Coastal storms risk assessment for Mamaia and Eforie barriers

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Abstract—The level of damage for Mamaia and Eforie Barriers shows that in a risk assessment to coastal storms, more important than the inundation limit is, in fact, the density of elements (buildings, roads, etc.) that can be affected.

Keywords— *coastal storms; inundation scenarios; risk assessment*

I. INTRODUCTION

Storms are a major threat for the large number of people living in coastal areas. The rapid climate change has led to intensified coastal storms throughout the world, resulting in extreme damage to households and even loss of human lives. This is the main reason for the increasing interest in risk assessment and disaster risk reduction measures in the last decade.

This paper aims to assess the risk to coastal storms for two vulnerable sectors of the Romanian Black Sea coast – Mamaia and Eforie barriers. These sectors represent very important touristic areas, with valuable infrastructure, which can be highly affected in the event of a major storm. We focused our analysis on the risk of buildings and infrastructure, excluding the potential loss of human lives because we considered that a major storm is most likely to occur in the active season (winter season), when the number of tourists on the two barriers is low.

II. METHODOLOGY

The methodology is based on three scenarios: the impact of low storms (significant wave height of 2.5 m), severe storms (significant wave height of 5 m) and extreme storms (significant wave height of 7 m). We calculated the maximum horizontal distance that storm waves can reach on the beach in order to establish the inundation limits (computed by the ratio between wave run-up and foreshore slope) for each scenario.

First, we computed wave run-up level (measured vertically from the waterline) for all three scenarios using the approach proposed in [1]:

$$R_{u2\%}=1,1*\left(0,35*\beta_f*(H_s*L_0)^{1,2}\frac{[H_s*L_0(0,563\beta_f^2+0,004)]^{1,2}}{2}\right) \quad (1)$$

where β_f is the foreshore beach slope defined over the area of significant swash activity, H_s is the significant wave height and L_0 is the offshore wave length, which can be expressed as $L_0=gT^2/2\pi$. In order to determine the horizontal distance of wave run-up on the beach, we used the equation proposed in [2]:

$$X_{max}=\frac{R_{u2\%}}{\tan(\beta_f)} \quad (2)$$

where $R_{u2\%}$ is the 2% exceedance level for run-up peaks on natural beaches and β_f is the foreshore beach slope.

For determining the water levels in the point of maximum run-up and of flow velocities on the beach we made a medium profile for each barrier, by interpolating 15 different profiles for Mamaia Barrier and 4 for Eforie Barrier. After that we established the highest point on each beach in order to compute the overwash extension. The water level at the top of the above mentioned point can be obtained using the approach proposed in [3]:

$$h=\frac{\tan\beta_w X_c}{X_R \cos\beta} (X_R-X_c) \quad (3)$$

where: X_R is the horizontal distance of wave run-up on the beach (the same as X_{max}), X_c is the distance from the still water line to the highest point on the beach, β is the beach slope and $\tan\beta_w$ is a constant (0,035).

The flow velocities were computed using the equation proposed in [4]:

$$u=0,66\sqrt{gh} \quad (4)$$

where: g is the gravitational acceleration and h is the water level at the highest point on the beach.

Knowing the two values, water level and velocity, we were able to determine the inundation rate for each barrier (Tab. I).

TABLE I. INUNDATION RATES FOR MAMAIA AND EFORIE BARRIERS

	Water level/Depth (m)	Velocity (m/s)	Depth-Velocity Product (m ² /s)
Mamaia Barrier	1.081	2,148	2.323
Eforie Barrier	1.890	2.841	5.370

Based on this methodology and on the results, we could assess the risk for each building and for infrastructure inside the inundation limits of each scenario. This way, we have obtained a comprehensive database containing information like: type of building, type of use, year of construction, surface, materials they were made of, market value, etc.

III. RESULTS

The inundation limits range between approximately 25 m for low storms (26.53 m for Eforie Barrier and 24.28 m for Mamaia Barrier), 90 m for severe storms (90.75 m for Eforie Barrier and 88.01 m for Mamaia Barrier) and 190 m for extreme storms (193.87 m for Eforie and 194.73 m for Mamaia) (Fig. 1 and 2). Taking into consideration the good correlation between risk degree and barrier width, for Eforie Barrier, characterized by lower widths, the inundation limit for extreme storms exceeds in some places its width, affecting not only all the buildings, but also important infrastructure that connects the northern part of the coast with the southern one. Being almost double in size, Mamaia Barrier does not experience the same problems, but the high density of buildings increases its risk. In the case of low storms, only unanchored wooden structures could be affected, while for severe storms they would be totally damaged. Anchored wooden structures would only be partially damaged during severe storms and totally destroyed in case of an extreme storm, while concrete and brick structures could be partially affected on the ground floor in the worst case scenario (an extreme storm) (Table II.).

Fig.1. The inundation limits on Eforie Barrier

For the risk assessment, we only considered the limit for extreme storms for both barriers. Because the value per square meter is different along Mamaia Barrier, we had to divide it in 5 areas: area A1 - situated between Tăbăcărie Lake and Melody Bar, A2 - between Melody Bar and Rex Hotel, B1 - between Rex Hotel and “At the Barrels”, B2 - between “At the Barrels” and Summerland residential area and B3 - between Summerland and the northern limit of the barrier [5] (B3 area - Fig.2). Overlaying the maximum inundation limit over the buildings we were able to extract the ones that could be inundated during an extreme storm. A number of 218 buildings on Mamaia Barrier and 50 on Eforie Barrier could be inundated during a major event (Table III.). After calculating a mean area for the buildings and extracting the mean values per square meter from [5], we could determine the mean value of the losses on the two barriers: 108.382.802 €for Mamaia Barrier and 7.582.700 €for Eforie. The latter is crossed by a road and a railway of national importance, both affected by the event, with a value of 13.780.840 €(of which 7.840.000 € for 2 km of road and 5.940.840 €for 1.597 km of railway) according to [6]. This means that the value of losses for Eforie Barrier is 21.363.540 €, for both buildings and infrastructure.

Fig. 2. The inundation limits on Mamaia Barrier

IV. CONCLUSIONS

Even though, at first all tend to assume that, because the limit of Eforie Barrier is exceeded, the risk should be higher, in fact, the most important variable is the percentage of buildings or things that could be affected. Although the losses are much smaller than on Mamaia Barrier, the disruption between the northern and the southern part of the coastal area deriving from the inundation of the road and the railway, affects not only the barrier, but also all the communities located south. This

type of assessment can be a starting point for disaster risk reduction measures and better management strategies that can diminish the potential losses on Mamaia and Eforie barriers in case of severe and extreme storms. Another gain from risk assessment analysis should be the

awareness of all the problems that coastal communities will have to face due to climate change.

TABLE II^a. DEGREE OF DAMAGE BASED ON THE INUNDATION RATES

House type	Depth-Velocity Product (m ² /s)		
	Inundation	Partial damage	Total damage
<i>Wood - Framed: Unanchored</i>	0 - 1,99	2 - 2,99	3 - >7
<i>Wood - Framed: Anchored</i>	0 - 2,99	3 - 6,99	>7
<i>Masonry, concrete and brick</i>	0 - 2,99	3 - 6,99 (if v is also ≥ 2 m/s)	>7 (if v is also ≥ 2 m/s)

^aTable modified after [7]

TABLE III. POTENTIAL LOSSES PRODUCED BY AN EXTREME STORM ON THE TWO BARRIERS

	Mamaia Barrier					Eforie Barrier
	A1 area	A2 area	B1 area	B2 area	B3 area	
No. of buildings affected	61	42	21	21	73	50
Mean area per building (m)	1.121	899	1.955	598	388	382
Mean value per m ² (€)	578	616	568	554	541	397
Mean price per building (€)	647.938	553.784	1.110.440	331.292	209.908	151.654
Mean price per area (€)	39.524.218	23.258.928	23.319.240	6.957.132	15.323.284	7.582.700

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