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Wind induced overtopping risk of a breakwater

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ABSTRACT

When the waves break on the slope of break water in the breaking zone, some amount of wave energy by turbulence due to wave breaking the remaining energy induced the waves to over top the break water. The vertical distance between highest water level and water table levels is known as the foreshore level of wave in breakwater zone. This study follows the previous studies which are paid escalade waves on the impermeable beach smooth. Wind Induced overtopping risk of a breakwateris calculated during a service period using data from local wind and the average occurrence of strong winds and the performance function , z, for theovertopping event and apply the method AFOSM (Advanced First Order Second Moment)for the feature confidence and likelihood of occurrence overtopping for a strong wind. Firstly the results show that the risk for three different values $(H_c - H_0)$ *are very variable. Secondly, If the water level is higher, considering the type of probability distribution for the wind will be more sensitive; As can be seen, in lesser* $(H_c - H_0)$*, more differences is obtained in the probabilities of each distribution.*

Key words: Probability of overtopping, risk, reliability, AFOSM method, breakwater.

INTRODUCTION

Increasing of water height because of the wind and wave at the back wall of break water is an event that could be Induce overtoppingin some cases.As result of waves hitting to lateral surface of the breakwater, a certain amount of water is drawn on the side of the line that called wave run-up. Depending on the amount of slope and kind of breakwater and wave height when hitting to it, the wave run-up can be very difference. In fact, with considering of wave run-up as well as other factors (such as tides), the maximum water level may be obtained at the edge of the breakwater that can be used to control overtopping of breakwater. Fig (1) shows how wave run-up occurred on the breakwater.

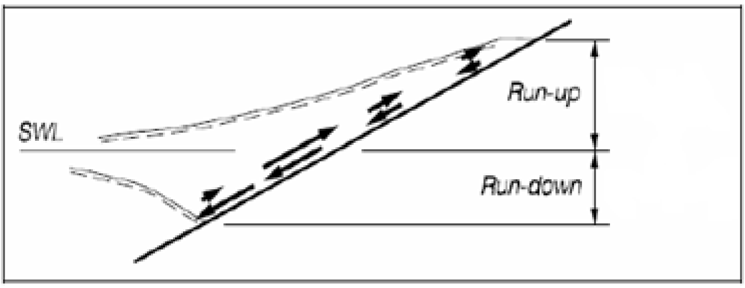

Figure 1 - the wave run-up near the break water[1].

Overtopping phenomenon is defined as $H > H_c - H_0$ that H_c is the final level of top of the breakwater, H_0 is water level height in the front of the break water and H is increasing of height of water level in the front of the break water due to wind, with this criterion, probability of overtoppingdue to the wind is defined as equation(1):

$$p_f = p(H > H_c - H_0) \quad (1)$$

$$p_f = p(z < 0) \quad (2)$$

$$z = (H_c - H_0) - H \quad (3)$$

z is called, the function and overtopping occurs when z<0. Wind induced overtopping follows from poison distribution with average occurrence rate (v_W). Then the wind induced overtopping risk can be estimated over a period of time of T by using of the following equation:

$$P_W(T) = 1 - \exp(-v_W T p_f) \quad (4)$$

So if v_W the average occurrence rate and p_f are known, the risk can be estimated. There are several methods to calculate p_f such as direct integration method, Monte Carlo method, AFOSM and MFOSM methods.[2]showed that AFOSM is appropriate method between the available methods to estimate levee safety. In this paper probability of overtopping because of wind and wave are calculated by using of risk analysis with AFOSM (Advanced First Order Second Moment) method. Then risk of overtopping because of wind and wave are calculated by random nature of wind and wave of coastline a definite period. In this paper, only the wind and wave profile considered random. Finally the height of the free board in breakwater design is calculated.

2. Wind induced overtopping probability

Wave height as result of wind usually is divided into two parts: (1)the effect of wind on wave height h_t is called setup and (2) the effect of wave on wave height h_r is called run upon the upstream slope of breakwater. [3] presented equation (5) for calculation of h_t for higher wind speeds as follows:

$$h_t = 0.045 V_w \sqrt{F_e} \quad (5)$$

In equation (5) h_t is setup on ft, V_w is wind velocity on (mile/hr) and F_e is along windward on mile. Run up height h_r is a function of wave profile that depends on ratio between wave height and wave length, slope, roughness and permeability of breakwater.[4], [5] presented the chart that shows function of these parameters on run up height h_r. The equation (6) is expressed instead diagram as follows:

$$h_r = a h_s \exp\left[-b\left(\frac{h_s}{L_W}\right)\right] \quad (6)$$

Values of a and b are presented in Tab (1) for the slope of the breakwater. In the equation (6), h_s is dominant wave height that is found following empirical formula:

$$h_s = 0.034 V_w^{1.06} F_e^{0.47} \quad (7)$$

Tab 1. Amount of a, b in equation (6) [5]

a and b in rough cover slope		**a and b in soft cover slope**		Slope(vertical to horizontal)
7.86	1.21	3.73	2.67	1 : 2
8.39	1.19	5.45	2.76	1 : 2.25
8.88	1.16	6.86	2.80	1 : 2.5
9.50	1.08	8.94	2.75	1 : 3
11.72	0.96	10.71	2.28	1 : 4

During a occurred strong wind, the probability of overtopping is calculated by equation (1), so that:

$$H = h_t + h_r \qquad (8)$$

h_t is water setup due to wind(ft), h_r is wave run up(ft), V_w is wind velocity ($^{mile}/_{hr}$), h_s is Dominant wave height(ft) and F_e is effect of fetch width (mile). Finally the function (Z)can be defined as follows:

$$Z = (H_c - H_0) - \left[0.45 V_w \sqrt{F_e} + 0.034 a V_w^{1.06} F_e^{0.47} \exp\left[-0.028 b \, {V_w^{0.18}}/{F_e^{0.09}}\right]\right] \qquad (9)$$

By using of AFOSM (Advanced First Order Second Moment) method P_f is calculated as follows:

$$P_f = 1 - \varphi(\beta) \qquad (10)$$

$\beta = \frac{E(Z)}{\sigma_Z}$ is reliability index, σ_Z is Standard deviation of the Z distribution, $E(Z)$ is Expected value and $\varphi(\beta)$ is the standard normal cumulative distribution that is evaluated in β level.

3. Wind velocity determination

For calculation of probability distribution of annual maximum wind velocity is used from 3 probability distribution function as follows:

Extreme Value Type I (Gumbel) [6]:

f(x) = á exp[-á(x - c) - exp(-á(x - c))]

F(x) = exp[-exp[-á(x - c)]]

$$\mu = (0.577216/\alpha) + c$$

$$\sigma^2 = \pi^2 / (6\alpha^2)$$

Extreme Value Type II (Frechet)[7]:

$$f(x) = {c}/{\alpha} \left(\frac{\alpha}{x}\right)^{c+1} \exp\left[-\left(\frac{\alpha}{x}\right)^{c}\right]$$

$$F(x) = \exp\left[-\left(\frac{\alpha}{x}\right)^{c}\right]$$

$$\mu = \alpha \ \tau(1\text{-}1/c)$$

$$\sigma^2 = \alpha^2[\tau(1-\frac{2}{c}) - \tau^2(1-\frac{1}{c})]$$

Rayleigh Distribution[8]:

$$f(x) = {(x-c)}/{\alpha^2} \exp[-{1}/{2}({(x-c)}/{\alpha})^2]$$

$$F(x) = 1 - \exp[-{1}/{2}(\frac{(x-c}{\alpha})2] \quad \mu = \sqrt{{\pi}/{2\alpha}} + c$$

$$\sigma^2 = (2 - {\pi}/{2})\alpha^2$$

In above relationships f(x) is probability density function, F(x) is distribution function, μ is average and σ^2 is variance. Wind velocity V_w must be measured above the water level for estimation of setup and run up but available data for V_w is used from Zabol station in land. For correction of V_w, [5] presented a factor that is showed in Table (2).

Tab 2. Amount of correction factor for wind velocity

Fetch wind length (mile)	0.5	1	2	3	4	5
(Wind velocity in water/ Wind velocity in land) (correction factor)	1.08	1.13	1.21	1.28	1.31	1.31

4. Research limitations/implications

Performance Function, Z, for the overtopping probability of occurrence of a strong wind depends on some factors such as wind velocity, V_w, the effective wind Fetch, F_e, the water level(H_0) and the level of the break water crest(H_c). It should be noted that no errors related to the model formulation by Bretschneider and Savilleis not considered. Therefore, the wind velocity (V_w) is the only random variable. Maximum wind velocity is assumed that be occurred in the direction of effective wind Fetch.

5. Numerical result

In this study is paid to evaluation of wind induced overtopping risk as follows:

1- Use of local wind data and determination of occurrence average of sewer wind.
2- Determine the function z for the overtopping of breakwater.
3- Putting the values of all variables, X_i, in the function and uncertainty analysis for these variables.

4 - Apply the AFOSM method for reliability index.
5 -Overtopping probability for the occurrence of a strong wind (P_f).

6 -Calculated wind induced overtoppingrisk in a service period using the relation (4).

In order to further clarify how to apply the concept of wind induced overtopping riskthat was described in the previous sections, wind induced overtopping risk of a constructed breakwater in Oman Sea is calculated. Fetch length is assumed 1200 m. Information of wind velocity readings are measured in Zabol for 36 years of data (1998-1964).Correction factor should be relevant to the interpretation of the surface water is applied to the land use Table (2) that is obtained 1.13.Also list for this year's is presented as a series of annual maximum wind data in Table (3). Need to remember that this study is used from every 3 statistical distribution (Gumbel, frechet, Rayleigh) and the combined failure. The calculated values for the mean and variance of each distribution are presented in Table (4) below.

Tab 3. Annual maximum wind velocity in Zabol air station

year	Wind velocity (km/hr)	year	Wind velocity (km/hr)	year	Wind velocity (km/hr)
1963	83	1975	56	1987	78
1964	87	1976	83	1988	81
1965	52	1977	56	1989	78
1966	59	1978	89	1990	70
1967	46	1979	148	1991	78
1968	52	1980	65	1992	85
1969	52	1981	56	1993	70
1970	68	1982	54	1994	74
1971	68	1983	96	1995	63
1972	56	1984	142	1996	70
1973	56	1985	89	1997	81
1974	83	1986	78	1998	85

Table 4.probability of overtoppingdue to the occurrence of a strong wind

distributionRayleigh	distributionFrechet	Gumbeldistribution	Parameter
51.49 14.84	52.07 17.75	55.66 15.83	*Average* Standard deviation
0.39	0.27	0.34	r_i
$7.4 * 10^{-1}$	$7.1 * 10^{-1}$	$7.3 * 10^{-1}$	P_f for $H_c - H_0 = 1$
$2.0 * 10^{-1}$	$2.5 * 10^{-1}$	$2.2 * 10^{-1}$	P_f for $H_c - H_0 = 1.5$
$1.04 * 10^{-2}$	$2.87 * 10^{-2}$	$1.55 * 10^{-2}$	P_f for $H_c - H_0 = 2$

By using of probabilistic distribution for wind velocity, overtopping probability is varied considerably. Lowest P_f is for Rayleigh distribution and highest P_f obtained by for Frechet distribution. Since the probability distribution for wind is still not known exactly, it can be assumed that each of these distributions is correct, then combined possibility is used for P_f. [9] presented weight method to calculate the combined probability of an occurrence of a wind in the form provided N distribution with respect to:

$$P_f = \sum_{i=1}^{N} r_i P_{fi} \tag{19}$$

$$r_i = \frac{1/var_i(V_W)}{\sum_{j=1}^{N}\left[\frac{1}{Var_j(V_W)}\right]} \tag{20}$$

r_i values of each distribution are given in Table 4.Wind induced overtopping risk at different return periods, $P_W(T)$, can be calculated by use of the equation (4). Using the annual maximum wind velocity data in Table 3, average occurrence rate of wind is obtained 0.493.With an average occurrence rate 0.493, v_W = 0.493, the results in Table (5) based on different return periods and amounts of $P_W(T)$ is presented.

Tab(5).Amount of $P_w(T)$ per amount of different $H_c - H_0$

	$P_w(T)$	$P_w(T)$	$P_w(T)$
return period T (year)	$H_c - H_0 = 1$	$H_c - H_0 = 1.5$	$H_c - H_0 = 2$
1	3.03×10^{-1}	1.05×10^{-1}	1.69×10^{-2}
5	8.35×10^{-1}	4.26×10^{-1}	8.18×10^{-2}
10	9.73×10^{-1}	6.71×10^{-1}	1.57×10^{-1}
50	1	9.96×10^{-1}	5.74×10^{-1}
100	1	9.99×10^{-1}	8.19×10^{-1}
1000	1	1	1

RESULTS

In this study wind Induced overtopping risk of a break water is calculated during a service period using data from local wind and the average occurrence of strong winds and the performance function, z, for the overtopping event and apply the method AFOSM (Advanced First Order Second Moment) for the feature confidence and likelihood of occurrence overtopping for a strong wind. A value of 1, 1.5 and 2 meters for overtopping $(H_c - H_0)$ is considered. Tab. 1 show firstly the amount of risk for three different values of $(H_c - H_0)$ are highly variable so that the risk changes strongly depends on change of $(H_c - H_0)$ and secondly whenever the water level is higher, considering the type of probability distribution for the wind to be more sensitive. And then Tab. 2 shows $P_w(T)$ for weighted average of 3 probability distributions used for wind velocity. There liability index, β, is calculated using AFOSM. Overtopping probability for wind occurrence, P_f, has been calculated and shown in Table. Overtopping risk of wind at different return periods, can be calculated. Using data from the annual maximum wind velocity is shown in Table (3), the average wind incidence rate is obtained equal to 0.493. For $v_w = 0.493$, the results are presented are based on different return periods and amounts of $P_w(T)$. Firstly the results show that the risk for three different values $(H_c - H_0)$ are very variable. So that the changes of risk depend on Changes of $(H_c - H_0)$. The higher sea water level is the lesser of $(H_c - H_0)$, the more rate of overtopping phenomenon in the shorter return period. It can be concluded that the risk of wind overtopping becomes important only when if is associated with the other factors (e. g. tsunami and tide); Secondly, If the water level is higher, considering the type of probability distribution for the wind will be more sensitive; As can be seen, in lesser $(H_c - H_0)$ more differences is obtained in the probabilities of each distribution.

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