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SBM/CALM DESIGN WAVE CLIMATE PREDICTION

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Abstract- A CCPP was constructed in Vlore Bay. Due to the non-availability of natural gas in Albania, the GT should operate with fuel oil. A Single Buoy Mooring (SBM/CALM) system was selected for boat anchoring and PLEM structure connected with the pipeline for downloading and transferring the fuel oil. To carry out the engineering design a lot of data was necessary. These data include climates and extreme conditions for winds and waves, tidal current data, and tidal ranges. This study is presented the derivation of these conditions and aimed to establish a wind climate applicable to the site. For this reason was carried out a derivation of 100-year, 10 years, and 1 year directional and omnidirectional extreme wind parameters. An offshore wave climate was established using computational wave modeling to derive a wave climate at the site of the SBM/CALM. Computational wave modeling to derive nearshore extreme wave conditions at the SBM/CALM corresponding to 100-year, 10-year and, 1-year directional, and omnidirectional wave parameters were performed as well. Also was carried out a literature review to gather information on tidal, geostrophic, and wind-driven currents in Vlore Bay. For the study, the SWAN software was selected to forecast wave conditions at the site of the SBM/CALM for both extreme events and annually-averaged climates. The 100 years all-direction extreme significant wave height at the SBM/CALM was predicted at 4.2m. A review of the existing literature of flow data in the region was also carried out from which it was concluded that currents in the bay were unlikely to exceed 0.5ms^{-1}. We hope to give our modest help to the engineers that deal with offshore structure.

Keywords: Significant Wave Height, SBM/CALM, Wave Model, Wave Energy, Weibull Prediction, Wind Model.

1. INTRODUCTION

To provide the PP with fuel oil the construction of an SBM/CALM was needed. The capacity of the boats should be in the order that allows at least one month of operation of the PP. A boat capacity of 15000 - 20000 m^3 was selected as input for the design. At least a water depth of approximately 13m was necessary for the boat navigation [1]. The data needed for such design includes climates and extreme conditions for winds and waves, tidal current data, and tidal ranges. This study is presented the derivation of these conditions.

The wave climate in Vlore Bay consists of the waves which are generated offshore and then propagate in the west and north entrances into the bay and the waves which are generated locally within the bay from the winds that blow from the south direction. For the study, the SWAN software was selected to forecast wave conditions at the site of the SBM/CALM for both extreme events and annually-averaged climates. The 100 years all-direction extreme significant wave height at the SBM/CALM was predicted at 4.2m.

A review of the existing literature of flow data in the region was also carried out from which it was concluded that currents in the bay were unlikely to exceed 0.5m^{-1}. The scope of this study is as follows:

- Establish a wind climate applicable to the site.
- Derivation of 100-years, 10 years, and 1-year directional and omni-directional extreme wind parameters (1-hour, 10' and 1' mean @ 10m elevation).
- Establish an offshore wave climate.
- Computational wave modeling to derive a wave climate at the site of the SBM/CALM (presented as wave scatter diagram of H_S vs T_{ZUC} for relevant direction sector).
- Computational wave modeling to derive nearshore extreme wave conditions at the SBM/CALM corresponding to 100-year, 10- year and 1-year directional and omni-directional wave parameters (H_S, T_P, T_{ZUC}, and relevant spectral shape).
- Carry out a literature review to gather information on tidal, geostrophic, and wind-driven currents in Vlore Bay [2].

2. WIND FORECAST

2.1. Wind Data

There were considered three sources for taking the wind data to determine the wind climate and extreme conditions.

Measurements at the city airport. This site was found to be the only suitable coastal land-based station within a distance applicable to Vlore Bay. Nine years worth of data was available for the period 1983-1991. An initial review of this data showed that wind directions appear to be recorded to the nearest 45 degrees compass point and wind speeds to the nearest 2-knot wind speed. Records were known to be 10-minute means and recorded approximately every 3 hours.

Data was taken from the Met Office European Wave Model for a point that represents the wind and waves at the entrance of the Bay. This model is a second-generation spectral wave model covering European waters to a grid resolution of 25-30 km. It is connected with the weather forecasting models and is then is calibrated comparing with measured data.

In addition, information is taken from previous studies and site observations. From this information, was found that strong local winds happen in the Bay. These are strong winds created by thermal interaction between cold air from the mountains and the warmer air over the waters of the sea, sending violent squalls. These winds come from the south. The average wind speed for one hour is in the range of 20 to 25ms^{-1}, and a maximum wind speed of 45ms^{-1} is recorded in 20 years.

2.2. Wind Climate in Vlore Bay

The results showed that there was a lower percentage occurrence of winds in the higher wind speed bands in the Uk Met Office European model wind climate compared to the wind data measured at Vlore Airport. For example, there are 0.08% of observation between 18ms^{-1} and 24ms^{-1} in the Met Office model and 0.475% of winds 34-35 knots (~17.5ms^{-1}-28.3ms^{-1}) at Vlore Airport. Also, the maximum measured winds were greater than those included in the model wind climate.

From the site information, it was considered that the Met Office model winds would not be representative of the wind climate in Vlore Bay. Hence at the time of this study, the most appropriate source of wind data available is the winds measured at the city airport and so this climate is presented as being representative of winds that occur in Vlore Bay.

2.3. Extreme Wind Speed

The extreme wind speeds corresponding to return periods of 1, 10, and 100 years were collected for the duration of 1 hour, 10 min, and 1 min.

Given the significant number of calms/missing values in the data set (43%) these values were removed from the climate before deriving the required extreme wind speeds. As were all observations of wind speed greater than 64 knots. Both groups of observations appeared unusual in comparison to distribution of the remaining observations. With these observations removed it can be observed that wind speeds of up to 55 knots (~28.3ms^{-1}) have been measured. These winds occur from southerly sector.

The 1-year return period wind speeds were derived using a countback analysis on the wind climate.

An extrapolation technique was used to estimate the wind speeds for 10 and 100 year return periods based on the wind climate. Various probability distributions can be fitted and, at present, there is no theoretical justification for the use of one particular distribution compared to another. However, experience has shown that the three-parameters Weibull distribution usually fits the data well. Therefore, for this study wind speeds corresponding to the selected return period events were calculated using the Weibull distribution method. Particular attention was given to obtaining a good fit for the large wind speed observations for each direction sector.

The 1-hour duration wind speeds are presented in Table 1. The shorter duration wind speeds were derived using factors recommended by PIANC. These factors are used in the absence of site information on the relationship between 1-hour duration and gust wind speed.

From Table 1 it can be found that the biggest extreme wind speed occurs in the sector which is centered on 180°N corresponding to the 1 and 100 year return period for the duration of 1-hour and the magnitude of wind speeds is 27.6 ms^{-1} and 44.2 ms^{-1}. The extreme wind speeds presented are the best estimate of those that occur at the site. Although they have been derived from the best available data of wind, it should be acknowledged that this data had a high percentage of missing records.

Table 1. Extreme wind conditions

Return period (year)	Wind direction sector (°N)	1 hour duration wind speed (ms^{-1})
1	360	23.2
	45	14.2
	90	19.4
	135	21.1
	180	**27.6**
	225	17.2
	270	18.6
	315	19.8
	All direction	27.8
10	360	27.8
	45	19.9
	90	22.1
	135	27
	180	36.7
	225	21.2
	270	19.8
	315	24.6
	All direction	38.9
100	360	39.1
	45	25.5
	90	27.8
	135	31.9
	180	**44.2**
	225	24.8
	270	27.8
	315	31.4
	All direction	47.7

3. OFFSHORE WAVE DATA

3.1. Extreme Offshore Wave Conditions

This study was required, the offshore extreme wave conditions, which correspond to 1, 10, 100 years of return periods. Significant wave heights connected to the selected return period events were calculated using the offshore wave climate with Weibull distribution.

The offshore wave climate data were further analyzed to determine a typical wave steepness of the (larger) offshore waves for each direction sector of interest. This steepness, 0.045, was used to assign mean wave periods to the extreme significant wave heights derived above. Table 2 presents the extreme wave conditions. Given that the entrance is exposed predominantly to waves generates by winds blowing over the Adriatic Sea and Ionian Sea a JONSWAP spectral shape was assumed, with a T_m/T_p ratio of 0.78.

From Table 2 it can be seen that the biggest waves take place in the sector centered on 210°N. The significant wave height for 1 and 100 year return period for the sector is respectively 3.5 m and 5.6 m. The site is more uncovered from the offshore waves that come from the west and north-west, than from the waves that came from the south-west. The biggest significant wave heights from west and north-west for the return period of 1 and 100 years are respectively 2.8m and 4.8m.

Table 2. Extreme offshore wave conditions.

Return period (year)	Wave direction (°N)	Significant wave height (m)
1	210	**3.5**
	240	2.4
	270	2.1
	300	2.3
	330	**2.8**
	360	2.6
	All direction	4.5
10	210	4.6
	240	3.6
	270	3.1
	300	3.3
	330	3.8
	360	3.5
	All direction	5.6
100	210	**5.6**
	240	4.7
	270	4.0
	300	4.3
	330	**4.8**
	360	4.4
	All direction	6.7

4. NEARSHORE WAVE MODELING

4.1. Introduction

Wave conditions at the SBM/CALM are composed of waves created offshore which then propagate and enter in the bay from the west and north waves which are created locally inside the bay from the winds that blow from the south. Waves that came from offshore and waves created in the Bay due to winds were modeled using the SWAN software for forecasting the wave climate at the area of the SBM/CALM.

4.2. The SWAN Wave Transformation Model

SWAN is a 3rd generation wave model, which is a spectral wave transformation model for coastal wave studies. SWAN takes into consideration all the effects of friction, refraction, wave-wave interaction, and wave breaking [3]. The model is adequate for the wave energy transformation in coastal regions. This is more accurate where the seabed characteristics, like offshore banks, have as a consequence the wave breaking and the interaction between the waves.

The model also covers wave created by wind inside the area of the model. Therefore, the software is particularly convenient in area such as this where wave climate may be controlled by those which are created locally by winds.

The model can also cover the incidence of wave reflection and diffraction from offshore structures by giving appropriate reflection coefficients to the different boundary elements [4].

4.3. Application of SWAN to Vlore Bay

The model was adjusted to cover the Bay. The model bathymetry was taken from data from the C-Map database of electronic Admiralty Chart data. This database includes charts produced by Instituto Idrografico della Marina and in particular IIM Chart LITORALE DI VLORE.

The model has a single rectangular grid that is aligned with the north direction. The detail of the grid system is given in Table 3 and Figure 1 presents a color plot of the model area.

Table 3. SWAN model grid system

Grid number	Grid spacing (m)	Number of nodes	Grid origin (WGS84 UTM 34N co-ordinates)
	x direction y direction	x direction y direction	x direction y direction
1	200.0 200.0	116 163	349800 4464300

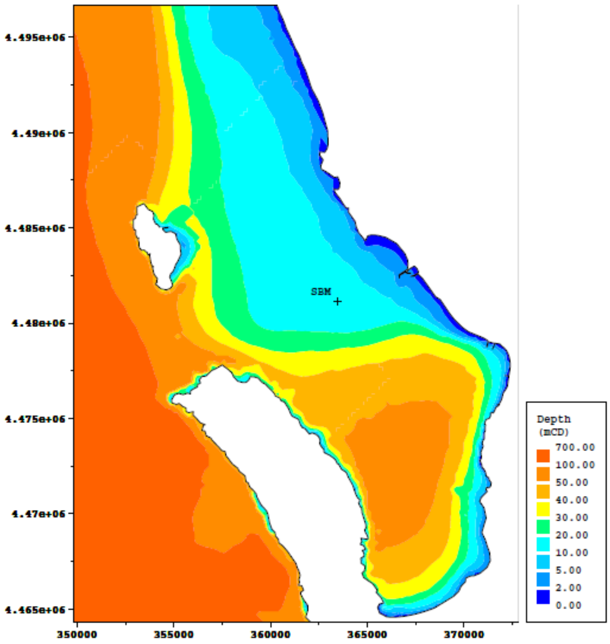

Figure 1. SWAN model bathymetry

SWAN was executed for a set of extreme wind states and offshore wave conditions. For the extreme wind conditions, the southerly wind direction sectors centered on 135°N, 180°N, and 225°N were considered. For each direction sector and return period, the model was run for three wind directions, the central wind direction plus 15° on either side of the central wind direction. Extreme wind speeds derived from the Vlore airport measured data were used. Given that SWAN represents fetch limited wave growth and not duration limited wave growth a three-hour duration wind speed was utilized as input data for model.

For the offshore wave conditions, all wave direction sectors between 210°N and 360°N were considered as shown in Figure 2. For each direction sector and return period, the model was run for three wave direction, the central wave plus 10° on both sides of the center direction of the wave. To allow for wave growth over the model area a wind speed was applied during the model run for each offshore wave condition.

These wind speeds were obtained from an analysis of the wind data and were chosen to be representative of the wind speed that would occur at the time of the offshore wave [5].

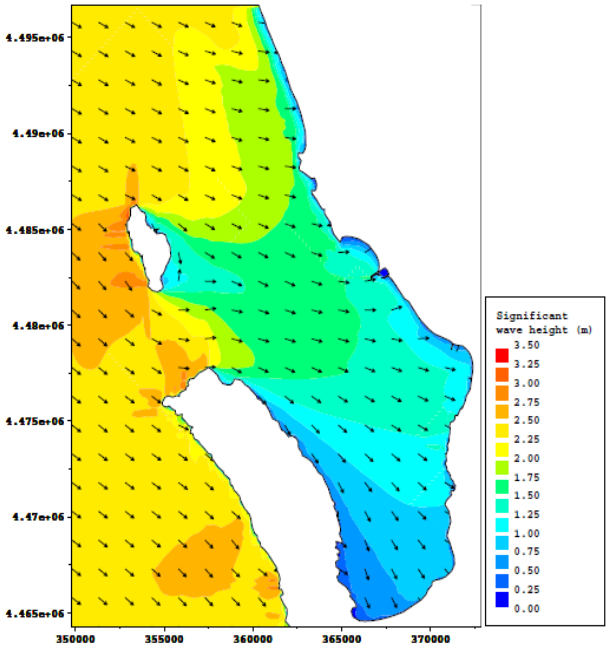

Figure 2. SWAN model results for 1 year return period 300°N offshore wave

The extreme wind and wave condition runs were carried out at a steady water level corresponding to Mean high water springs at Durres (+0.3mCD).

In addition, a large number of SWAN model runs were carried to cover the range of offshore wave conditions that can occur to derive a nearshore wave climate at the site. Given that the tidal range is small, these runs were carried out at a still water level corresponding to Mean Sea Level at Durres (+0.15mCD) [2].

Results from each of the model runs were extracted at the site of the SBM/CALM. The SBM/CALM was located on approximately -13.1mCD model depth contour 4.3 km away from the shoreline Figure 1.

5. CURRENTS

It was carried out a literature review regarding the flows in the region. Due to missing of the data, the study was performed based on the limited data that was found.

The level of the water due to spring tides is low in the range of 0.3 m. The other tides have a smaller magnitude. The tidal flow is approximately 6000 m^3/sec. The average speed of the tidal current is of the order of 0.06 ms^{-1}. This flow doesn't vary strongly with the depth, so 0.06 ms^{-1} will be the maximum value for the tidal current.

The flows caused by wind are limited because the Bay is surrounded on three sides by the land. The water surface slope generated from wind drag will slow down the accelerating flow. The direction of the wind may be such as to push water inside or outside of the bay. When a stable flow will be created the flow will be near zero (because the water can not run across the coast).

The wind-driven flow is reduced by the limited area and the current usually can not be greater than 1% of the wind speed. The maximum wind speed measured is in the range of 45 ms^{-1} and the current speed is expected to be in the range 0.4-0.5 ms^{-1} [6].

Also are expected other oceanographic flows due to salinity and temperature differences caused by the river inflows, solar heating, and evaporation, but anyway, such flow (in magnitude of 0.5 ms^{-1}) can not penetrate the bay.

The largest current expected will have flows not greater than 0.5 ms^{-1}. Anyway, there are some exceptional events that create internal waves and tsunamis. The current speeds derived from these occasional events should be in the magnitude of 0.5 ms^{-1} and not more.

As powerful earthquakes can happen, we can not exclude that if a tsunami is generated near to the site, currents of 1 ms^{-1} may occur.

6. WEIBULL DISTRIBUTION AND PREDICTION OF EXTREME WAVE CLIMATE

Does exist some methods for evaluating extreme events when limited data are available. They accommodate a standard probability distribution relevant to the available data. To achieve the extreme wave heights the corresponding extreme probability levels should be replaced in the equation.

The available data should be a representative pattern, for an instant, is acceptable one year of records. It is important that events which are recorded should be independent between them. We have used a great number of measured H_S values and have assumed that the absence of independence between adjacent values will be overcome by the big number of the data involved.

In the previous studies is found that the most reliable method for adjusting distributions of wave data is the Weibull distribution equation (1) with three parameters. These parameters should be calculated after we have plotted the various exceedance levels on the logarithmic scaled graph (2) and then is drawing the regression curve as a straight line through the points. In order to cross-check the results, the procedure should be reproduced by computer software, and then the results are compared between them.

The distribution of the extreme value [7]:

$$P(H_S) = 1 - \exp\{-[(H_S - a)/b]^C\} \tag{1}$$

where, H_S is significant wave height, P is probability less than H_S and a, b, c are parameters to be found.

Weibull Scales [7]

$$\log\{-\log[1 - P(H_S)]\} = c[\log(H_S - a) - \log b] \tag{2}$$

$$y = \log\{-\log[1 - P(H_S)]\} \tag{3}$$

$$x = \log(H_S - a) \tag{4}$$

where, x and y are plotted on linear scales.

Using the appropriate probability are determined the waves with a return period (N years). We should set the duration of the return period event, to calculate the probability. For example, if we chose 3 hours, it is calculated a total of 2922 hour periods per year, and the equation (5) give the probability of the 10 year return period event [7]:

$$P(10yearevent) = 1 - 1/(10 \times 2922) = 0.99966 \tag{5}$$

The relationship between the expected highest wave ($H_{\max}$) and the H_S is given by the formula [7]:

$$H_{\max} / H_S = (1/2 \ln N)^{1/2} \tag{6}$$

The number N in the above equation (6) is the number of waves in the sequence.

7. SWAN WAVE TRANSFORMATION MODEL

SWAN uses a spectral wave transformation model to achieve realistic evaluations of wave parameters in the coastal zone and current climate.

The program does work on a spectral representation of the wave action balance equation (or energy balance in the lack of currents) and all physical processes expected to ocur are modeled. There are no limitations imposed on the spectral evolution. This makes this software a third-generation wave model.

The wave model was understood to be a computationally feasible third - generation spectral wave model, used for waves in not deep water taking into consideration the currents in that area [8].

7.1. Application of SWAN to Vlore Bay

The SWAN model describes the waves in parameters of density spectrum $N(\sigma, \vartheta)$. The separate variables are the relative frequency σ and the direction of the wave ϑ (this is the direction measured normal to the wave crest). The density of the action is equivalent to the ratio of the density of energy with the relative frequency [9]:

$$N(\sigma, \vartheta) = E(\sigma, \vartheta) / \sigma \tag{7}$$

The wave action density spectrum can change in time and in a two-dimensional space. In Cartesian coordinates, the equation of balance is given [9]:

$$\frac{\partial}{\partial t} N + \frac{\partial}{\partial x} C_x N + \frac{\partial}{\partial y} C_y N + \frac{\partial}{\partial \sigma} C_\sigma N + \frac{\partial}{\partial \vartheta} C_\vartheta N = \frac{S(\sigma, \vartheta)}{\sigma} \tag{8}$$

7.2. The Transfer Mechanism of Energy from Wind to Waves

The transfer mechanism of the energy from the wind to the waves is explained with the resonance occurrence mechanism. Usually is explained as the addition of linear and exponential growth [9]:

$$S_{1n}(\sigma, \vartheta) = A + B \times E(\sigma, \vartheta) \tag{9}$$

The coefficients A and B depend on the wind direction and speed and from the frequency and direction of the wave and take into consideration the interaction of wind-waves by bearing attention on boundary conditions as effects of atmospheric layer and the roughness sea surface [10].

7.3. White capping

This phenomenon is controlled by the slope of the waves. In the SWAN wave model, the white capping formula is founded on an impulse model [9].

$$S_{ds,w} = -\Gamma \tilde{\sigma} \frac{k}{\tilde{k}} E(\sigma, \vartheta) \tag{10}$$

where, Γ is a coefficient that is dependending on the slope, k is the number of the wave and $\tilde{k}$, and $\tilde{\sigma}$ indicate a mean wave number and a mean frequency respectively. The Γ derive from the wind input data [11].

7.4. The Induced Dissipation due to Water Depth

This phenomenon is produced by the friction and the motion of the seabed, by infiltration, or by back - scattering on the irregularities of the seabed. For mediterranean sea, which has a seabed with sand, the main mechanism is seabed friction, which is given below [9]:

$$S_{ds,b}(\sigma, \vartheta) = -C_{bed} \frac{\sigma^2}{g^2 \sinh^2(kd)} E(\sigma, \vartheta) \tag{11}$$

The coefficient C_{bed} depends on the seabed friction. There are proposed a lot of models, like the nonlinear formulation based on drag or more complicated, eddy viscosity model [12].

7.5. The Induced Wave Breaking due to Water Depth

This process is not well understood and the knowledge regarding its spectral modeling is very poor, but we can model the total dissipation. The laboratory observation shows that the pattern at the start of unimodal spectra is nonsensitive to the induced breaking of the wave due to water depth. The below expression has been used in the SWAN model [9]:

$$S_{ds,br}(\sigma, \vartheta) = \frac{D_{tot}}{E_{tot}} E(\sigma, \vartheta) \tag{12}$$

where, E_{tot} represents the total energy of the wave and D_{tot} represents the portion of the total energy dissipation due to the breaking of the wave. The D_{tot} value is dependent on the breaking parameter $\gamma = H_{\max}/d$ (where for the local water depth d, $H_{\max}$ represents the maximum wave height). In SWAN $\gamma = 0.73$ is a constant value [13].

7.6. The Transmission of the Wave

The model can evaluate the transmission of the wave across an offshore structure, for an instant a breakwater. The bathymetric grid of the model can not resolve the too small plan area of the obstacles and for this reason, it is modeled as a line. The ratio between the (significant) wave height at the down wave side of the structure and the (significant) wave height at the upwave side gives the transmission coefficient.

SWAN assumes that over an offshore structure the frequencies remain invariant and only the energy of the spectrum is influenced and not the spectral pattern [14].

7.7. The nonlinear interaction wave-wave

The development of the spectrum, in deep water, is controlled by the wave-wave interaction. The wave energy is transferred from the spectral peak to lower frequencies (and the peak frequency moves to lower values) and to higher frequencies (when the mechanism that dominates the energy dissipation is the white capping) [15].

It was found that the full calculation of wave – wave interactions need a lot of time and it is inconvenient in any operational wave model. There are several techniques, to improve computational speed, which accommodate parametric or other types of approximations methods [16].

The current model for wind-generated surface gravity waves can be used on any scale, as it now can calculate on spherical coordinates (longitude, latitude), using more accurate numerical propagation schemes, which allow performing calculations in different situations, such as laboratory, coastal areas, seas, and oceans [17].

7.8. Typical Results of SWAN

- From the software were taken graphics of significant wave height H_s, and vector outlines of the direction of the mean wave, on the model space.
- Tables of H_s, T_z, T_p on onshore areas. For instance, the model may be used to explore the relationship between the offshore and inshore wave heights.
- Wave-induced forces per unit surface area fields, and other parameters can also be calculated from SWAN. For the sediment transport model, these results may be used as input.
- The 2D spectrum (frequency and direction) on onshore areas. This information can be used as input to harbor models or mathematical models of beach processes. Also, can be used to produce the random wave sequence for design purposes in a physical model.

8. RESULT AND DISCUSSION

1) From the SWAN were taken the extreme wave conditions and annually-averaged climate data at the site of the SBM/CALM. In addition, were taken color contour pattern of mean wave direction vectors and significant wave height, throughout the model domain.

2) The result presents the southerly extreme local wind-generated wave conditions at the SBM/CALM. The data collected presents the extreme wave conditions at the SBM/CALM that were a result of offshore waves that propagate to the site from the north-west and west. In each case, the greatest significant wave height that is predicted at the SBM/CALM for each wind direction sector/offshore wave direction sector is presented.

3) From data collected it can be observed that the greatest significant wave heights for 1 year and 100-year at the SBM/CALM are 2.5 m and 4.1 m respectively and are due to strong southerly winds. For the longer period of waves from offshore the greatest significant wave heights for 1-year and 100-year are 1.9 m and 3.6 m respectively.

4) The all-directional extreme wave conditions for the return periods of 1, 10, and 100 years are taken and the 100-year return period all directional extreme is 4.2 m.

5) For the wave conditions presented mean wave periods of up to 6.3 sec and peak wave periods of up to 11.5 sec have been predicted. An analysis of the wave spectra at the SBM/CALM showed that the shape of the wave spectra was generally JONSWAP with a gamma of approximately 1.5 for the locally generated wind and waves and a gamma of 2 for the longer period waves from offshore.

6) Results that present the annual averaged wave climate at the SBM/CALM were achieved. These wave climates include waves from offshore from directions between 120°N and 360°N and local wind-generated waves from wind directions between 120°N and 225°N. Of particular note from these climates is that the site experiences some swell waves with mean periods above 15 sec.

7) It should be noted that the SBM/CALM site will experience waves from all directions and this should be taken into consideration during the design phase of the SBM/CALM/. However, it is considered that waves with wave directions between north and south-east will be smaller than those presented.

9. CONCLUSIONS

1) A single Buoy Mooring (SBM/CALM) is being proposed in Vlore Bay, Albania. The SBM/CALM will be installed approximately in a water depth of 13 m CD and 4.3 km away from the coastline within the area of the bay. The wind and wave climate was necessary for use during the design of this structure. This study presents the derivation of these conditions.

2) The SBM/CALM will undergo the action of the waves that are produced offshore and then come through the entrance to the bay across the site from the north and west. The SBM/CALM will also undergo the action of the waves created locally by winds from the south and south–east.

3) The wind conditions in the bay were set up using the wind data recorded for nine years on site. This was the best source of wind data available at the time of this study, despite there were a big number of records missing from this data set. To calculate extreme wind speeds for return periods of 1, 10, and 100 years, the wind conditions were analyzed. The wind speed calculated for all directions 100 year return period and 1-hour duration was 47.7 ms^{-1}.

4) To calculate the wave conditions, representative of that which happen at the entrance of the bay, was used twenty years records of wave data from (UK) Met Office European Wave Model.

5) To calculate the extreme offshore wave conditions corresponding to return periods of 1, 10, and 100 years, these data were analyzed. The significant wave height derived was 6.7 m for all direction offshore for a return period of 100 years.

6) A third-generation wave refraction model was built up to depict the bay and used to transform the offshore wave climate and to calculate local wind-generated wave climate at the SBM/CALM. That way for relevant direction sectors, either extreme wave conditions and climate were forecasted. It was forecasted that for 100 year return period, the all-direction nearshore wave condition was 4.2 m.

7) It was carried out a literature review regarding the flows in the region. Due to missing of the data, the study was performed based on the limited data that was found. Based on this limited data, the largest current expected will have flows not greater than 0.5 ms^{-1}, however, we recommend that an ADPC is deployed in the bay to confirm this statement.

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