

Wave runup and overtopping on smooth-slope NEXC block

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Abstract: Constant wave runup and overtopping during monsoon coupled with storm-surge events have poses threat to the coastal's community in flooding and land loss. The study was to further the research on the wave interaction issue using the modified NAHRIM Coastal Protection and Expansion (NEXC) block. The aim was to determine the significant relationship prediction model from the experiment variables due to water level changes. The study was conducted in 30 m long, 2 m height, and 1.5 m width of wave flume using gamma 3.30 of wave height JONSWAP spectrum under 1:15 and 1:8 mobile bed scenarios. Parameters were downscaled to 1:10 and based on Peninsular Malaysia's east coast hydrodynamics conditions. 36 different test scenarios were simulated every 20 minutes with three repetitions, enables 108 samples to be retrieved. Using statistical tools, correlation tests between the variables in the experiment results indicates wave runup, significant wave height and overtopping discharges are strongly correlated to the bed gradient and smooth-slope NEXC block. Changes in water level from shallow to deep, mild to steep mobile bed gradient with 30° to 60° block affect the relationship H_s-q decrease while $R_{u2\%}-q$ positively increase. Overtopping was not directly affected by water level but positively affected on wave runup and negatively to significant wave height. The fitted relationship design model using a General Full Factorial method was verified with 0.338069 of standard error and 98.12 % of R-square. Finally, the significant relationship predictive model was obtained to have 26 interaction terms in the model successful.

Keywords: JONSWAP spectrum, mobile bed, smooth-slope block, wave flume, General Full Factorial

Track Name: Coastal Management and Marine Ecosystem



1. Introduction

The rising of the seawater level was expected to impact not only the coastal ecosystem but including the loss of functionality and biodiversity, coastal inundation and inland migration such as coastal land loss, increment possibility on wave interaction especially on the open long-span sandy beach exposed [1]. The higher sea levels will bring more intense characters of the sea level rise (SLR) [2]. This resulted in destructive forces of waves surge, leading to the penetration farther inland than before. Thus, it will cause the risk of groundwater pollution, saltwater intrusion, coastal erosion, property damages and also extinction of coastal flora and fauna [3-5, 22].

In terms of shoreline and existing coastal protection structure damages, the main factor that drives these effects was the propagation of aggressive wave interactions of wave runup and its overtopping [6, 7]. Nowadays these factors are considered as one of the major and various threats [15-18] that damaging beaches [31], coastal land loss and inundation due to the impact of rising seawater levels [21, 23]. the vulnerability potential is higher at low-lying, soil or sandy coastal areas with no protective coastal layer structure or no strong embankment [8-10, 14].

Lately, Malaysia coastal especially at Peninsular Malaysia has shown its hydrodynamic characteristic status as experiencing the unexpected extreme impact of sea level rise [11], leaving its east coastline the most vulnerable to wave regime [19, 20]. This is because the east coast of Peninsular Malaysia has a long span with open-wide sandy beach materials and exposed directly to the hydrodynamic regime from the South China Sea. Hence, wave interaction especially waves runup and its overtopping has become an important issue among researchers, scientists, local authorities, and young scholars. Finding the best solution in understanding its impacts on the management wise, social, economic and psychology was the main concern [35]. However, at the same time, it has eventually triggered an initiative to develop the innovative coastal structure dealing with the impacts, especially on the coastal flooding effects and expanding term.

In conjunction with research in wave interaction, the formula for wave runup, $R_{u2\%}$ (m) and overtopping discharges, q (l/s/m or $m^3/s/m$) [33] on sloping bed gradient and smooth slope coastal structure has been updated with its coefficient values, $c = 1.3$. The c value gives a slightly curved line on a log-linear graph, where the exponential distribution gives a straight line, with smooth plane and breaking (plunging) waves on the bed gradient as below:

$$\frac{q}{\sqrt{g \cdot H_{m0}^3}} = \frac{0.026}{\sqrt{\tan \alpha}} \gamma_b \cdot \zeta_{m-1,0} \cdot \exp\left[-\left(2.5 \frac{R_c}{\zeta_{m-1,0} \cdot H_{m0} \cdot \gamma_b \cdot \gamma_f \cdot \gamma_\beta \cdot \gamma_v}\right)^{1.3}\right]$$

And with a maximum of slope as below formulae:

$$\frac{q}{\sqrt{g \cdot H_{m0}^3}} = 0.1035 \cdot \gamma_b \cdot \zeta_{m-1,0} \cdot \exp\left[-\left(1.35 \frac{R_c}{H_{m0} \cdot \gamma_f \cdot \gamma_\beta \cdot \gamma_v}\right)^{1.3}\right]$$

These formulae will react if one the influence factor changes, such as γ_b is the influence factor for a berm, γ_f is for roughness elements on a slope, γ_β is for oblique wave attack and influence factor for a wall at the end of a slope, γ_v . Wave runup defined as the vertical difference between the highest point of wave run-up and the still water level (SWL) [33, 34] that will change with the beach and offshore wave properties. An exceeded by 2 % the number of incoming waves at the toe of the structure for sloping structures with gentle face bed gradient of range 1:8 to 1:15 is quoted as

$$\frac{R_{u2\%}}{H_{m0}} = 1.65 \cdot \gamma_b \cdot \gamma_f \cdot \gamma_\beta \cdot \zeta_{m-1,0}$$

1.1 Issues, motivation and problem statement

Long-span and open wide effects of the east coastline of Peninsular Malaysia to the density wave regime from the South China Sea has posed the coastline in great threats. On the other hand, the tidal differences around the coastal area [12, 13] affects the intensity of the wave response towards the inland of the coastline or beach.

These issues have alarmed local authority and other parties to responding as it becomes a threat to all residents who inhabit the coastal areas especially during monsoon season with storm-surge coupled with high tide and SLR events [15, 26]. The effect may bring massive impact to resident's inhabit the coastal area, tourism, aquaculture, plantation area and coastal forest reserve area [25].

In 2016, NAHRIM as focal national excellence centre in coastal and its environment has taken the initiative to conduct detailed research and development, in producing an innovative coastal protection structure name as NAHRIM Coastal Protection and Expansion (NEXC) block that is expected to control the problem of coastal damages and at the same time may expand naturally of the impacted coastal land area. The results on the laboratory testing and one-year duration of block system installation with onsite performance analysis have proven its function to re-nourish the beach through the natural accretion process and effectively stabilize the impact of erosion [26, 27].

However, due to caused matter on wave interaction issue prevailed on the front of the block system, had not investigated. This has motivated further research using the modified NEXC block by using the irregular wave on the mobile bed. As applying mobile beds in the physical laboratory quite challenging, it is believed that added beach material in the research has become less interesting among the researchers.

A strong motivation for the study is aiming to determine the relationship statistically for optimal relationship prediction model in minimizing the overtopping discharges due to mobile bed and water level changes using the various angle of smooth-slope NEXC block with the irregular wave. Moreover, it is important to statistically analyze experiment data to assure reliability on the significant relationship towards a better understanding of the effects at the block area.

The main objective of this study is to examine and determine a significant relationship model of the smooth-slope NEXC blocks in affecting wave overtopping and runup due to water level changes in the sandy area.

2. Site conditions

The study had adopted the east Peninsular Malaysia coastal area as the downscale model in the physical laboratory and was conducted at the National Water Research Institute of Malaysia (NAHRIM) Laboratory, Selangor, Malaysia. The study area also has been choosing based on the coastal area was unique with the tidal types and location of wide-open facing to the South China Sea its long-span stretch coastline of sandy beach. Moreover, because of its strategic location, it received most of the active hydrodynamic activity throughout the year. The nearest and narrow part to the deepest bathymetry at -60 m depth and 30km away from the shoreline was located at latitude 4.86° and longitude 103.72° (Figure 1).

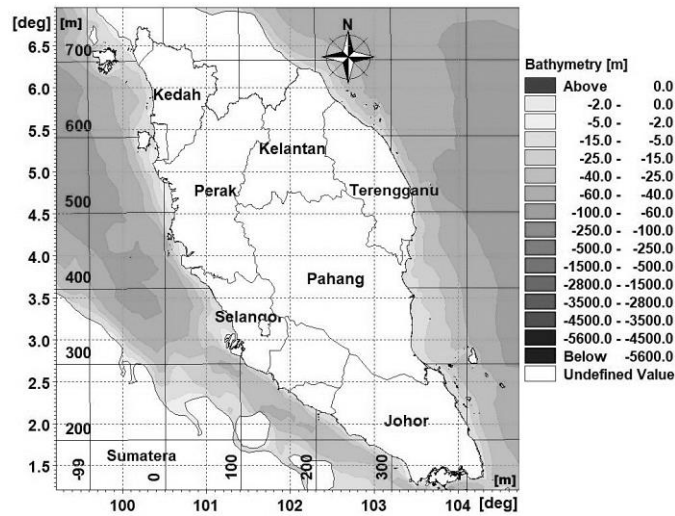


Figure 1. Bathymetry along the East coast of Peninsular Malaysia.

Peninsular Malaysia coastal area experiencing three types of tides. Based on their position, the east and southern part coastlines of the Peninsular experienced mixed tide prevailing diurnal and semidiurnal, while the major coastlines of the west experienced semidiurnal tide [13, 39, 40] (Figure 2). Furthermore, Peninsular Malaysia is mostly surrounded by the sea, which is affected by a wind-driven wave generated [29, 30]. This can be observed from the wave movement in Malaysia which follows the monsoon wind movements (Figure 3).



Figure 2. Types of the tide at Malaysia waters area [39].

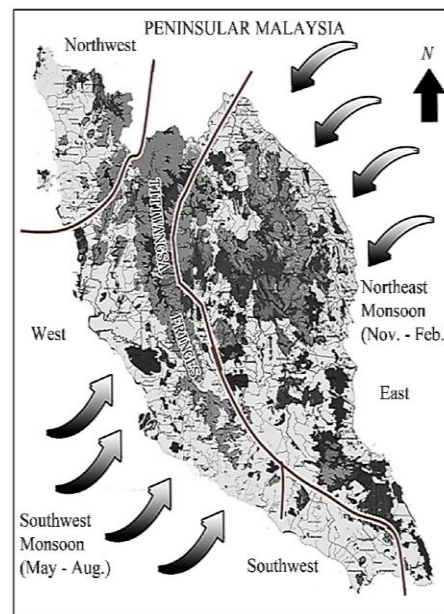


Figure 3. The Yearly Movement of Monsoon Winds and Waves in Malaysia [28].

3. Methodology and Experiment Setup

3.1 Geometry and Hydrodynamics parameters

Data records of 9 years wave from the offshore are analyzed using Extreme Value Analysis (EVA) for long-term times series statistical analysis to obtained 100 years return period of peak wave period, T_p and spectrum significant wave height, H_s in order downscale to laboratory use. The study has considering wave angles that perpendicular to the beach shoreline and suited it with the apparatus limits. The significant spectrum wave that perpendicular to the shoreline of the east coast of Peninsular Malaysia was from sector 61° to 90° .

The range of the spectrum wave height applied in the wave input was 0.1 m, 0.13 m, and 0.15 m using wave height of JONSWAP spectrum with gamma 3.30 were imposed on the block. Input parameters (Table 1) were downscaled to 1:10 and according to the hydrodynamic conditions using a combination of water depths of 0.9 m and 0.95 m with the 30° , 45° and 60° of the smooth-slope NEXC block's front-face angle (Figure 4).

Table 1. Input parameters used in the model.

Parameters	Values
Block sloping angle, α ($^\circ$)	30, 45 and 60
Induce wave height, H_{mo} (m)	1.0, 1.3 and 1.5
Water Level, d (m)	0.9 and 0.95
Beach Slope, β ($^\circ$)	4 and 7
Peak wave period, T_p (s)	2

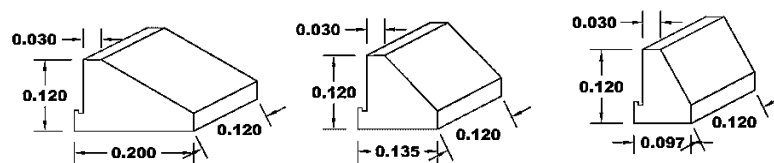


Figure 4. Three types of physical blocks used in the physical model.

3.2 Beach Profile and overtopping tank Setup

The beach profile setup was the most critical phase before filling up with the beach material and other model's accessories. A strong wood framework underneath the mobile bed is to reduce the usages on beach material of $100 \mu\text{m}$ of fine sand and bed gradient of the model are nicely compacted accordingly to gradient 1:15 and 1:8. Blocks were set at 13.5 m and 7.2 m of the horizontal length of the mobile bed to block's toe, L_s for both bed gradients respectively (Figure 5). The Beach foreshore in this study was assumed as one straight slope without any obstacle or berm. The wave overtopping tank was setup accordingly to the bed steepness with a 10 cm chute to guide the overtopping discharges flow into the tank [33, 34]. Extra water tank storage was prepared outside of the model which connects with the water pump from the overtopping tank.

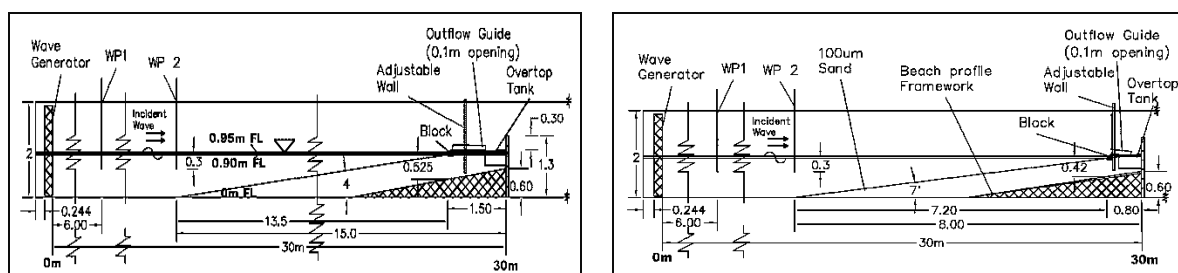


Figure 5. Schematic diagram of experimental wave in 30 m model with 1:5 (left) and 1:8 (right) beach gradient.

3.3 Calibrations

To ensure the success of the experiment, all the instruments were maintained checked and calibrated, especially the wave flume's paddle and wave probes. To define the minimum time simulation of mobile bed reaches its equilibrium in required model scale's size, the wave paddle was allowed to run for 0.5 to 1 hour with bed material but without other instruments and smooth-slope NEXC blocks.

The wave was the most challenging parameter to calibration as it needs extra attention and a precise method. The wave conditions were measured using 2 sets of twin wire resistance type on 30 cm wave probe's sensor and its capabilities, to read wave height up to 0.15 m. Both wave probes are connected to an installed computer with Hr Merlin software, which processed the signals into Hr-Daq software to derive the significant wave height, H_s , and means zero-crossing wave period, T_m from the wave energy spectrum. This study used the wave spectrum of JONSWAP which defined by wave height with Gamma 3.30.

Calibration on wave probes needs to calibrate at least 3 times repeated for each water level condition. This is to ensure signal transmitted from wave sequence to computer through probe device will eliminate any uncertainties in the process, with minimum calibration value, are achieved > 0.999 . If the wave height and wave period are less than this value, then the setting needs to be adjusted and repeated until reached satisfactory calibration.

3.4 Data Analyzing

Statistical analysis was very important not only to assure the numerical accuracy and reliability of all statistical outputs but also used to provide solutions to complex problems. This can be applied to big data sets of many variables in finding a good pattern of the data. The results of statistical analysis have been significant for both in explanation a pattern and also for model prediction. It was one of the most convenient and easy tools in assisting to reach the goal of analyzing data using statistical software and its extension tools.

There are 4 parameters with 2 and 3 different levels this study has involved. Minitab Software has been chosen to achieve the most satisfactory of the statistical analysis data result. The tools to design the experiment was using General Full Factorial (GFF) method. The tools are quite amazing and well-known as one of the ideal tools in generating an empirical relationship model in practical to improving parameters [32] especially to interpret the response output of the experiment.

A correlation test was conducted using the Spearman rank method, r_s as it is appropriate in measuring the strength and direction of association between two ranked for both continuous and discrete ordinal variables [36, 37]. In theory, two method calculation will be applied according to the data, either it does have not (left) or has the tied ranks (right) as quoted below:

$$r_s = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \quad \text{or} \quad r_s = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}$$

To choose between alternative models, Bayesian Information Criterion (BIC) is used to check, compare and determines objectively the best model, as it's the one that minimizes the considered information criterion to penalizes less the more complex model [38] in the search method that compares models sequentially. The term log-likelihood is giving everything aligned to their most favourable and p is the number of parameters considered in the model. BIC is defined as:

$$\text{BIC} = 2.(\log\text{-likelihood}) + (p.\log n)$$

To obtain a prediction value that might impact the future changes of the response, a robust fit regression model of the GFF method was used to analyze further variables of the correlated parameters and responses. As in this study, a linear trend is fitted to wave overtopping discharges of each parameter variable in an iteratively BIC technique. Then, the method will deal with solution determination and outliers' detection. Depending on the p-value and standard error, S value from the trend line, weights of measurements are adjusted accordingly and the trend line is then re-fitted. The process is repeated until the solution converges. As it is very rare in physics of the 3-ways interaction and the 4-ways interaction, and no this is allowed to have enough degree of freedom to do the analysis. So, any insignificant parameter has to be set aside and refitting the model back. Randomized order in the block design of the variables has been applied in design tools to minimize the effect of variability when it is associated with discrete data.

4. Results and Discussion

4.1 Defining and measured the results of the input parameter's response

Due to various not been previous physical laboratory doing comparisons of various smooth-slope NEXC block on different mobile bed gradients with irregular incident waves affecting response performance of each scenario block applied during experimental. The result of the experiment has found out the highest overtopping discharges, wave runup and significant wave height at bed toe was 8.50 l/s/m, 0.6 m and 0.025 m.

Figures 6a and 6b show the distribution data of 2 types of bed gradients in each figure. Indicated that the data in Figure 6a and 6b show the wave overtopping and significant wave height will decrease with increase in water level from shallow to deep, whenever mobile bed changes from mild to steep gradient with the smooth-slope block from 30° to 60°. However, Figure 6b interaction of wave runup and overtopping discharges show significant increases due to changes on these 3 parameters from lowest to the highest value.

Not much of the data distribution can be analysed using this visual and quantitative raw data. Thus, the further analysis method is required to understand and better statistically analyze the relationship between the input parameters with the responses.

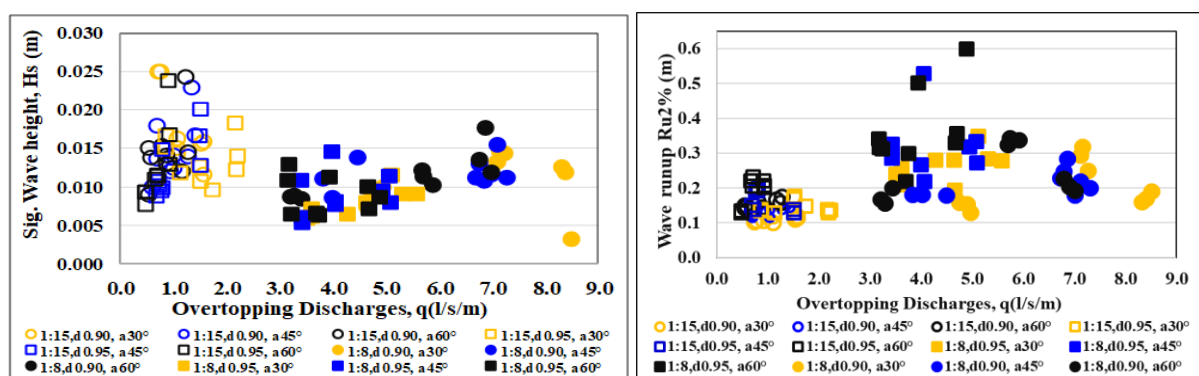


Figure 6. Distribution of significant wave height at bed toe (left) and wave runup (right) over the overtopping discharges with 1:15 and 1:8 beach gradient, the water level of 0.9 m and 0.95 m at 0.1 m, 0.13 m and 0.15 m wave height.

4.2 Significant wave height at the bed toe ($H_{s,bedtoe}$)

Using the correlation test, the confidence interval (CI) of the probability was set to 0.95 or 95 % that the true mean lies within the range. Table 2 indicates that most of the relationship between the $H_{s,bedtoe}$ with sample 2 are in a negative correlation with beach gradient (β_{bed}), water level (h_{water}) and smooth-

slope NEXC block (α_{block}). While the relationship was positively correlated with the incident wave height (H_{mo}) with r_s equal to 0.334.

Table 2. Pairwise of Spearman rank's correlation on the $H_{s,bedtoe}$ with the input parameters.

Sample 1	Sample 2	N	Correlation, r_s	95 % CI for r_s	p-value
$H_{s,bedtoe}$ (m)	β_{bed} (°)	108	-0.475	(-0.616, -0.305)	0.000
$H_{s,bedtoe}$ (m)	h_{water} (m)	108	-0.337	(-0.499, -0.153)	0.000
$H_{s,bedtoe}$ (m)	α_{block} (°)	108	-0.029	(-0.217, 0.160)	0.762
$H_{s,bedtoe}$ (m)	H_{mo} (m)	108	0.334	(0.150, 0.496)	0.000

Even though, β_{bed} show the r_s value is -0.475, anyhow the value is less than 50 % of the strong r_s value. On the other hand, the sample with α_{block} is statistically not significant because its p-value (0.762), which is greater than the usual significance level of 0.05 and the r_s (-0.029) was weakly far from $r_s = -1$. As a result, it indicates that a negative significant linear relationship occurs in between the $H_{s,bedtoe}$ with the β_{bed} and d_{water} , while a positive linear relationship with H_{mo} .

4.3 Wave Runup ($R_{u2\%}$)

In the $R_{u2\%}$ relationship evaluation, clearly can be stated that the strongest relationships are with the β_{bed} with r_s value is 0.74, followed by 0.341 with the water level, 0.288 with the α_{block} and less correlated with the 0.158 of H_{mo} . However, the test indicates the relationship between $R_{u2\%}$ are with the α_{block} and h_{water} , which both have a p-value of 0.000, are strong significantly correlated.

The analysis results also clearly stated that there is a significant linear relationship in between the $R_{u2\%}$ with all three parameters of β_{bed} , h_{water} , and α_{block} , but not with the H_{mo} . Eventually, the analysis result has presently the $R_{u2\%}$ have a strongly significant linear relationship with the β_{bed} but significant with the h_{water} , and α_{block} .

Table 3. Table Pairwise of Spearman's rank correlation of the $R_{u2\%}$ with the input parameters.

Sample 1	Sample 2	N	Correlation, r_s	95 % CI for r_s	p-value
$R_{u2\%}$ (m)	β_{bed} (°)	108	0.740	(0.626, 0.823)	0.000
$R_{u2\%}$ (m)	h_{water} (m)	108	0.341	(0.157, 0.502)	0.000
$R_{u2\%}$ (m)	α_{block} (°)	108	0.288	(0.101, 0.456)	0.002
$R_{u2\%}$ (m)	H_{mo} (m)	108	0.158	(-0.033, 0.338)	0.102

4.4 Overtopping Discharges ($q_{overtop}$)

Analysis of the correlation in Table 4 indicates the $q_{overtop}$ have a positive correlation with the β_{bed} and the H_{mo} while showing a negative correlation with the d_{water} and the α_{block} . However, among these 4 set samples, the only d_{water} is not significantly correlated but strongly correlate with the β_{bed} , which the r_s (0.866) was close to the +1 with a p-value of 0.000.

Even though the relationship of $q_{overtop}$ with the H_{mo} and α_{block} is indicating $r_s = 0.372$ and -0.21, which this value was below 50 % of the r_s , these 2 samples are still significantly correlated. Thus, it is concluded that the $q_{overtop}$ have a strong positive linear relationship with the β_{bed} but a negative and positively significant linear relationship with α_{block} and H_{mo} respectively.

Table 4. Pairwise of Spearman rank's correlation on the $q_{overtop}$ with the experimental parameters.

Sample 1	Sample 2	N	Correlation, r_s	95 % CI for r_s	p-value
$q_{overtop}$ (l/s/m)	β_{bed} (°)	108	0.866	(0.798, 0.912)	0.000
$q_{overtop}$ (l/s/m)	h_{water} (m)	108	-0.146	(-0.327, 0.045)	0.132

$q_{overtop}$ (l/s/m)	α_{block} (°)	108	-0.21	(-0.386, -0.020)	0.029
$q_{overtop}$ (l/s/m)	H_{mo} (m)	108	0.372	(0.191, 0.529)	0.000

4.5 Experiment output responses

To determine the stronger relationship between the 3 responses, all experiment output responses are evaluated. Analyze based on the matrix plot and the correlation value given, indicate that all responses are significant with each of the responses in the sample analyzed. However, the most significant correlate was $R_{u2\%}$ with the $H_{s,bedtoe}$ and with the $q_{overtop}$. Both show the p-value are $0.000 > 0.05$ respectively.

However visually and analysed value shows that the strongest positive linear relationship is between the $R_{u2\%}$ with the $q_{overtopping}$, which the r_s value is 0.595. While the other two correlation analyses on responses: $R_{u2\%}-H_{s,bedtoe}$ and $q_{overtop}-H_{s,bedtoe}$, indicate have a negatively significant linear relationship, as both have $r_s = -0.566$ and -0.202 respectively. Hence the result strongly indicates that $q_{overtop}$ positively correlates and very dependent on $R_{u2\%}$ changes value. While $R_{u2\%}$ negatively correlate and dependent on the $H_{s,bedtoe}$ closely.

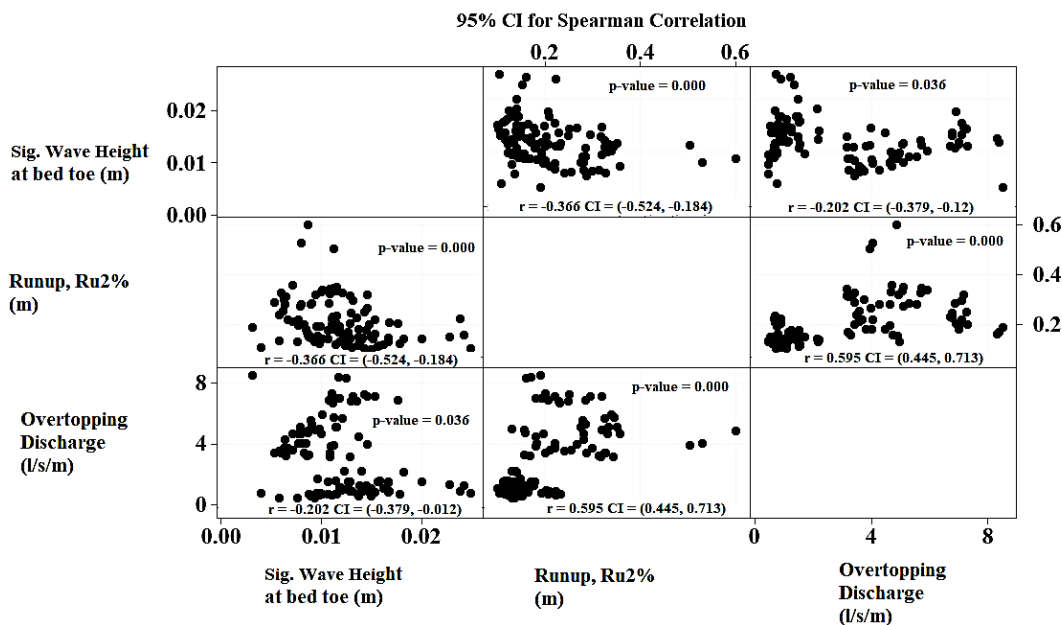


Figure 7. Presented the Spearman correlation’s matrix plot with full correlation interval.

4.6 Significant relationship prediction model

The model was designed to develop a useful pre-experiment matrix setup of the physical model using the JONSWAP spectrum which will apply the parameters and its levels more than 2 on mobile bed material. The regression model used $H_{s,bedtoe}$ and $R_{u2\%}$ as a covariate and 95 % of the two-sided confident level for all intervals. To measure the strength of the difference between observed and expected values, a standardized residual was applied. The original design model reveals the model was 99.86 % in R-square (R-sq), S is 0.108253 and included both covariates in the model (Table 5).

Table 5. Summary of the optimum relationship prediction model.

Model	S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
Before	0.108253	99.86 %	99.79 %	1.94273	99.67 %	-96.69	-37.97
After	0.338069	98.12 %	97.91 %	13.8863	97.63 %	89.39	120.38

However, to obtain the best model and using significant parameters in the model, the model was analysed based on the p-value terms and using stepwise with BIC. This means, in obtaining the fittest

model, refitting and diagnostic tools need to eliminate the insignificant parameters. After refitted the model, clearly seen that no covariate is in the regression model and only strong significant parameters are included. The refitted design model shows the R-sq 98.12 % with S (0.338069) increase but still, less than 0.5, BIC increase from negative (-37.97) to positive (120.38) value and all coefficient term relationship have p-value less than 0.05 (Table 6), which indicate the model is considered as satisfied diagnostic and fitted. S value much have a big discrepancy as both the 3-ways and 4 ways interaction are set aside from the model makes design series value in this interaction terms have been ignored.

Figure 8 on the upper right of the Pareto chart indicate that all parameters interaction terms were critical in the model. Residual plotting also shows that no long tail in the pattern of the normal probability plot, fewer outliers and the residuals almost approximately follow a straight line. This verified the assumption of the residuals is consider are normally distributed. While residuals versus fits plot show but the points fall randomly on both sides of zero value, a slight curvature pattern in the points. However, it verifies the assumption of the residuals are randomly distributed and have almost constant variance. Additionally, the residuals in the observation order plot are fall randomly around the centre line in time order. Thus, an assumption that the residuals are independent of one another is verified.

Table 6. Coefficients and significant level of the interaction terms.

Term	Coef	SE Coef	95 % CI	T-Value	P-Value	VIF
Constant	3.0836	0.0325	(3.0190, 3.1482)	94.79	0.000	
β_{bed}						
0.0667	-2.0347	0.0325	(-2.0993, -1.9702)	-62.55	0.000	1.00
0.1250	2.0347	0.0325	(1.9702, 2.0993)	62.55	0.000	*
h_{water}						
0.90	0.4495	0.0325	(0.3849, 0.5140)	13.82	0.000	1.00
0.95	-0.4495	0.0325	(-0.5140, -0.3849)	-13.82	0.000	*
α_{block}						
0.57735	0.4203	0.0460	(0.3289, 0.5116)	9.14	0.000	1.33
1.00000	-0.0396	0.0460	(-0.1309, 0.0517)	-0.86	0.391	1.33
1.73205	-0.3807	0.0460	(-0.4720, -0.2893)	-8.27	0.000	*
H_{mo}						
0.10	-0.8662	0.0460	(-0.9575, -0.7749)	-18.83	0.000	1.33
0.13	0.0910	0.0460	(-0.0003, 0.1824)	1.98	0.051	1.33
0.15	0.7752	0.0460	(0.6839, 0.8665)	16.85	0.000	*
Bed gradient x h_{water}						
0.0667 0.90	-0.4858	0.0325	(-0.5504, -0.4212)	-14.93	0.000	1.00
0.0667 0.95	0.4858	0.0325	(0.4212, 0.5504)	14.93	0.000	*
0.1250 0.90	0.4858	0.0325	(0.4212, 0.5504)	14.93	0.000	*
0.1250 0.95	-0.4858	0.0325	(-0.5504, -0.4212)	-14.93	0.000	*
$\beta_{bed} \times H_{mo}$						
0.0667 0.10	0.5084	0.0460	(0.4171, 0.5997)	11.05	0.000	1.33
0.0667 0.13	-0.1406	0.0460	(-0.2319, -0.0492)	-3.06	0.003	1.33
0.0667 0.15	-0.3678	0.0460	(-0.4592, -0.2765)	-8.00	0.000	*
0.1250 0.10	-0.5084	0.0460	(-0.5997, -0.4171)	-11.05	0.000	*
0.1250 0.13	0.1406	0.0460	(0.0492, 0.2319)	3.06	0.003	*
0.1250 0.15	0.3678	0.0460	(0.2765, 0.4592)	8.00	0.000	*
$h_{water} \times H_{mo}$						
0.90 0.10	-0.2802	0.0460	(-0.3715, -0.1888)	-6.09	0.000	1.33
0.90 0.13	0.1577	0.0460	(0.0664, 0.2490)	3.43	0.001	1.33
0.90 0.15	0.1225	0.0460	(0.0311, 0.2138)	2.66	0.009	*
0.95 0.10	0.2802	0.0460	(0.1888, 0.3715)	6.09	0.000	*

0.95	0.13	-0.1577	0.0460	(-0.2490, -0.0664)	-3.43	0.001	*
0.95	0.15	-0.1225	0.0460	(-0.2138, -0.0311)	-2.66	0.009	*

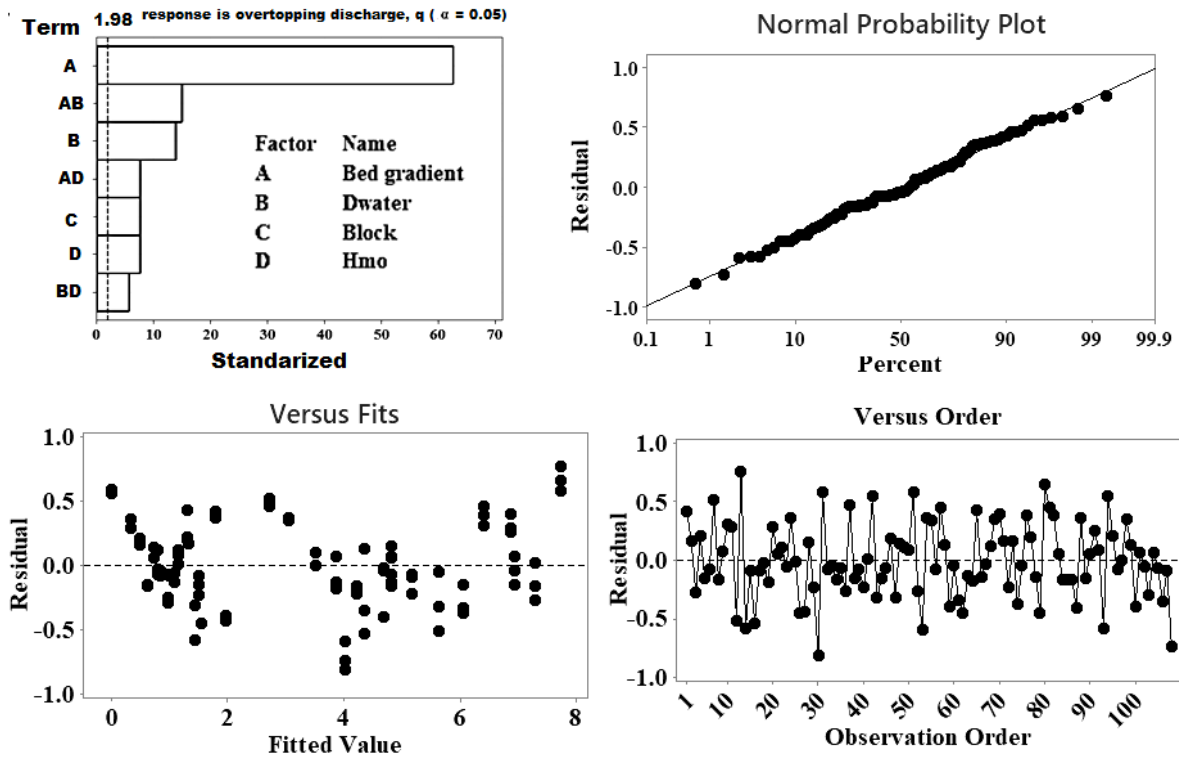


Figure 8. Pareto chart of the standardized effects (upper left) and residual plot for the fit regression model (normal probability plot, fitted value and observation order).

There are 10 linear terms, 37 interactions of 2-way terms, 43 interactions for 3-way terms and 48 interactions for 4-ways terms in the model before fitted and gone through the insignificant parameter’s isolation. However, the fitted and significant relationship predictive model has obtained 10 linear terms and 16 interactions of 2-way term terms through the GFF method. This model is for direct predictive calculation on overtopping discharge on smooth-slope NEXC block using mobile bed due to water level changes and quote as follow:

$$\begin{aligned} \text{Overtopping discharge, } q = & 3.0836 - 2.0347\beta_{1:15} + 2.0347\beta_{1:8} + 0.4495h_{0,90} - 0.4495h_{0,95} + 0.4203\alpha_{30^\circ} - \\ & 0.0396\alpha_{45^\circ} - 0.3807\alpha^\circ - 0.8662H_{mo,0.10} + 0.0910H_{mo,0.13} + 0.7752H_{mo,0.15} - 0.4858\beta_{1:15},h_{0,90} + \\ & 0.4858\beta_{1:15},h_{0,95} + 0.4858\beta_{1:8},h_{0,90} - 0.4858\beta_{1:8},h_{0,95} + 0.5084\beta_{1:15},H_{mo,0.10} - 0.1406\beta_{1:15},H_{mo,0.13} - 0.3678 \\ & \beta_{1:15},H_{mo,0.15} - 0.5084\beta_{1:8},H_{mo,0.10} + 0.1406\beta_{1:8},H_{mo,0.13} + 0.3678\beta_{1:8},H_{mo,0.15} - 0.2802h_{0,90},H_{mo,0.10} + 0.1577 \\ & h_{0,90},H_{mo,0.13} + 0.1225h_{0,90},H_{mo,0.15} + 0.2802h_{0,95},H_{mo,0.10} - 0.1577h_{0,90},H_{mo,0.13} - 0.1225h_{0,90},H_{mo,0.15} \end{aligned}$$

5. Conclusion

The experimental result using 3 types of smooth-slope NEXC block on mobile bed using wave height JONSWAP spectrum due to water level changes have successfully obtained 36 different scenarios with 108 data at 30m long multi-functional wave flume at NAHRIM laboratory, Selangor, Malaysia. Experiment data have shown that both interactions of $q_{\text{overtop}}-H_s$ will decrease but $R_{u2\%}-q_{\text{overtop}}$ significant increases with an increase in water level from shallow to deep, whenever mobile bed changes from mild to steep gradient with a smooth-slope block from 30° to 60°.

Correlation tests between the parameters and responses of the experiments indicate that $R_{u2\%}$, $H_{s,bedtoe}$ and $q_{overtop}$ are strongly correlated to the β_{bed} of the model. While both $R_{u2\%}$ and $q_{overtop}$ significant relationship with the α_{block} . Test on the responses output shown that $q_{overtop}$ dependently to the $R_{u2\%}$, meanwhile found out that $R_{u2\%}$ was dependant to the $H_{s,bedtoe}$. Finally, the fitted relationship design model with the most significant experimental variables has presented the optimal predictive model of $q_{overtop}$ has obtained 10 linear terms and 16 interactions of 2-way terms. However, this method needs to further analyze and fitted using the response optimizer method for a better model.

The analysis has also shown that the overtopping is not directly affected by water level but water level will be affected on wave runup and significant wave height. The optimal relationship prediction model of overtopping discharges was verified and satisfied to apply in experimental physical setup accordingly to the overtopping proportions required.

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