Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (41) No. (4) October, 2019

Experimental Study of Wave Overtopping on Seawalls

Mohamed A. Salah [1], Yasser E. Mostafa [2], Ahmed M. Balah [3]
1 Demonstrator, Dept. of Irrigation and Hydraulics, Ain Shams University.
2 Professor of Harbor Engineering and Marine Structures, Ain Shams University
3 Assistant Professor, Dept. of Irrigation and Hydraulics, Ain Shams University.

الملخص
إن تخطى الأمواج للحوائط البحرية هي ظاهرة مؤثرة في تحديد كفاءة اعمال حماية السواحل .ويعد تقييم معدلات تخطى الامواج جانبا اساسيا في تصميم المنشآت الساحلية. وقد ثبت ان زيادة خشونة اسطح الحوائط البحرية المائلة له أثر ملحوظ في تقليل معدلات تخطي الأمواج لهذه الحوائط. يعرض هذا البحث تأثير تبديد طاقة الأمواج على تقليل معدلات تخطى الامواج باستخدام النماذج التجريبية وذلك للحائط البحرى ذات ميول 2 افقى: 1 رأسى، مع تغيير خشونة الحائط واضافة حاجز أمواج غاطس امامه. أجريت الاختبارات المعملية في قناة معملية خاصة للامواج في قسم الري والهيدروليكيا بكلية الهندسة جامعة عين شمس، وتم تنفيذ الاختبارات المعملية علي مجموعة مختلفة من النماذج من اجل تحديد تأثير العوامل المختلفة المتعلقة بطرق تبديد طاقة الأمواج علي معدلات تخطي الأمواج الغير منكسرة. حيث تم اختبار حائط بحرى له سطح أملس، حائط بحرى أملس السطح مع وجود حاجز أمواج غاطس على مسافات مختلفة من الحائط البحرى، واخرا حائط بحرى له سطح خشن مكون من طبقتين من الحجارة مع تغيير ارتفاع هذا السطح الخشن. وقد تم تحديد تأثر الخشونة بالمقارنة بالنتائج المتحصل عليها من المعادلات المستنتجة من الدراسات السابقة وتم استنتاج معاملات تخفيض معدلات التصرف لكل حالة والتي يمكن استخدامها في التصميم.

Abstract
Wave overtopping is a key process in coastal environment. The assessment of the wave overtopping rates is an important aspect in the design of different coastal structures, such as seawalls. It was found that increasing the roughness of the seawall slope has significant impact on reducing the wave overtopping rates due to its energy dissipation effect. This paper presents the study of modeling wave overtopping using experimentally to investigate the effect of energy dissipation on reducing wave overtopping discharge for sloped seawall 2H:1V with an inherent or artificially added degree of roughness. Experimental tests were conducted in the wave flume at the Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University. Different models were tested under various wave and water depth conditions to examine the efficiency of the two types of energy dissipation measures; increasing the roughness of the seawall slope and construct a submerged breakwater in front of the wall. Only non-breaking waves are investigated. The tested models include a smooth seawall, a smooth seawall with submerged breakwater in front of it at variable distance and a rough seawall with two-layers of riprap and varying the riprap height. The impact of the proposed energy dissipation measures was quantified by comparing the obtained results to known wave overtopping estimation formulae in literature where no such measures were adopted and accordingly the reduction factors for these measures were deduced.
Keywords: *seawalls, wave overtopping, wave energy dissipation, experimental modelling.*

Introduction
A major part of the protection of coastal areas is safety against flooding. Due to the effects of global warming, global sea level rises at an increased rate every year as a combination of water expanding, as well as land ice melting. Ultimately this leads to an

increased wave attack on coastal defense structures. In order to prevent major damage to infrastructure, human life, or nature, detailed knowledge of the overtopping process, both individual as well as average overtopping rates, is required. This knowledge can be employed in design guidelines for engineers around the world to protect the hinterland of coastal defense structures everywhere.

Recently, December 2010, a storm attacked Alexandria city and its beaches. The storm generated deep wave height of 7.5 meter for the first time in the last 100 years. As a result of this surge storms, water and sand overtopped the seawall and destroyed many parts of it. Figure 1 shows one example of this serious problem. Due to the continuity of coming wave and speedy winds, the sea level has been raised for about one meter causing a serious flooding problem.

Wave Overtopping on Seawalls

Historically, sloping dikes have been the most widely used option for sea defenses along the coasts of the Netherlands, Denmark, Germany and many parts of the UK. Dikes or embankment seawalls have been built along many Dutch, Danish or German coastlines protecting the land behind from flooding, and sometimes providing additional amenity value. Similar structures in UK may alternatively be formed by clay materials or from a vegetated shingle ridge, in both instances allowing the side slopes to be steeper.

Figure 1 Wave flooding due the sea level rise at Alexandria coastline, 2010.

Wave overtopping is the average discharge per linear meter of width, q, for example in m^3/s per m or in l/s per m. The methods described in previous studies calculate all overtopping discharges in m^3/s per m. In reality, there is no constant discharge over the crest of a structure during overtopping. The process of wave overtopping is very random in time, space and volume. The highest waves will push a large volume of water over the crest in a short period of time (less than a wave period), whereas lower waves may not produce any overtopping.

During the last two decades, available literature on wave overtopping has drastically increased. In the past, many different manuals were available: in the UK, the Netherlands as well as Germany. These manuals (EA Overtopping manual (Besley, 1999), TAW Technical Report on Wave run up and wave overtopping at dikes (Van Der Meer, 2002), Owen (1980) and Die Küste (EAK 2002)) alongside, at the time, new research in several international collaboration projects such as CLASH (Crest Level Assessment of coastal Structures by full scale monitoring, neural network prediction and Hazard analysis on permissible wave overtopping) have led to a strong surge of internationally available data.

However, a desire was present to bundle the existing knowledge into one code that can be used as a basis for all design purposes. This gave rise to the EurOtop Manual (2007). Due to the available new research since 2007, an updated version of the manual was released last year, EurOtop Manual (2016).

The Van der Meer & Bruce (2014) prediction formul, using the values of coefficients *a* and *b* specified in EurOtop 2016. (for non-breaking waves)

$$\frac{q}{\sqrt{g\,{H_{m0}}^3}} = a\,\exp\left[-\left(b\,\frac{R_c}{H_{m0}}\right)^{1.3}\right]$$

In this prediction formula, q is the average overtopping rate, H_{m0} is the incident spectral wave height measured at the toe of the structure, R_c is the crest freeboard and a and b are empirically determined constants. The reliability of the constants is given by $\sigma'(a)=\sigma(a)/\mu(a)=0.15$ and $\sigma(b)=0.10$.

$a = 0.09 - 0.01\,(2 - \cot\alpha)^{2.1}$ for $\cot\alpha < 2$ and $a = 0.09$ for $\cot\alpha \geq 2$

$b = 1.5 + 0.42\,(2 - \cot\alpha)^{1.5}$, with a maximum of $b = 2.35$ and $b = 1.5$ for $\cot\alpha \geq 2$, in our case $\cot\alpha=2$, so $a= 0.09$ & $b = 1.5$. then the equation will be written as:

$$\frac{q}{\sqrt{g\,{H_{m0}}^3}} = 0.09\,\exp\left[-\left(1.5\,\frac{R_c}{H_{m0}}\right)^{1.3}\right]$$

This formula can be used for all ranges of relative crest freeboard values R_c/H_{m0}, which is a welcome improvement from the previously recommended prediction formula. The Van der Meer & Bruce (2014) formula is partly based on the research by Victor et al. (2012), and the most drastic change was the inclusion of the exponent 1.3, which allows to more accurately predict dimensionless overtopping rates for low values of the relative crest freeboard $R_c/H_{m0} < 0.5$ in sloped structures. It should be noted that this formula was designed based on deep water conditions only and it is suggested by Nørgaard et al (2014) to adjust the coefficients *a* and *b* in the case of shallow water conditions.

Experimental Setup

The experimental testing was performed at the wave flume at the Irrigation and Hydraulics Department, Faculty of Engineering, Ain-Shams university, shown in

Figure 2, during the period from January to July 2019. This wave flume has a width of 0.80m, a height of 0.60 m and a total length of 10.0 m end-to-end, including the wave generation section at one end and Collection tank at the other end. Figure 3 shows a schematic drawing of the wave flume, wave paddle, wave gages, seawall model and water collection tank.

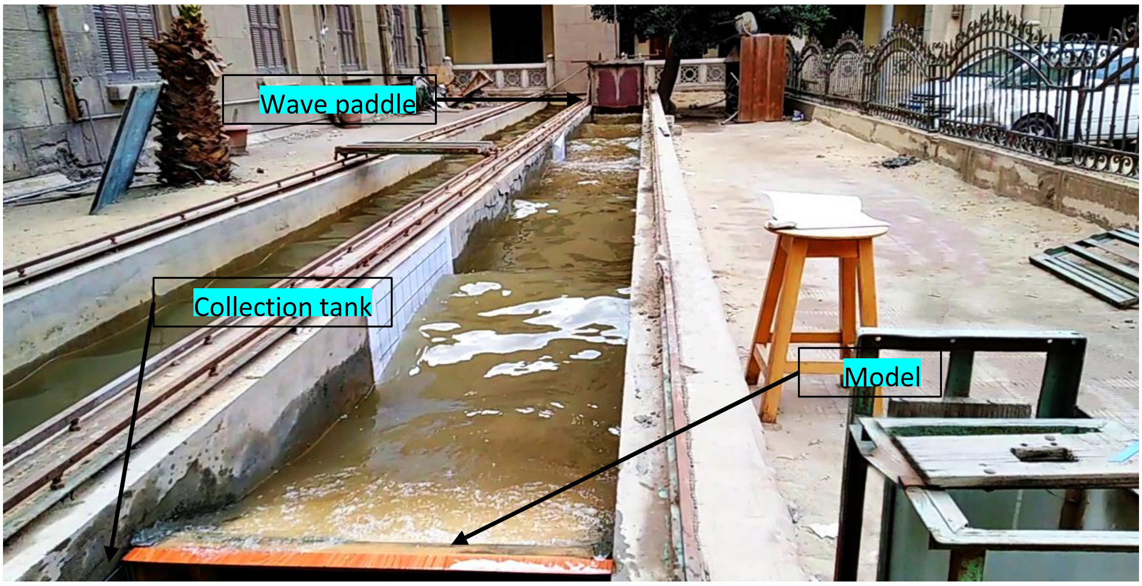

Figure 2 Experimental wave flume

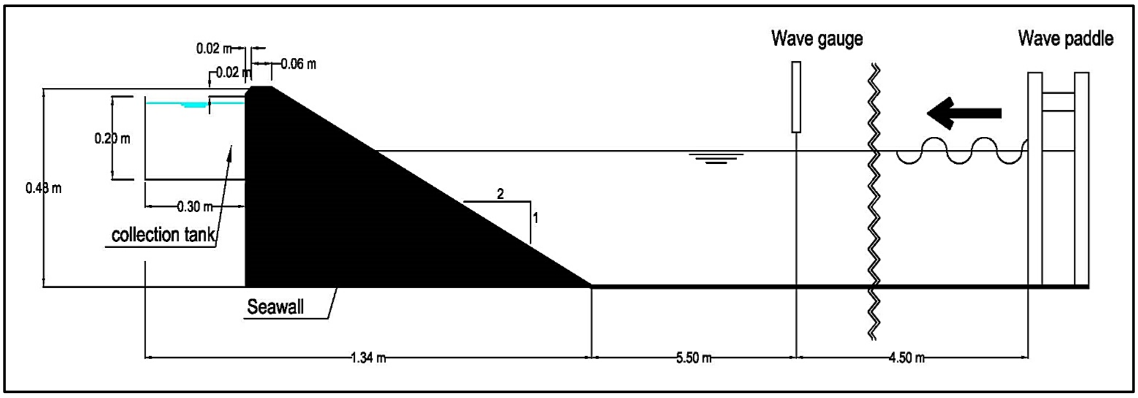

Figure 3 Schematic view of the wave flume, wave paddle, wave gages, seawall model and water collection tank.

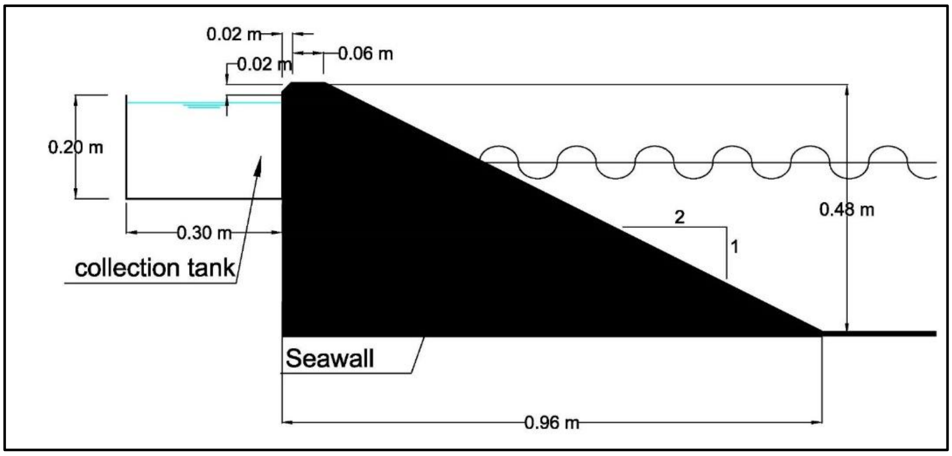

Figure 4 Details of model cross-section and water collection tank. (Units: centimeters).

Measuring the wave heights in the flume is done by wave gauge (**Sonic Wave Sensor**), positioned at distance from wave maker. The basic operating principle is to measure the ultra sound travel time. at one end of the flume an overtopping collection tank has been installed (80 × 30 × 20 cm). This overtopping tank is made out of glass and protected by the test structure that is in place. In this collection tank vertical scales fixed on the side wall of the tank. The maximum volume the tank can hold is 48 liters. The details of the model cross section and water collection tank are shown in Figure 4.

Physical model tests were performed with different seawall profiles under the same marine conditions, i.e. water-level, input wave height and period. The overtopping is measured for each seawall profile to compare the influence of roughness on seawall on overtopping rates. The effect of wind was not included in the scope of this study. For all setups there are hydraulic boundary parameters that changed within range as in table.

Table 1 Hydraulic boundary conditions of the test setups

Crest height (above foreshore)	0.48	m
Water depth at toe of the structure	0.26-0.42	m
Water depth at the wave paddle	0.45-0.62	m
Freeboard (R_c)	0.06-0.22	m
Wave height (H_{m0})	0.08-0.20	m
Wave peak period (T_p)	1.05-1.55	sec
Wave steepness (S_0) based on $T_{m-1,0}$	0.03-0.085	-
Dimensionless freeboard (R_c / H_{m0})	0.40-2.355	-

The three setups studies were as follows:

- Setup-1: Smooth seawall (2:1) (H: V), which is the reference case
- Setup-2: Smooth seawall with submerged breakwater at distance from the model (1.0 m & 3.0 m and 5.0 m).
- Setup-3: Rough seawall by adding riprap-two layers on sloped seawall.

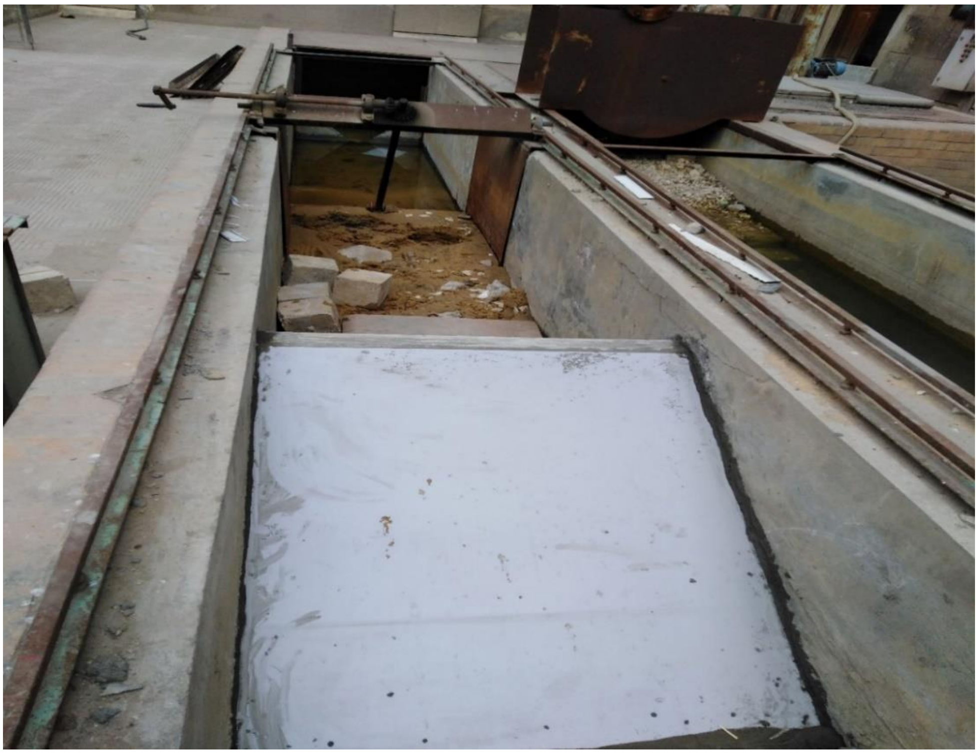

Figure 5 Smooth seawall with front slope 2:1 (H: V).

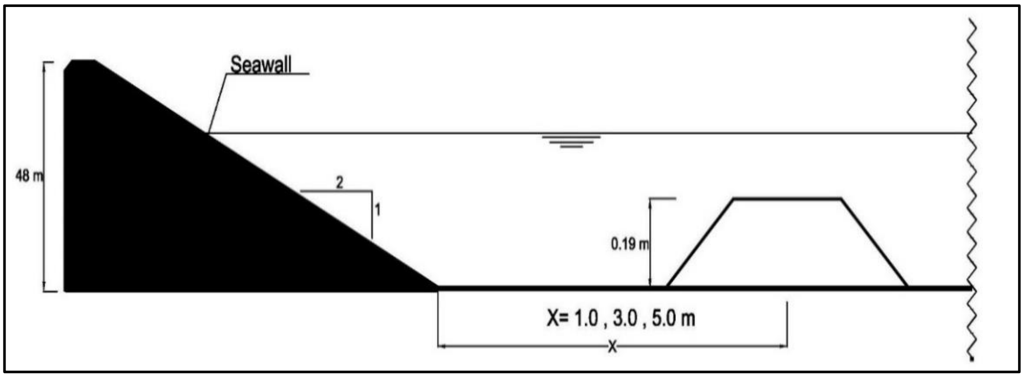

Figure 6 Sketch of the submerged breakwater in front of the seawall model.

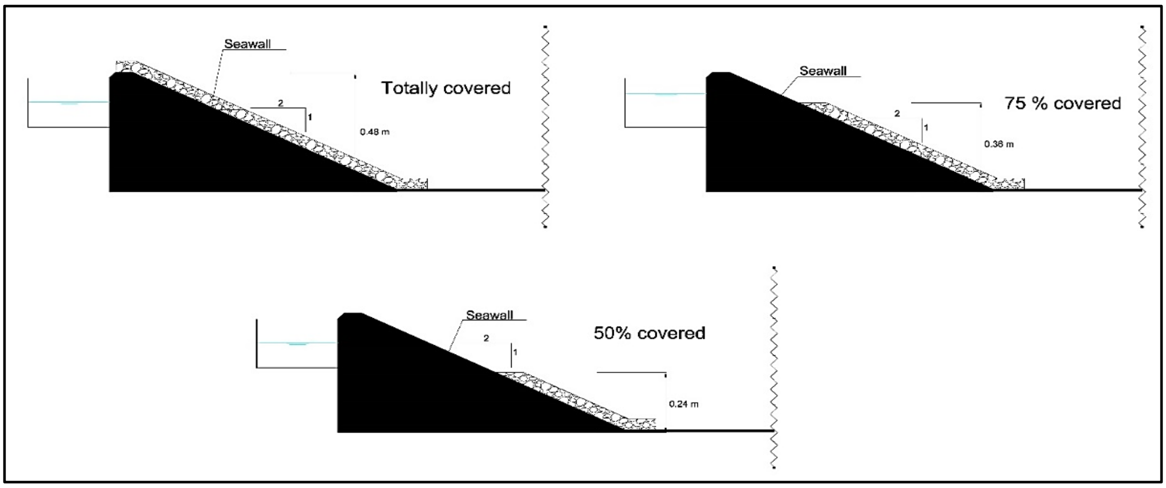

Figure 7 Different setup of rough seawall case.

Results and Analysis
Reference case: smooth seawall

For smooth seawall geometry, a total number of 35 tests were performed. Typically, the study of overtopping discharge is performed using two main parameters: the dimensionless overtopping rate $q/\sqrt{g\ H_{m0}{}^3}$ and the relative crest freeboard R_c/H_{m0}, as the latter combines the two most influential parameters concerning overtopping.

As can be expected from the known influence of the parameters, all test setups show a decreasing trend of the dimensionless overtopping rate $q/\sqrt{g\ H_{m0}{}^3}$ with increasing relative crest freeboard R_c/H_{m0}. Figure 8 indicates that the decreasing trend is visually similar to the traditional Weibull-shape. This behavior is expected with low values for the relative crest freeboard R_c/H_{m0}, wave heights can be quite large in comparison to the freeboard of the structure, which affect in increasing the overtopping volumes. On the other hand, large values for the available freeboard will control the overtopping process which results in lower overtopping volumes.

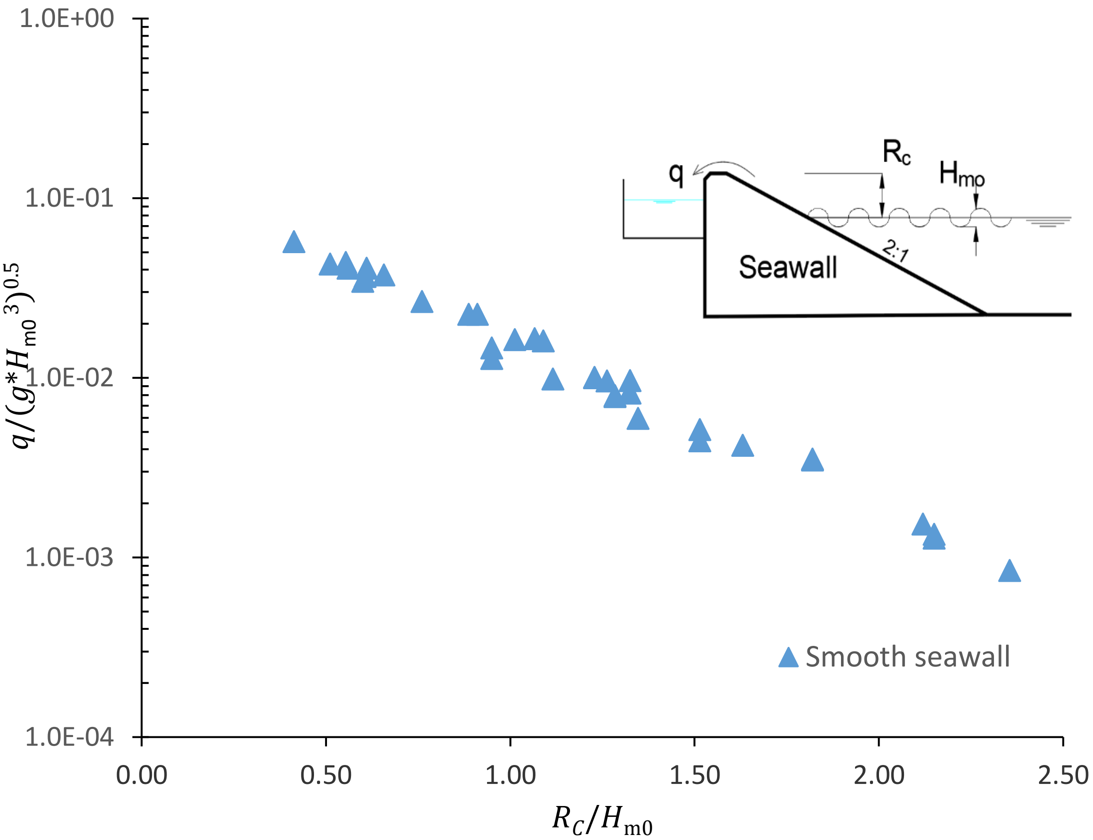

Figure 8 Dimensionless overtopping rate $q/\sqrt{g\ H_{m0}{}^3}$ as a function of the relative crest freeboard R_c/H_{m0} for smooth seawall.

Figure 9 shows the results of the current study for smooth seawall condition with Van der Meer & Bruce (2014) (EurOtop manual 2016 equation 5.11). in addition to the mean prediction line in the graph, the 5% lower and upper confidence limits have been plotted (= 90% confidence interval))

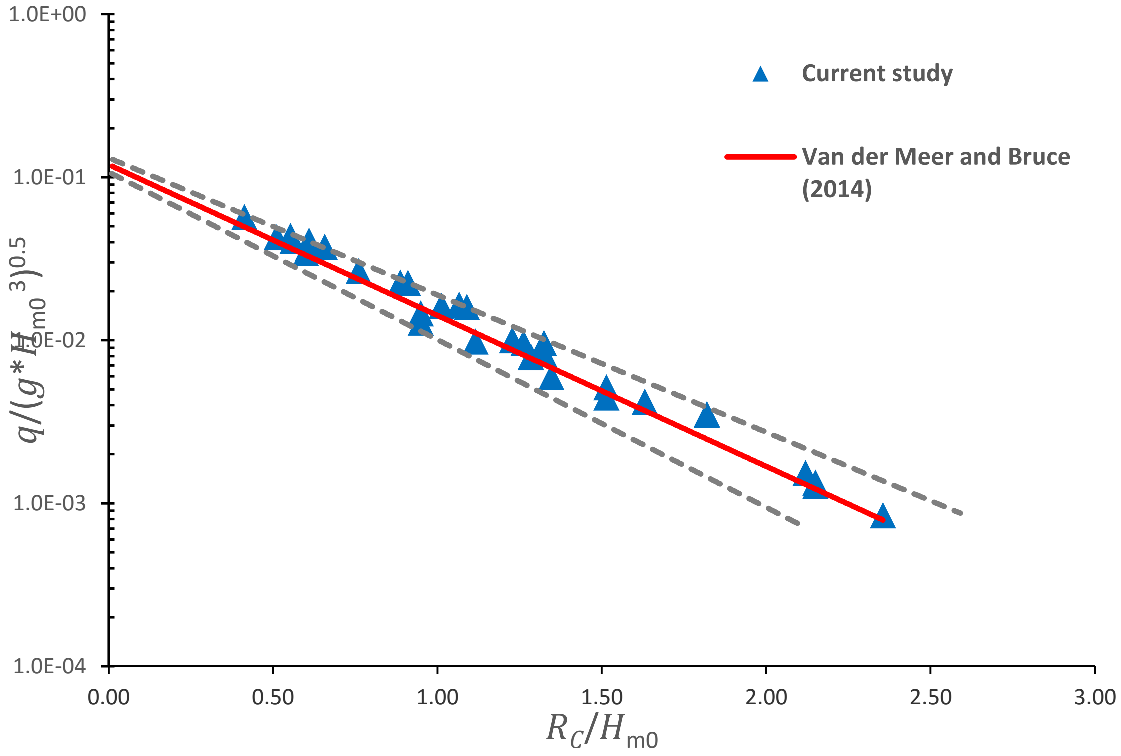

Figure 9 Dimensionless overtopping rate $q/\sqrt{g\,H_{m0}{}^{3}}$ as a function of the relative freeboard R_C/H_{m0} and including equation of Van der Meer and Bruce (2014) case of smooth seawall.

Smooth seawall with submerged breakwater.

A submerged Breakwater was added at a certain distance from the model (X= 1.0, 3.0, 5.0 m), which are equivalent to ($\frac{X}{H_{BW}}$ = 5.25 & 15.79 &26.31) where H_{BW} is the height of the submerged breakwater. A total of 90 tests were performed, 30 tests were conducted for each case. In this section, the impact of changing location of submerged breakwater on overtopping discharge over seawall is discussed.

Figure 10 shows dimensionless overtopping rate $q/\sqrt{g\,H_{m0}{}^{3}}$ as a function of the relative crest freeboard R_c/H_{m0} for the three cases compared to the reference case.

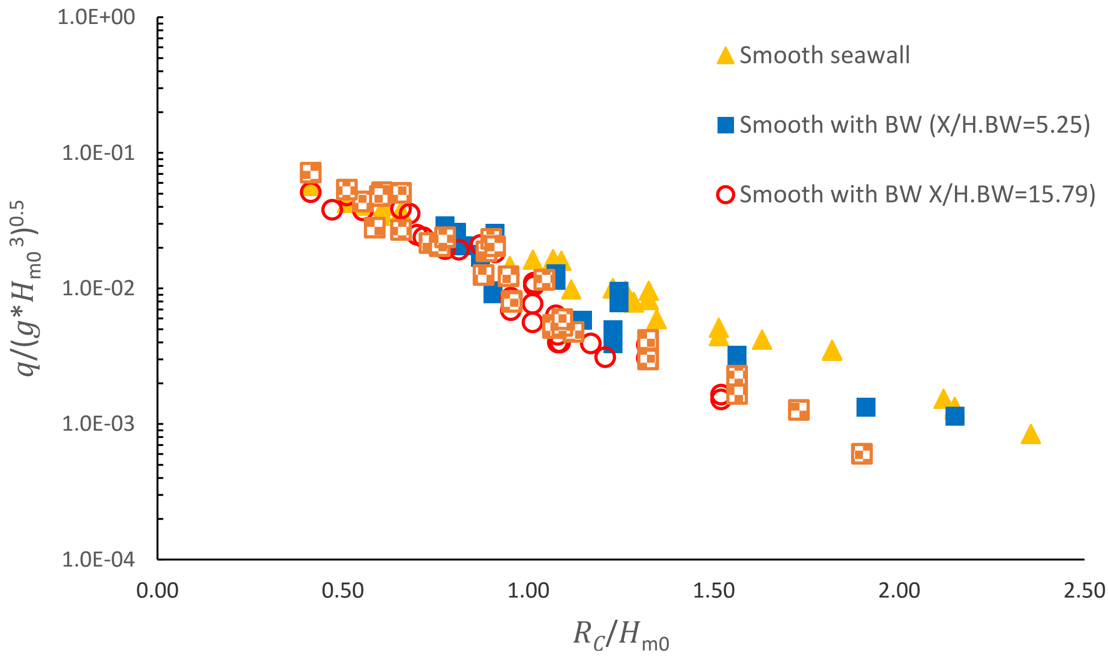

Figure 10 Dimensionless overtopping rate $q/\sqrt{g\ H_{m0}{}^3}$ as a function of relative crest freeboard R_c/H_{mo} for all cases of submerged breakwater.

At the three location of submerged breakwater when R_c/H_{m0} <1.0 there are a minor change with reference case due to decreasing in freeboard and that meaning increasing in water depth, so the effect of dissipation due to submerged breakwater will be vanish. From Figure 10 the results arising from the present laboratory experiments show that the location of submerged breakwater at distance 3.0 m from the seawall ($\frac{X}{H_{BW}} = 15.79$) was the best in reducing overtopping rate compared to the other two cases ($\frac{X}{H_{BW}} = 5.25$ and $\frac{X}{H_{BW}} = 26.31$).

Calculation of Reduction Influence Factor γ_f

To determine the Reduction Influence Factor γ_f, the method of least mean square errors (MSE) was used. First, γ_f is added to the prediction formula (Van der Meer and Bruce (2014)) in the denominator of the relative crest freeboard R_c/H_{m0}.

$$\frac{q}{\sqrt{g\ H_{m0}{}^3}} = 0.09\ exp\left[-\left(1.5\frac{R_c}{H_{m0}\ \cdot\gamma_f}\right)^{1.3}\right]$$

to determine Influence Factor $\boldsymbol{\gamma_f}$, the method of least mean square errors was used. Then, by varying values for γ_f from 0.00 to 1.00 in increments of 0.01, the errors are determined between the predicted values of each specific test within the considered setup and the actual observed value of the dimensionless overtopping of that test. Initially, these values were used in a classical least mean square error calculation to determine the best fitting $\boldsymbol{\gamma_f}$.

In Figure 11, Figure 12 and Figure 13 the prediction formula that mentioned above with the reduction influence factor γ_f were plotted . As was found for which value have best feting, a reduction factor of $\gamma_f = 0.90$ for case which breakwater at distance 1.0 m from the model, at the other setups where distance equal 3.0 & 5.0 m the reduction factor was found $\gamma_f = 0.80$ & $\gamma_f = 0.83$ respectively.

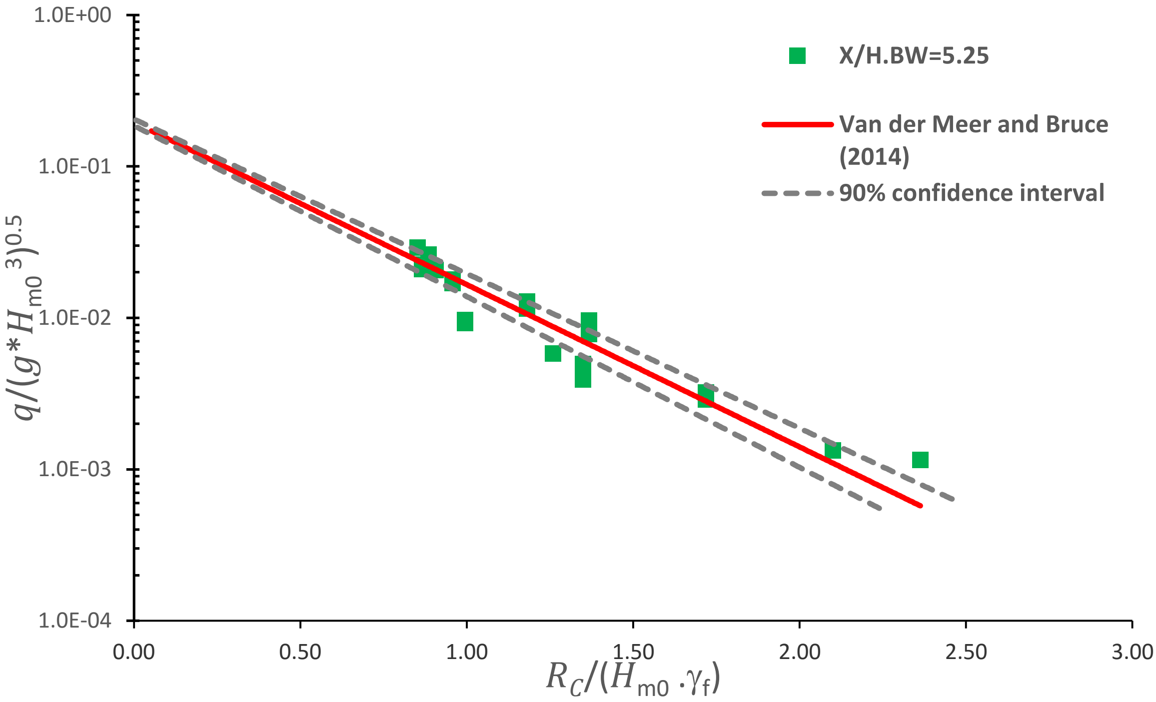

Figure 11 Dimensionless overtopping rate $q/\sqrt{g\ H_{m0}{}^3}$ as a function of relative crest freeboard R_c/H_{mo} for case of Breakwater at distance 1.0 m from the model with reduction influence factor γ_f.

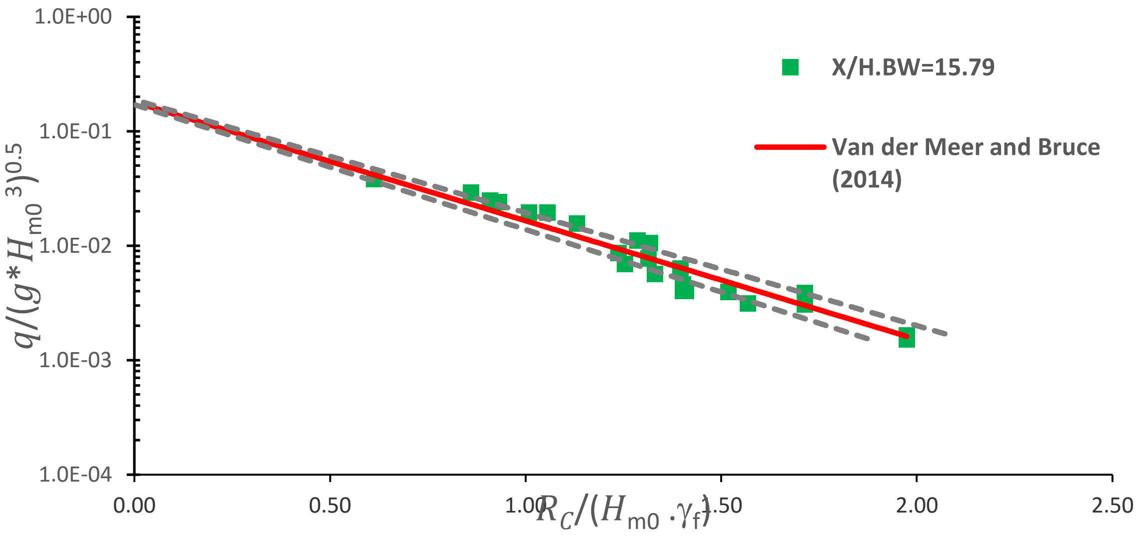

Figure 12 Dimensionless overtopping rate $q/\sqrt{g\ H_{m0}{}^3}$ as a function of relative crest freeboard R_c/H_{mo} for case of Breakwater at distance 3.0 m from the model with reduction influence factor γ_f.

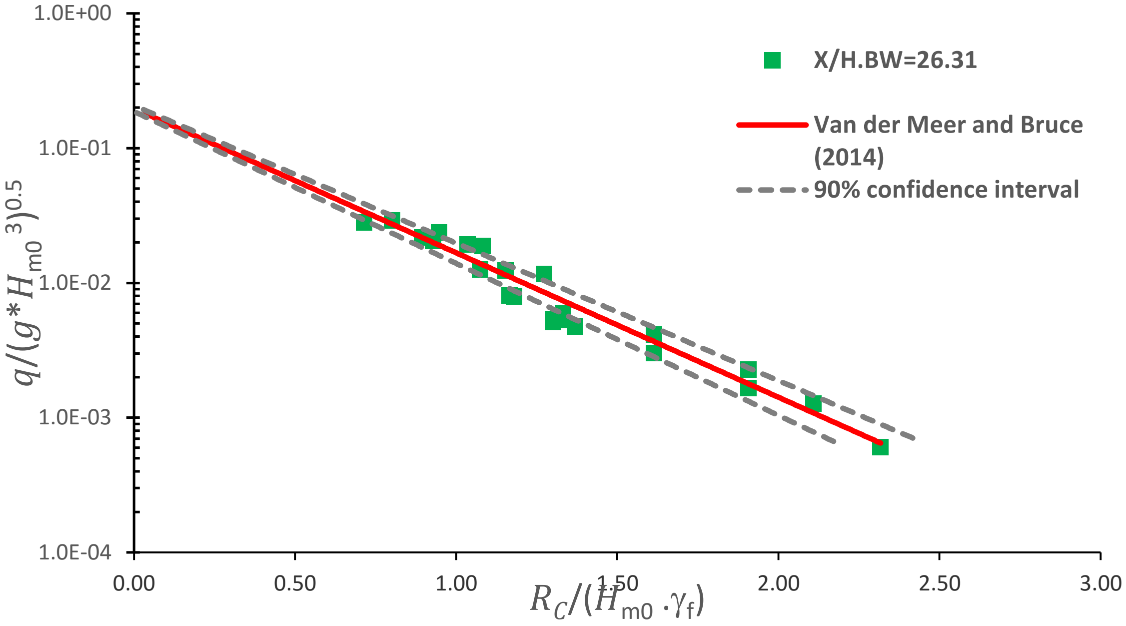

Figure 13 Dimensionless overtopping rate $q/\sqrt{g\,H_{m0}{}^{3}}$ as a function of relative crest freeboard R_c/H_{mo} for case of Breakwater at distance 5.0 m from the model with reduction influence factor γ_f.

Rough seawall

Third setup to decrease overtopping by adding riprap-two layers on sloped seawall to dissipate energy at the seawall model. Riprap of d_{50} equals to 6 mm was used to make a rough slope based on slope stability of stones to can resist waves and to be stable against movement.

Three setups were studied with different height of riprap that covered the front slop of the model to understand the relation between height of riprap (H_r) on sloped seawall with the influence factor of roughness (γ_f).

Fist setup was conducted by covering all of the front seawall slope ($\frac{H_r}{H_{s.w}} = 1.0$). The second setup was conducted by covering 75% of the front slope ($\frac{H_r}{H_{s.w}} = 0.75$) and the third setup was by covering 50% of the slope ($\frac{H_r}{H_{s.w}} = 0.5$). For each case, 2-layers of riprap were used.

For this geometry, a total number of 75 tests were performed; 25 tests were conducted for each case of riprap height. The dimensionless overtopping rate $q/\sqrt{g\,H_{m0}{}^{3}}$ that was obtained in these tests is shown as a function of the relative crest freeboard R_c/H_{m0} in **Figure 14**.

Also **Figure 15** shows dimensionless overtopping rate $q/\sqrt{g\,H_{m0}{}^{3}}$ as a function of the distance of the relative crest freeboard R_c/H_{m0} for the three cases with graph of reference case.

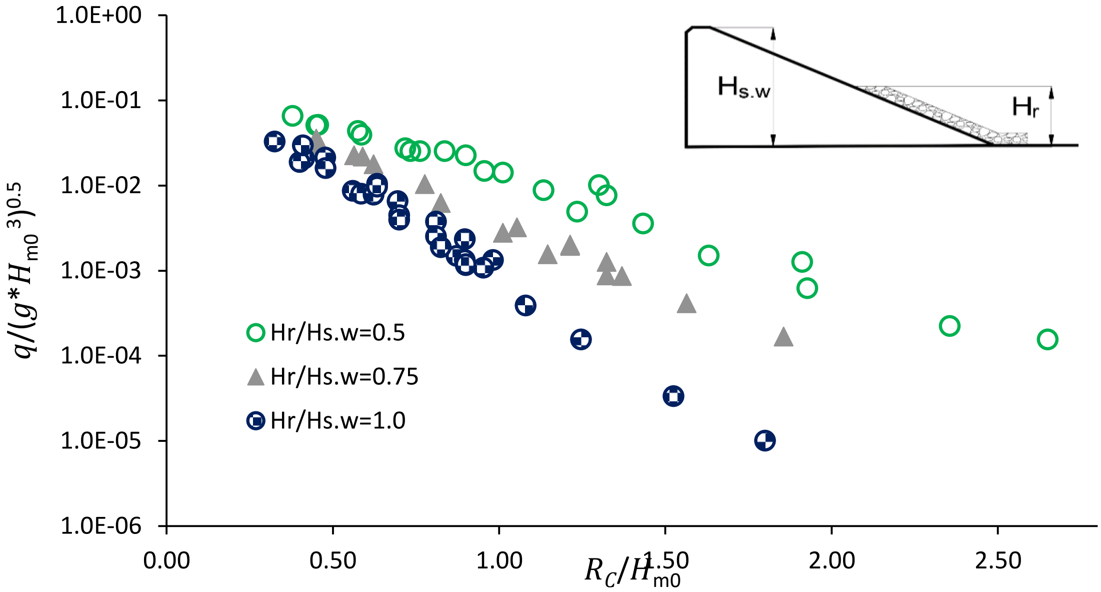

Figure 14 Dimensionless overtopping rate $q/\sqrt{g\,H_{m0}{}^3}$ as a function of relative crest freeboard R_c/H_{mo} for all tests cases of Rough seawall.

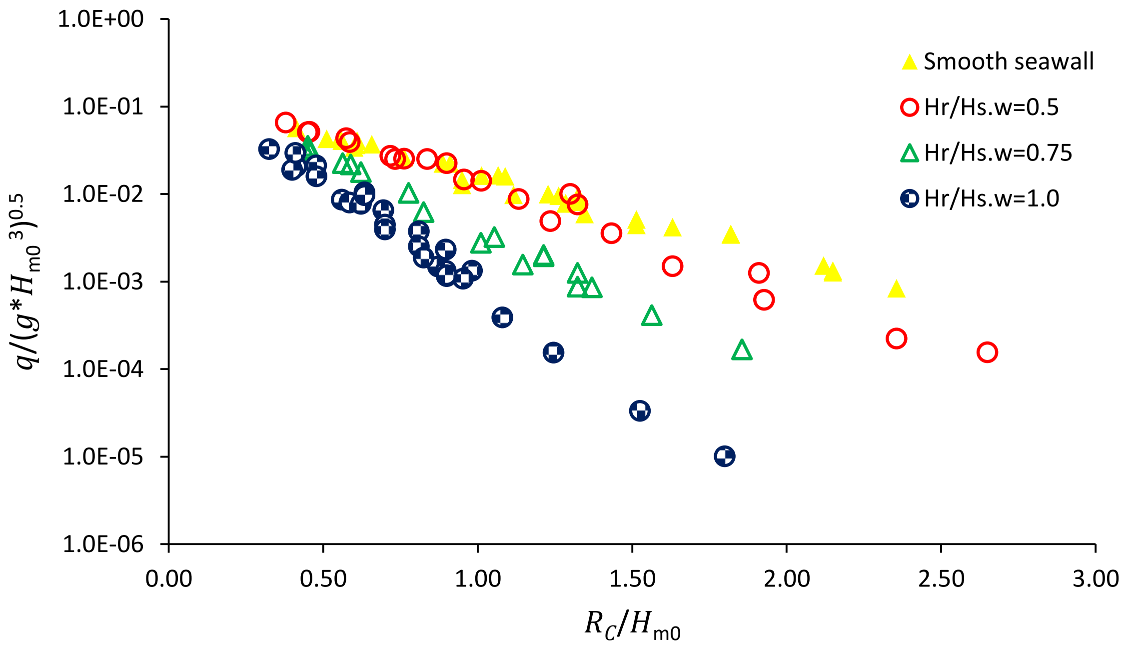

Figure 15 Dimensionless overtopping rate $q/\sqrt{g\,H_{m0}{}^3}$ as a function of relative crest freeboard R_c/H_{mo} for all tests cases of Rough seawall with reference case (smooth seawall).

From Figure 15 as expected it is shown that there were reducing in overtopping rate due to the 2-layers of riprap on front slope of the model.

It can be seen that both cases led to similar overtopping rates. When $R_c/\,H_{mo}$ is higher than about 1.5, the 50% rough slope started to reduce the overtopping rates as part of the wave run up slope was rough. While in case of 75% rough ($\frac{H_r}{H_{s.w}}$ = 0.75),it can be seen that as expected this setup gives as expected more reduction in overtopping rate than case of half rough, but when the relative freeboard R_c/H_{m0} < 0.5 the effect of friction or roughness of the riprap will disappear and act as smooth seawall.

For case of fully rough as in figures, it obviously shown that it was the best setup in reducing overtopping rate because it covers all of the front slope and form the best wave energy dissipation conditions.

It is noted that for relative freeboard R_c/H_{m0} < 0.6 effect of fully rough on reducing overtopping discharge is so close in results with the case of 75% rough ($\frac{H_r}{H_{s.w}}$ = 0.75). Therefore, for sites with expected low freeboards, 75% roughness may be used instead of full rough slopes to reduce the construction costs.

Calculation of Roughness Influence Factor γ_f

The previous results clearly indicated that the height of slope roughness affects the overtopping rates. This is also dependent on the ratio between riprap height (H_r) and water depth in front of the seawall face (d_{toe}),so all of rough setups data were plotted as in Figure 16 between the reduction factor a function of height of riprap and water depth at the toe of structure.

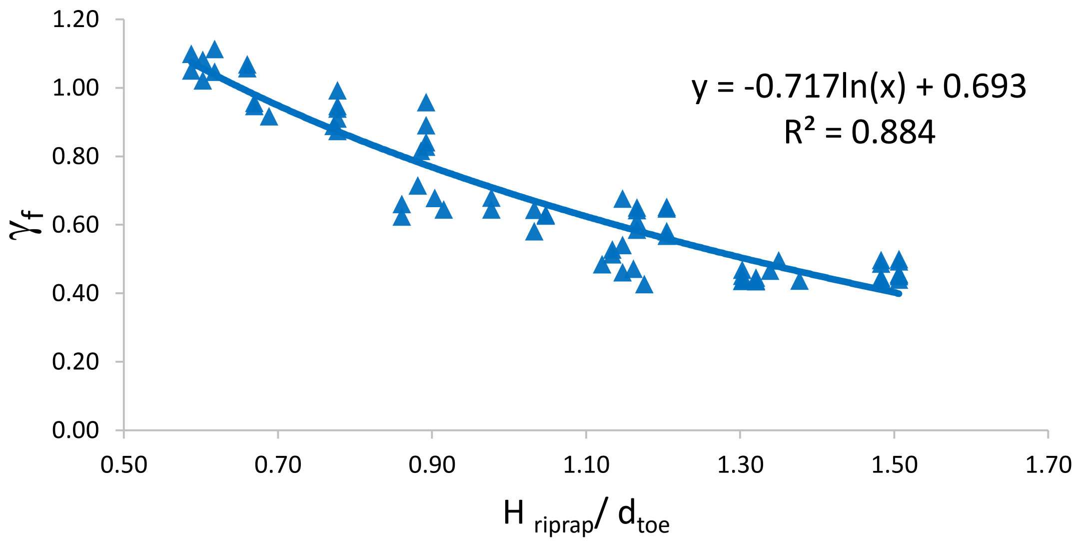

Figure 16 reduction factor γ_f of all rough setups versus H $_{riprap}$/ d_{toe}

A Logarithmic descending trend can be seen in the data points of Figure 17, with Equation (4.1).

$$\gamma_f = -0.717 \ln \frac{H_{riprap}}{d_{toe}} + 0.693$$ .... Equation **Error! No text of specified style in document.-1**

Equation (4.1) was deduced for seawall slope 2(H):1(V), where $0.6 \le \frac{H_r}{d_{toe}} \le 1.50$

It is noted form the **Error! Reference source not found.** that when the riprap height to water depth ratio was lower than 0.6 ($\frac{H_r}{d_{toe}} \leq 0.6$) the roughness influence factor (γ_f) was equal to 1This means that when the riprap became submerged with water depth, the effect of roughness became useless and the seawall slope had a similar behavior to the smooth slope.

The results of rough setup have been plotted in standard log linear diagram (dimensionless overtopping rate $\frac{q}{\sqrt{g\,H_{m0}^3}}$ on the Y-axis and dimensionless freeboard $Rc/(H_{m0}\,.\gamma_f)$ on the X-axis) in Figure 17 where γ_f is introduced in the abscissa of the graph. This means all data points for non-breaking waves are much better predicted by the adapted formula by Van der Meer and Bruce (2014).

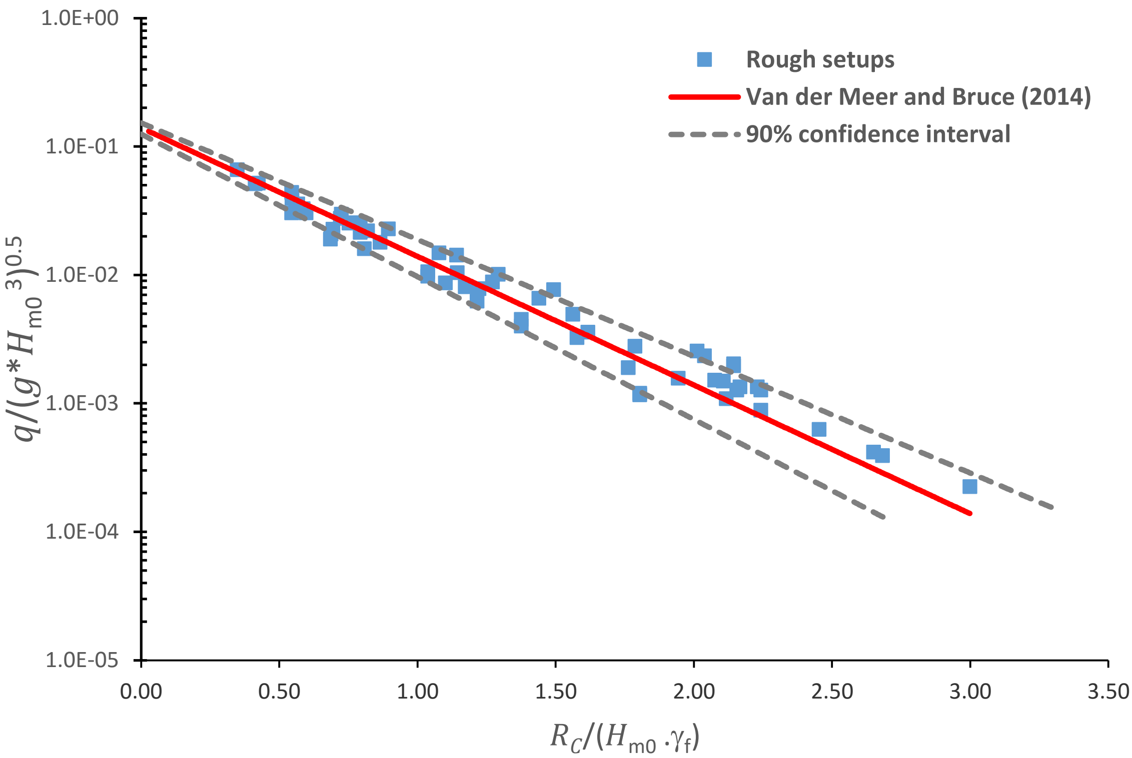

Figure 17 Dimensionless overtopping rate $q/\sqrt{g\,H_{m0}^3}$ as a function of relative crest freeboard R_c/H_{mo} for all cases of rough setups with roughness influence factor γ_f.

In Figure 18, the results of all 200 tests that have been performed on slope seawall with rough elements in this Master's thesis are shown. With increasing relative crest freeboard R_c/H_{m0}, a general decreasing trend is found for the dimensionless overtopping rate $q/\sqrt{g\,H_{m0}^3}$ which is consistent with the traditional behavior of smooth slope structures. The reduction in dimensionless overtopping rate $q/\sqrt{g\,H_{m0}^3}$ is much lower in case of fully rough slope with riprap.

The results arising from the present laboratory experiments show that riprap in double layer placed on the front slope (fully rough) was the best in reducing overtopping rates than other types, while the 0.75 rough slope ($\frac{H_r}{H_{s.w}} = 0.75$) being the second best. The case of submerged breakwater with a distance to the seawall model of 3.0 m ($\frac{X}{H\ BW} = 15.79$) and 5.0m ($\frac{X}{H\ BW} = 26.31$) come in the third place. The case of half rough slope ($\frac{H_r}{H_{s.w}} = 0.5$) somehow leads to similar overtopping rates compared to the case of submerged breakwater with a distance to seawall of 1.0 m ($\frac{X}{H\ BW} = 5.25$).

From practical and construction cost prospective, in general, it is recommended to use two layers of riprap at the seawall slope (full rough slope). If the relative seawall crest freeboard ($R_c/\ H_{mo}$) is expected to be lower than about 0.8, two layers of riprap can be placed from the slope to about 0.75 of the seawall heights. The selection depends on the allowable overtopping rates and construction costs.

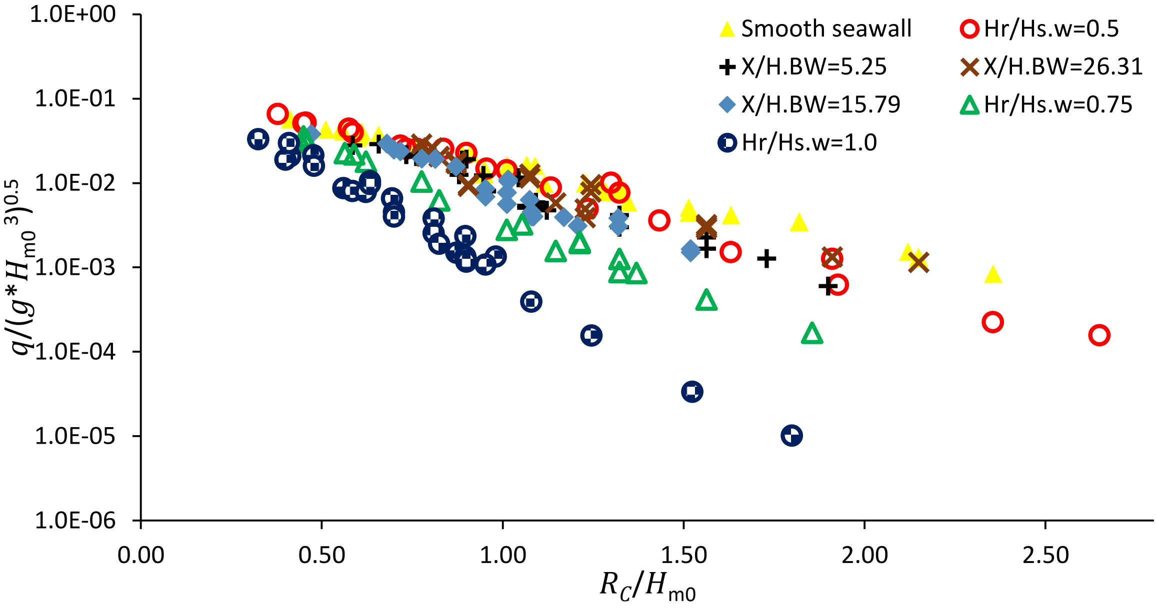

Figure 18 Dimensionless overtopping rate $q/\sqrt{g\ H_{m0}{}^3}$ as a function of relative crest freeboard R_c/H_{mo} for all cases of rough setups with roughness influence factor γ_f.

Conclusion and Recommendations

In the range of the conducted experimental conditions, the following conclusions can be drawn:

1- Laboratory experiments for the Smooth seawall with slope 2H:1V showed that the results are inside the limit and range of the well-known empirical formula (Van der Meer & Bruce (2014) - EurOtop manual 2016)

2- The results arising from the present laboratory experiments show that the riprap in double layer on the front slope (fully rough slope) is the best alternative in reducing overtopping rate than other types, followed by the case of 75% roughness height.

3- The case of submerged breakwater with a distance to the seawall model of 3.0 m ($\frac{X}{H\ BW} = 15.79$) and 5.0m ($\frac{X}{H\ BW} = 26.31$) comes in the third place in reducing overtopping rate.

4- The roughness influence factor γ_f for the cases of submerged breakwater with distance to height ration ($\frac{X}{H_{BW}} = 5.25\ \&15.79\ and\ 26.31$) were found to 0.90, 0.80 and 0.83, respectively.

5- If the submerged breakwater is placed upstream the seawall to reduce the overtopping rates, the best location of submerged breakwater is when $\frac{X}{H_{BW}} = 15.79$.

6- For all setups of submerged breakwater, when $R_c/H_{m0} < 1.0$, the submerged breakwater has almost no impact in reducing the overtopping rates.

7- For a rough seawall slope with roughness that covers only half of the front slope ($\frac{H_r}{H_{s.w}} = 0.50$), when $R_c/H_{m0} < 1.25$ the riprap is actually submerged with high water level, which results in eliminating the effect of riprap, therefor the observed overtopping rate will be similar to the case of smooth seawall.

8- A descending trend was estimated between the reduction factor (γ_f) as a function of height of riprap relative to water depth at the toe of structure ($H_{riprap}/\ d_{toe}$). The following equation is presented for the range of test setups conditions:

$$\gamma_f = -0.717 \ln \frac{H_{riprap}}{d_{toe}} + 0.693$$

<u>Recommendations</u>

For future work on the primary subject of this research, it is suggested to consider the following points:

1- Conduct field studies to verify the experimental work.
2- Investigate more energy dissipation measures, such as using rips and staggered blocks in attempt to optimize the seawall design and construction costs.
3- Investigate the effect of irregular waves on the proposed seawall with energy dissipation measures.

References

- J. Van der Meer, N.W.H. Allsop, T. Bruce, et al. “EurOtop Manual on wave overtopping of sea defences and related structures. An overtopping manual largely based on European research but for worldwide application”, 2016.
- J. Van der Meer. “Wave runup and wave overtopping at dikes”, TAW Technical Advisory committee on Flood Defenses, 2002.
- B. El-Sharnouby and A. Soliman, “Behavior of shore protection structures at Alexandria, Egypt, during the storm of December 2010”, The International Maritime Transport and Logistics Conference, 2011.
- Frederic Meurisse and Kevin Vallverdu, “Experimental study of overtopping performance of steep low-crested structures with rough elements”,
- Nørgaard, J.Q.H., Lykke Andersen, T., Burcharth, H.F., “Distribution of individual wave overtopping volumes in shallow water wave conditions”, 2014.
- Koen van Doorslaer and Julien de Rouck, “Reduction of wave overtopping on a smooth dike by means of a parapet”, 2016.