment of Coastal-hazard Risk and Mitigation. Ocean & Coastal Management, **42**, 647 (1999).
6. H. UZUN, I. PITI: Coastal Erosion Recovery and Saving. J Environ Prot Ecol, **5** (1), 140 (2004); Design Manual for Coastal Facilities. Japan Society of Civil Engineers, 2000.

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