Chapter 9
Design of Wave Energy Distribution for the Harbour and Coast Protection

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Abstract In this study, we present wave climate analysis at specific location points in deep water of Adriatic Sea and refracted waves distribution in Porto-Romano coastal area in order to determine the wave energy distribution. The analysis of wave energy distribution for this coastal area and the design of wave refraction plans are the first step to find effective solutions for coast and harbour protection. The results from wave climate analysis show us that the most extreme waves are generated from south directions at Adriatic Albanian coast. The analysis of refraction plans for Porto-Romano coastal area illustrates gaining of the maximum wave at Porto-Romano harbour from the south-west direction.

9.1 Introduction

Along the Albanian coastline, having a total length of about 446 km, we can distinguish the Ionian littoral, with a length of about 172 km, where the dominant (80 %) is rocky high coast, and the Adriatic littoral, with a length of about 274 km, where on the contrary the dominant (74 %) is low-land coast (about 35 % by sandy beach and 39 % by river mouth deposits or marshlands). The coastal protection is important because of intensive erosion processes in low-land coast in the Adriatic littoral are identified.

Wind blowing over the surface of the Adriatic and Ionian Sea transfer energy to the water surface in the form of wind-generated waves. The analysis of wave energy distribution in this coastal area and development of wave refraction plans are the first step to find effective solutions for coast and harbour protection.

In this chapter, wave climate analysis at a specific location point (40.75°N and 19°E) in deep water of Adriatic Sea and refracted waves distribution in Porto-Romano coastal area are presented. In this location, because of suitable depth and

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shoreline configuration of the northern coast of the Durres Bay, a new commercial oil port is constructed.

9.2 Analysis of Wave Climate in Deep Water of Adriatic Albanian Coast

Waves are the dominant active phenomenon in the coastal zone. It is important to have a means to quantify wind-generated waves for use in various engineering analyses and designing coastal structures. It is also important to be able to predict these waves for a given wind condition, both wave hind casts for historic wind conditions and wave forecasts for predicted impending wind conditions.

It is desirable to select a single wave height and period to represent a spectrum of wind waves for use in various engineering problems. The most commonly used representative is significant wave height, which is the average height of the highest one-third of the waves. The significant wave height and period as well as the resulting spectrum of wind-generated waves depend primarily on the distance over which the wind blows (known as the fetch length), the wind speed and the duration of the wind.

Thus, the maximum length of geographical fetch at a specific location point (40.75°N and 19°E), in deep water of Adriatic Sea, is about 1150 km from south direction and about 700 km from north-west direction, the respective length of effective fetch are about 680 and 315 km (Fig. 9.1) (Petrillo et al. 2008).

The data of wave climate in this specific point, by model of Argoss (Dutch Company), are presented in Table 9.1, from 1992 to 2004 (13 years) (Petrillo et al. 2008).

The extreme probability of wind occurrence (2.6 %), predicted from wind conditions data, for the extreme wind speed (>22 node) coincide with south direction,

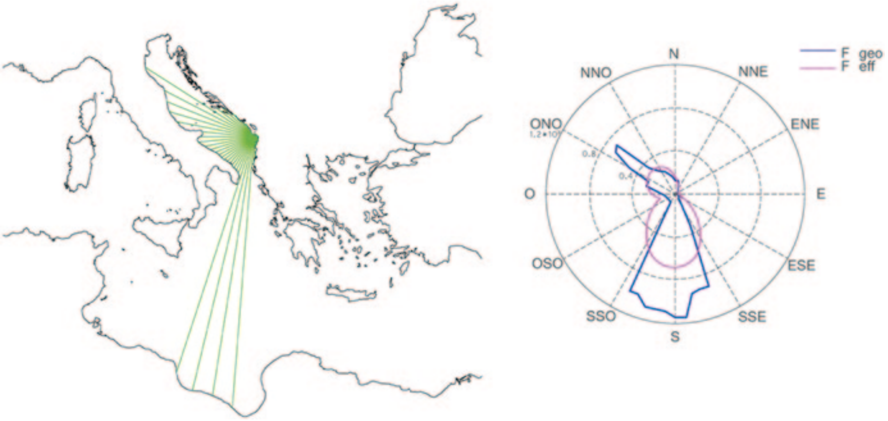

Fig. 9.1 Extension of geographical and effective fetch from a specific point in deep water of Adriatic Sea

Table 9.1 Wave measurements in deep water

Date/Time	Significant wave height Hs	Peak period Tp	Spectral mean period T-1,0 T-1,0	Principal wave direction	Wind speed	Wind direction
[MMDDYY hh:mm]	[m]	[s]	[s]	[degr]	[m/s]	[degr]
09/01/1992 0.00	0.2	4.9	4.7	302	2.8	160
09/01/1992 3.00	0.2	4.9	4.7	300	2.8	152
09/01/1992 6.00	0.2	4.9	4.7	255	2.8	144
09/01/1992 9.00	0.1	4.9	4.9	214	3.4	166
09/01/1992 12.00	0.5	3.6	3.1	184	4.0	184

Table 9.2 The extreme wave height and peak period in given deep water point, predicted from this data by probability distribution of Gumbel function, for various directions and return periods

Wave Direction	Wave significant height H_S (m)				Wave peak period T_P (s)			
	Return periods (years)							
	50	25	20	10	50	25	20	10
N	4.43	3.95	3.8	3.3	9.5	8.97	8.79	8.2
NNE	2.81	2.54	2.46	2.18	7.56	7.19	7.07	6.66
SSE	4.04	3.63	3.49	3.07	9.06	8.59	8.43	7.91
S	6.92	6.47	6.32	5.86	11.87	11.47	11.34	10.92
SSW	5.5	4.99	4.82	4.3	10.57	10.07	9.91	9.36
WSW	4.52	3.99	3.82	3.28	9.59	9.01	8.81	8.16
W	5	4.41	4.22	3.61	10.09	9.47	9.26	8.57
WNW	4.94	4.47	4.32	3.84	10.03	9.54	9.37	8.84

which is direction of maximum effective fetch. The extreme wave heights and peak periods in given deep water point for various directions and return periods are shown in Table 9.2.

Thus, by the wave climate at given specific point in deep water of Adriatic Albanian coast, the most extreme waves are generated from south direction.

9.3 Design of Refracted Wave Distribution in Porto Romano Coastal Area

Consider the design of a protective breakwater for a small marina that is located on the open coast. A typical design concern would be to predict wave conditions at interior points in the marina for a given deep water design wave height, period and direction (Lami 2002).

Wave refraction occurs in transitional and shallow water depths because wave celerity decreases with decreasing water depths to cause the portion of the wave crest that is in shallower water to propagate forward at a slower speed than the portion that is in deeper water. The result is a bending of the wave crests so that they approach the orientation of the bottom contours. Wave orthogonal, to remain normal to the wave crest, will also bend so that orthogonal that are parallel in deep water may converge or diverge as wave refraction occurs. This convergence or divergence of wave orthogonal will cause local increases or decreases in wave energy and consequently wave height (Lami 2003).

Design of wave energy distribution plans in this condition is realised by means of mathematical model, which is based on numerical solutions of two fundamental differential equations (Lepetit 1964). These equations, represented as geometric (quantitative) and energetic (qualitative) aspects, are:
the differential equation of wave orthogonal or wave direction

$$\frac{d\alpha_i}{dt} = \frac{\partial C_i}{\partial x_i}\sin\alpha_i - \frac{\partial C_i}{\partial y_i}\cos\alpha_i, \tag{9.1}$$

and the differential equation of wave front distribution

$$\frac{d^2\beta_i}{dt^2} + p(t)\frac{d\beta_i}{dt} + q(t)\beta_i = 0, \tag{9.2}$$

where: α_i—the angle between the tangent of wave orthogonal and the ox axis,
C_i—the wave celerity,
$\beta_i = b_i/b_0$—the coefficient of wave front distribution between two adjacent orthogonal from deep water to a refracted wave point, and

$$\begin{cases} p(t) = -\left(\dfrac{\partial C_i}{\partial x_i}\cos\alpha_i + \dfrac{\partial C_i}{\partial y_i}\sin\alpha_i\right) \end{cases} \tag{9.3}$$

$$\begin{cases} q(t) = C_i\dfrac{\partial^2 C_i}{\partial x_i^2}\sin^2\alpha_i - 2C_i\dfrac{\partial^2 C_i}{\partial x_i\,\partial y_i}\sin\alpha_i\cos\alpha_i + C_i\dfrac{\partial^2 C_i}{\partial y_i^2}\cos^2\alpha_i \end{cases} \tag{9.4}$$

where $K_r = \beta_i^{-1/2}$ is the wave refraction coefficient.

For solving these differential equations, the numerical methods of Euler, Adams and Runge–Kutta are used.

The basic equations of finite differences by Runge–Kutta method are:

$$\begin{cases} x_{i+1} = x_i + \left(C_i + C_{i+1}\right)\dfrac{\Delta t}{2}\cos\left(\alpha_i + \Delta\alpha_i/2\right) \\ y_{i+1} = y_i + \left(C_i + C_{i+1}\right)\dfrac{\Delta t}{2}\sin\left(\alpha_i + \Delta\alpha_i/2\right) \\ \alpha_{i+1} = \alpha_i + \Delta\alpha_i/2 \end{cases} \tag{9.5}$$

$$\begin{cases} \dfrac{d^2\beta_i}{dt^2} = \left(\beta_{i-1} - 2\beta_i + \beta_{i+1}\right) / \Delta t^2 \\ \dfrac{d\beta_i}{dt} = \left(\beta_{i+1} - \beta_{i-1}\right) / 2\Delta t \\ \beta_{i+1} = \dfrac{\left(p_i \Delta t - 2\right)\beta_{i-1} + \left(4 - 2q_i \Delta t^2\right)\beta_i}{p_i \Delta t + 2} \end{cases} \tag{9.6}$$

The wave climate in deep water (direction angle, wave height and period) and the bathymetrical relief of coastal area are the basic data for this numerical model.

According to the climatic data during several years in Durres station, the results show that the south-western, western and north-western winds are predominant.

Wave heights and respective periods in deep water of Porto-Romano coastal area are predicted by the analysis of this climatic data and their respective effective fetch, and by means of an analytical method.

The application of numerical model for the design of refracted wave distribution plans for three predominant wind direction (SW, W and NW) is realised on the strength of initial data: wave climatic in deep water and the bathymetric relief of Porto-Romano coastal area (Table 9.3, only SW direction).

The results of refracted wave distribution plan at SW direction of wind are presented in Fig. 9.2 and Tables 9.3 and 9.4.

9.4 Conclusions

- Analysis of wave energy distribution is important to find effective solutions for the protected harbours and shore in each coastal area.
- Wave climate in deep water and the bathymetrical relief of coastal area are the basic data for realised plans and analysis of wave energy distribution by numerical model.
- The analysis of refraction plans for Porto-Romano coastal area illustrates gaining of the maximum wave at Porto-Romano harbour from the south-west direction.
- For wave monitoring in deep water, it is necessary to install maritime stations on characteristic area along Albanian coast.

Table 9.3 The data of numerical model program for wave energy distribution

Coastal area	Porto Romano
Wave direction in deep water	SW
Wave period in deep water	$T=9.4$ s
Wave height in deep water	$H=5.54$ m
Direction angle of front wave in deep water with ox	$A_o=0°$
Scale of maritime map	1: 50,000
Dimension of unity square	$A=500$ m
Number of vertical unity	$M=14$
Number of horizontal unity	$N=28$
Position of primary point	$X_o=1$, $Y_o=1$

90	89	88	87	86	85	83	82	80	79	78	77	76	75
87	86	86	85	85	84	82	80	79	77	76	74	72	71
85	85	85	85	85	83	81	79	77	75	73	71	69	67
84	84	84	83	83	82	80	78	75	72	69	67	65	63
84	84	83	82	81	80	78	76	73	70	67	64	61	58
83	82	80	80	79	78	76	74	70	67	63	60	56	53
81	79	77	77	77	73	70	66	63	60	57	54	51	48
79	77	74	73	75	67	64	61	58	56	53	50	47	44
77	74	71	68	65	62	59	56	53	50	46	44	42	40
70	72	69	66	63	60	57	54	51	48	44	40	38	35
73	70	68	64	60	56	53	50	46	43	40	37	35	32
72	69	66	62	59	55	52	48	45	42	38	35	32	29
62	60	58	56	57	50	48	47	43	41	38	33	30	27
58	57	52	50	45	40	43	46	40	37	34	31	28	25
55	53	51	49	40	38	35	35	35	32	29	26	24	22
51	48	45	40	37	36	35	32	29	26	24	23	20	20
48	44	40	37	34	32	30	27	25	23	23	22	20	18
42	38	36	34	30	26	21	24	24	23	22	21	19	15
40	36	34	31	27	26	26	24	23	22	20	13	13	14
37	35	32	28	27	25	24	23	22	21	17	10	10	8
34	32	29	27	26	24	21	21	19	18	13	11	5	0
31	29	27	25	24	23	21	20	16	11	8	8	2	0
27	26	24	23	23	22	20	18	14	11	10	4	0	0
26	23	22	21	21	20	19	14	10	8	3	0	0	0
21	21	20	12	10	10	10	11	8	4	0	0	0	0
19	15	11	6	3	5	10	11	8	4	0	0	0	0
10	5	1	2	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

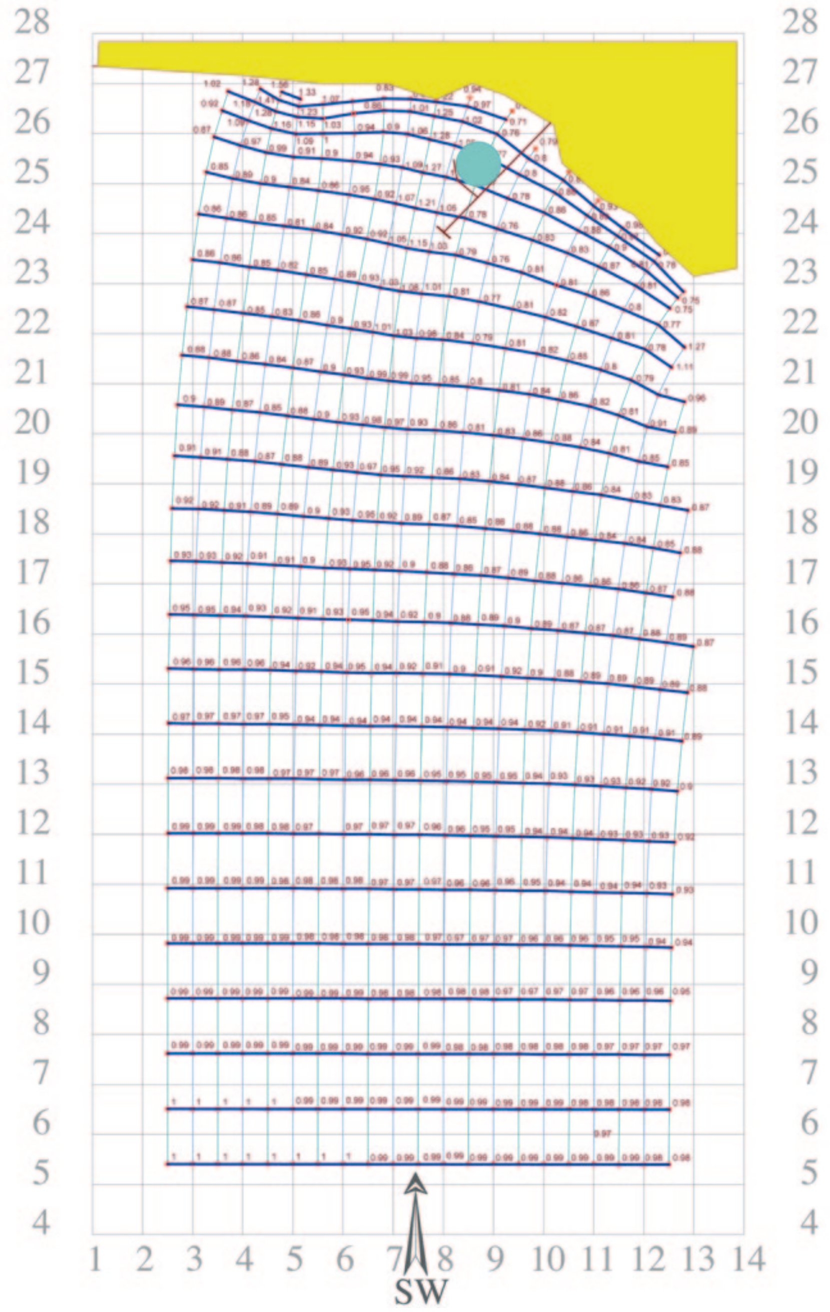

Fig. 9.2 Plan of wave refraction in the 'Porto-Romano' coastal area from S-W direction

Table 9.4 Results of numerical model

Orthogonal Nr. 13								
Nr	*t*	*X*	*Y*	FL	BE	WL	VL	EL
3	38	7.50	2.10	80.90	1.00	1.00	1.00	14.66
4	75	7.50	3.21	79.79	1.00	1.00	1.00	14.66
5	113	7.50	4.31	78.38	1.00	1.00	1.00	14.66
6	150	7.50	5.41	76.18	1.00	0.99	0.99	14.66
7	188	7.50	6.51	71.41	1.00	0.99	0.99	14.65
8	226	7.50	7.61	64.62	1.00	0.99	0.99	14.62
9	263	7.51	8.71	58.92	1.00	0.98	0.98	14.58
10	301	7.51	9.81	55.85	1.00	0.98	0.97	14.55
…	…	…	…	…	…	…	…	…
27	940	8.85	25.54	6.82	1.75	1.02	0.77	7.64
28	978	9.07	25.99	4.67	2.01	1.08	0.76	6.19
29	1015	9.25	26.28	2.72	2.34	1.08	0.71	3.62
30	1053	9.37	26.45	1.74	2.65	1.08	0.66	2.32

t the time of wave front (s), *X* and *Y* predicted position of the points of orthogonal (A m), *FL* the water depth in the points of orthogonal (m), *BE* the coefficient of wave front distribution between two adjacent orthogonal from deep water to refracted wave point of orthogonal, *WL* the shoaling coefficient at points of orthogonal, *VL* the relative height of refracted wave at points of orthogonal, *EL* the wave front celerity at points of orthogonal (m/s)

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