



8th International Conference on Asian and Pacific Coasts (APAC 2015)

Pressures on Gabion Boxes as Artificial Reef Units

Srineash V K^a, Murali K^b

^aResearch Scholar, Department of Ocean Engineering, IIT Madras, Chennai 600036, India.

^bProfessor, Department of Ocean Engineering, IIT Madras, Chennai 600036, India.

Abstract

Naturally occurring shoals and near-shore reefs act as good wave attenuators. Artificial reefs have been looked into as potential solutions for creation of surf waves. Recently, artificial reefs are being examined as soft solutions for coastal protection. Conventional hard approaches like construction of sea wall, groins, revetments, bulkheads and break waters have been successful over the past. However, they may sometimes create adverse impacts on the coastal environment. Thus, employing artificial reefs for shore protection would yield multiple benefits as they attenuate the waves away from shoreline and does not interact with the shoreline directly. Because of this, they are often called multipurpose reefs. Construction of reefs has been primarily based on geo bags and geo tubes. Sometimes, rubble mound construction has been used. However, there are construction and handling difficulties. Hence, gabions may be considered in artificial reefs due to their ease of construction and porous nature. Gabions also reduce the construction time, hence making it suitable to construct during adverse weather window. The porosity of gabions may also add favorable effects on the near shore environment. On the other hand, several installations of artificial reefs over the past decade have faced severe stability issues. Since literatures relevant to artificial reef are scanty, the present study brings out the experimental measurement of pressures on Gabion Boxes as artificial reefs. In order to relate the pressure to stability, pressures are measured over units at critical locations. An attempt has been made to use the measured pressures to obtain forces and thus stability factors of Gabion Box units in reef applications. The pressure measurement is made varying, the reef parameters and wave parameters. The purpose of varying the reef parameters (width of reef and height of the reef) is to come out with the optimum configuration of reef for a given wave climate. The pressure measurement corresponding to a particular reef configuration is presented in the paper.

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Peer- Review under responsibility of organizing committee , IIT Madras , and International Steering Committee of APAC 2015

Keywords: Wave breaking; Pressure; Shoaling; Dissipation; Wave steepness; Reflection; Transmission; Skewness; Kurtosis; Gabion.

1. Introduction

Gabion boxes are used in wave environment primarily for scour protection applications. The porous nature of gabions reduces the secondary flow around the structure. The Scour is attributed due to secondary flow around the structure, which causes a horse shoe vortices in front of the structure and lee wake vortices behind the structure (Sumer et al., 2001). This complex flow past the structure leads to the scour. Hence the porous gabions are often preferred to reduce the scour on the toe of the structure. This paper evaluates the application of gabion boxes as artificial reef units by pressure measurement; which may be used for quantifying the forces on the reefs. Present study extends the application of gabions from scour protection to wave attenuation by offshore wave attenuation. Unlike conventional measures of shore protection like seawall, bulkhead, revetments, groynes, which are present on the shore; artificial reefs are submerged and off the shore. The advantage of such offshore reef is that, the wave breaking will take place off-the shore and hence significant amount of wave attenuation will take place by over topping and wave breaking (Pilarczyk et al., 2003). The attenuated wave reaching the coast will have less energy, which prevents coastal erosion. Further, on a long run may also cause accretion (beach formation) on the shore. The artificial reefs are often described as soft measures of coastal protection as they have very less environmental impact compared to conventional hard measures like sea wall, bulk head, groynes. Artificial reefs made of gabion boxes were also studied as a potential to improve marine life (Firth et al., 2014). Artificial reefs are often combined with surfing, coastal protection and habitat formation. Hence they are called multipurpose reefs, one such reef is built at Gold coast, Australia (Black et al., 2001). This paper brings out the experimental results pertaining to pressure measurement on Gabion Box Artificial Reef units (GBAR) performed in shallow water wave flume in Department of Ocean Engineering, IIT Madras.

Nomenclature

H	Incident Wave Height (m)
H_t	Transmitted Wave Height
η	Wave Elevation (m)
T	Time period (s)
L	Wave length (m)
L_o	Deep water wavelength (m)
D	Water depth (m)
d'	Free board (depth of submergence of crest) (m)
g	Acceleration due to gravity (m/s^2)
B	Crest width of the reef
W	Base width of the reef
P_1	Absolute Maximum Pressure on Pressure gauge1 (N/m^2)
P_2	Absolute Maximum Pressure on Pressure gauge2 (N/m^2)
P_{d1}	Absolute Maximum Differential Pressure between crest and trough on Pressure gauge1 (N/m^2)
P_{d2}	Absolute Maximum Differential Pressure between crest and trough on Pressure gauge2 (N/m^2)
ρ	Mass density (Kg/m^3)
γ	Specific Weight of water (N/m^3)

2. EXPERIMENTAL SET UP

The Physical model study was performed in the wave flume which is 72m long, 2m wide and 2.7 m deep. A sloping false bottom was provided on the seaward side of the structure with a slope of 1 in 22 to shoal the waves. A sand bed was created on the flatter portion of the setup and model was placed on the sand bed. The purpose of using sand is to mimic the practical seabed condition in the field. Resistance type wave probe was used to find the instantaneous wave elevation before the structure. A Schematic sketch showing the experimental setup is shown in Fig. 1. The pressure measurement was made on the seaward and leeward side of the reef. Pressure gauges were

embedded inside the gabions and the sensing element was placed facing the wave. Pressure gauge P_1 was placed facing the wave paddle and P_2 was placed facing the beach. Pressure gauges were embedded on the second gabion from bottom at an elevation of 0.075 m from the sand bed. It was ensured that no projection was made beyond the structure (reef) due to instrumentation of pressure transducer. The Pressure gauges are capable of sensing pressure range of 0 – 0.5 bar; the sampling interval used was 40 hertz. The slope of the stepped reef was maintained 2 Horizontal : 1 Vertical in seaward direction and 1 Horizontal : 1 Vertical in leeward direction. The seaward slope is kept less steep (2:1) with a view to reduce the reflection and hence the forces on the structure. The gabions were arranged such that the longer side of the gabion is parallel to the wave direction. A resistance type wave probe WP1 was kept before the ramp to get wave height at 0.67 m water depth. Wave probe WP2 was kept 5m ahead of the structure to get the instantaneous wave elevations at that point. Wave probe WP3 was placed behind the structure to obtain the transmitted wave height. This transmitted wave height is used to non-dimensionalize the pressure gauge P_2 .

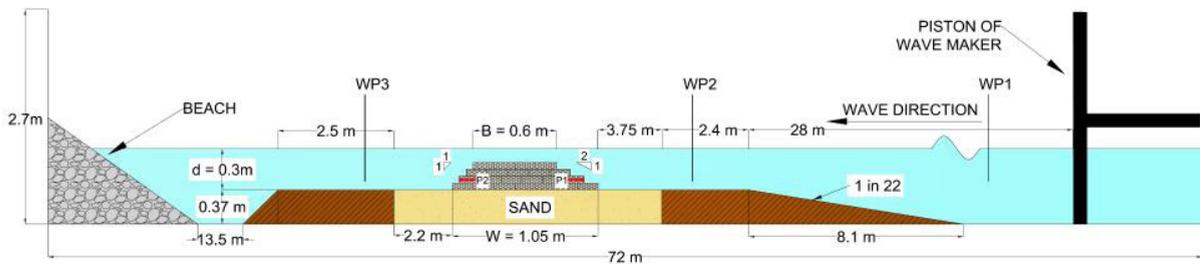


Fig. 1. Schematic Sketch of experimental setup

2.1 Model Preparation.

The gabion models used in the study was scaled according to Froude's law. The details of the model on comparison to a typical prototype values are show in table 1. The scale ratio adopted is 1:20. The wire mesh used in study resembling the cage of gabion is PVC coated Galvanized Iron of 0.9mm diameter with the wire diameter of 0.45mm. The weight of gabion was maintained as 0.624 kg. The gabion boxes were filled with gravels of size ranging between 7.5 mm to 12.5 mm.

Table 1. Comparison of dimensional parameters between model and prototype

Parameter	Units	Typical Prototype	Laboratory model
T	s	4.74 – 13.33	1.06 – 2.27
H	m	0.66 – 3.8	0.033 – 0.19
d	m	6	0.3
d'	m	2	0.1
B	m	12	0.6
W	m	21	1.05
Mass	kg	4992	0.624
Gabion Dimension	m	3 X 1 X 1	0.15 X 0.05 X 0.05
Stone Size	m	0.15 – 0.25	0.0075 -0.0125
Porosity	No unit	37 %	37 %

2.2 Non-Dimensional Parameters used in study

During the experimental process, the pressure on the structure was measured varying the wave parameters like B/L and H/L . The pressure is non-dimensionalized by dividing the obtained pressure by specific weight of water and by wave height at that location as $P/\gamma H$. The non-dimensional parameters affecting the pressure and statistical parameters are shown below.

$$(P/\gamma H, \text{Skewness, Kurtosis}) = f(B/L, W/L, H/L, d/L, d'/d) \quad (1)$$

The depth of submergence of the crest (d') of the reef was maintained as 10 cm throughout the study. During the experiments, the wavelength and wave heights were varied keeping the crest width (B) and water depth (d) constant. The table showing the ranges of various non-dimensional parameters used in the study is showed in Table 2.

Table 2. Range of non-dimensional parameters

Non-dimensional parameters	Range
B/L	0.16 – 0.4
W/L	0.28 – 0.7
H/L	0.018 – 0.058
H/d	0.11 - 0.61
d/L	0.08 – 0.2
d'/d	0.334

A Schematic figure showing wave transformation past the structure is shown in Fig. 2 (a) and a closer view of gabions along with pressure transducers is shown in Fig. 2 (b)



Fig. 2 (a) Wave Transformation past the reef (b) Location of Pressure gauges on GBAR

3. RESULTS AND DISCUSSION

3.1 Dynamic Pressure measurement on GBAR units

In the laboratory tests involving regular waves, the Pressure on P_1 and P_2 were recorded. This pressure record may be correlated to the forces induced on the gabions. Figure 3 contains the normalized plot showing the variation of non-dimensional theoretical through pressure, measured crest and trough pressures ($P/\gamma H$) at the location P_1 on the reef with dimensionless crest width parameter B/L . It has to be noted that during the process of non-dimensionalization, the incident wave height is used to obtain the dimensionless pressures for pressure gauge P_1 . The theoretical pressure estimate was made using Airy's linear wave theory at the point P_1 considering that the structure is absent at the location. Looking at the theoretical pressure, it can be inferred that the increase in wavelength increases the pressure since the crest width (B) is kept constant. This variation of theoretical trough pressure without the presence of the structure is done to compare with the measured crest and trough pressure in the presence of the structure. The absolute maximum value of dimensionless theoretical trough pressure ($P/\gamma H$) at location P_1 is found to be about 0.45 for a B/L of 0.16 and the absolute minimum value of dimensionless theoretical trough pressure is 0.27 for B/L of 0.4.

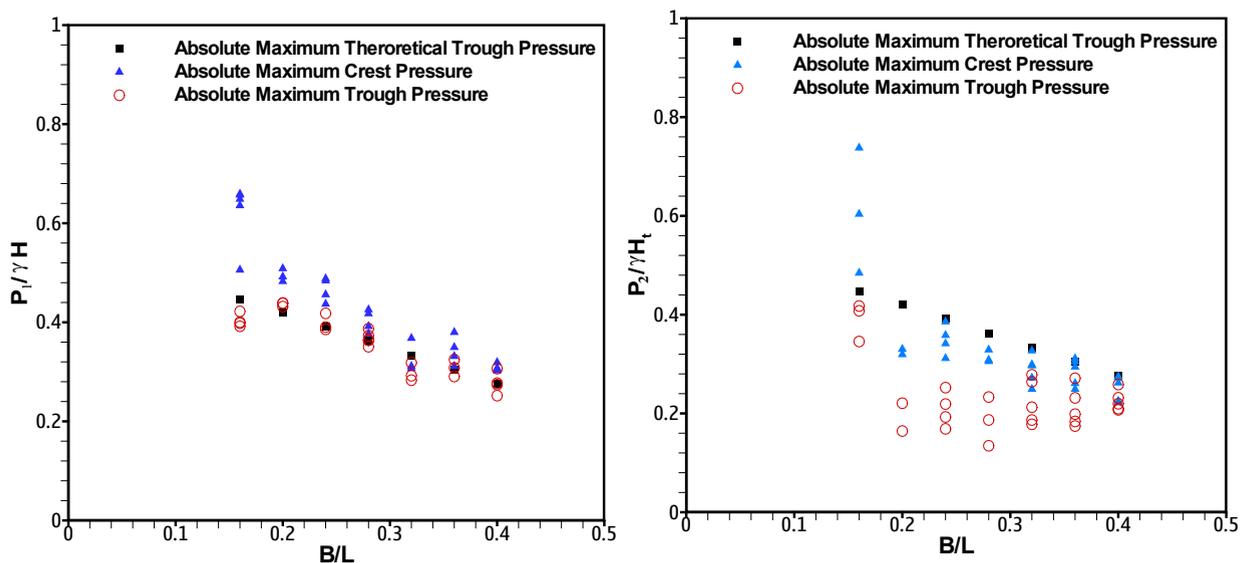


Fig. 3 (a) Variation of $P_1/\gamma H$ with B/L (b) Variation of $P_2/\gamma H_t$ with B/L

Looking at the variation of non-dimensional crest pressure ($P/\gamma H$) at location P_1 on the seaward face of the structure, a clear trend of increase in dimensionless measured crest pressure ($P/\gamma H$) with reduction in B/L . This is attributed due to fact that the crest pressure during the presence of the structure increases as the B/L decreases. This also confirms the fact that the pressure corresponding to the crest increases with increase in wavelength. The maximum value of dimensionless measured crest pressure ($P/\gamma H$) is 0.64 for a B/L of 0.16 and a minimum value of 0.3 for a B/L of 0.4 as shown in Fig. 3 (a).

Further, the dimensionless measured trough pressure ($P/\gamma H$) at P_1 is found to increase with decrease in B/L as showed in Fig. 3 (a). As discussed earlier, the measured trough pressure is also found to increase with the wave length. The absolute maximum value of dimensionless measured trough pressure ($P/\gamma H$) at location P_1 is found to be about 0.44 for a B/L of 0.2 and the absolute minimum value of dimensionless measured trough pressure is 0.25 for B/L of 0.4. This has got a good correlation with that of the theoretical through pressure. This correlation of theoretical trough pressure with the actual measured pressure on the structure at P_1 is evident from graph shown in

Fig. 3 (a). Thus for a reef of such configuration, one may be able to estimate the maximum pressure on the structure at point P₁, during the crest of the wave from the theoretical estimate of trough pressure (from Fig 3 (a)).

The pressure gauge P₂ was kept on the leeside of the structure facing the beach. Variation of dimensionless theoretical through pressure (using Airy’s linear theory), measured crest and trough pressures ($P/\gamma H_t$) at the location P₂ on the reef with dimensionless crest width parameter B/L is showed in Fig. 3 (b). The dimensionless theoretical trough pressure ($P/\gamma H_t$) is obtained here form the transmitted wave height (H_t) whereas for the former case it was incident wave height (H). As seen earlier, the variation of theoretical trough pressure at location P₂ neglecting the presence of the structure is done to compare with the measured crest and trough pressure during the presence of the structure. Non-dimensional theoretical trough pressure ($P/\gamma H_t$) is found to increase with the decrease in crest width parameter (B/L). The absolute maximum value of dimensionless theoretical trough pressure ($P/\gamma H_t$) at location P₂ is found to be about 0.45 for a B/L of 0.16 and the absolute minimum value of dimensionless theoretical trough pressure is 0.27 for B/L of 0.4.

Examining the variation of crest pressure using the non-dimensional parameter ($P/\gamma H_t$) in Fig. 3 (b); with the reduction in B/L, the non-dimensional crest pressure parameter is found to increase roughly with decrease in B/L. The maximum dimensionless measured crest pressure at P₂ was found to be about 0.74 for a B/L of 0.16 and a minimum dimensionless measured crest pressure of around 0.23 for a B/L of 0.4.

Similarly, the measured trough pressure on the leeside of the reef at point P₂ facing the beach can be ascertained by looking at Fig. 3 (b). The maximum absolute value of measured trough pressure was about 0.4 for a B/L of 0.16 and minimum absolute value of measured trough pressure was around 0.13 for B/L of 0.28. From Fig. 3 (b), it may be observed that there is no correlation of non-dimensional measured crest and trough pressures with the theoretical trough pressure. This is due to the distorted wave field past the structure. In other words, the structure modifies the wave field past the structure. It can also be observed from the Fig. 3 (b) that the non-dimensional measured through pressure is well below the theoretical estimate.

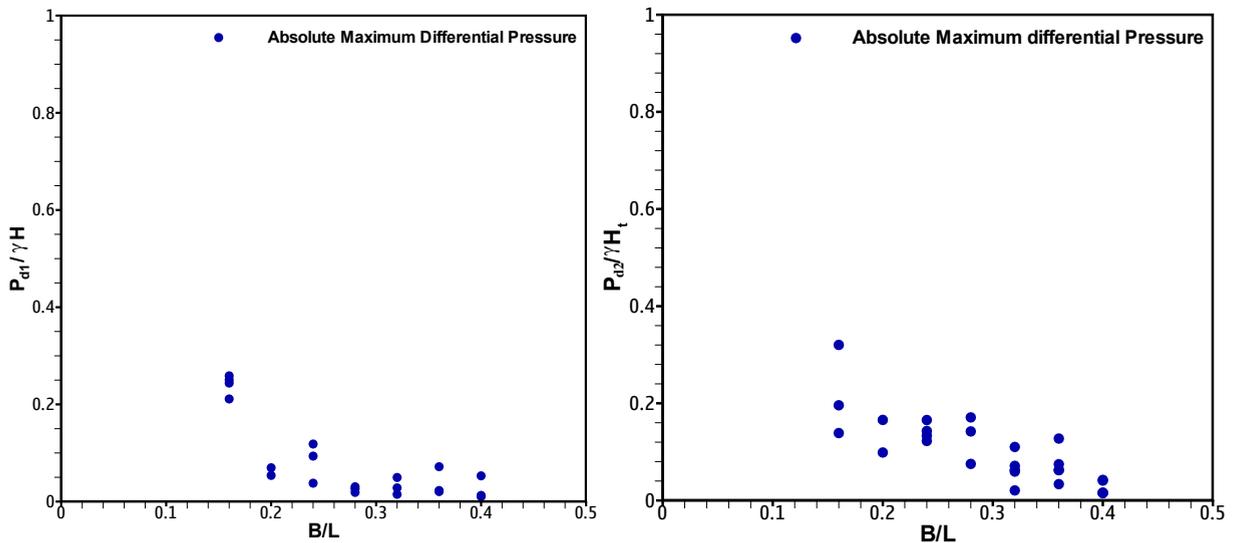


Fig. 4 (a) Variation of $P_{d1}/\gamma H$ Vs B/L (b) Variation of $P_{d2}/\gamma H_t$ Vs B/L

The differential pressure variation between the crest and the trough of the structure is studied in order to ascertain the relative unbalanced pressure component over the reef. This study may give a sense of unbalanced force on the structure due to cyclic force exerted by the waves. Figure 4 (a) shows the variation of non-dimensional differential pressure $P_{d1}/\gamma H$ with B/L. Figure 4 (b) shows the variation of non-dimensional differential pressure

$P_{d2}/\gamma H_t$ versus B/L . In both the cases the non-dimensional differential pressure is found to increase with decrease in B/L . It is evident from the Fig. 4 (a) that beyond B/L of 0.24, there is a steep rise in the non-dimensional measured differential pressure between the crest and the trough at location P_1 on (seaward side of reef). The steep rise in non-dimensional differential pressure for lower B/L is attributed due to the shoaling effect produced by the sloping bottom. Further the lower B/L corresponds to higher wavelength; the shoaling effect is seen to rise with increase wavelength. The maximum measured non-dimensional differential pressure is found to be about 0.26 for a B/L of 0.16 and minimum measured non-dimensional differential pressure is found to be about 0.01 for a B/L of 0.16. It can also be inferred that the higher B/L with less wavelength has very negligible pressure difference as the crest and trough are almost same. For higher B/L , the wavelength is less and hence lesser will be the shoaling effect.

Further from Fig. 4 (b) which shows the variation of maximum dimensionless differential pressure corresponding to P_2 on leeside of the reef, the increase in dimensionless pressure was found with decrease in B/L . Here the steep variation of differential pressure with increase in wavelength was not seen as that of the previous case. This may be due to distorted wave field past the structure as discussed earlier. The maximum dimensionless differential pressure is observed as 0.32 for B/L of 0.16 and minimum dimensionless differential pressure of 0.016 for a B/L of 0.4.

3.2. Statistical Analysis

The reef induced wave breaking phenomena was discussed on the previous sections. In order to understand the peakedness and asymmetry of the data obtained, analysis are done to find the skewness and kurtosis of the measurements. The skewness shows the asymmetry pertaining to the measurement whereas kurtosis shows the peakedness (shape) of the measurement. To find the skewness and kurtosis, mean and variance of wave record has to be ascertained. Therefore the mean, variance, skewness and Kurtosis is analyzed and presented below.

Figure 5 (a) shows the variation of Kurtosis of P_1 with the structure width parameter B/L . It is seen for P_1 that the kurtosis is almost same till B/L of 0.2 after which there is a sudden increase in kurtosis (measure of peakedness) which is due to the shoaling effect at higher wavelengths. The plot conveys that for any given B/L , The reef induced broken waves posses higher skewness (asymetry). The kurtosis varies from a maximum of about 2.1 for a B/L 0.16 to a minimum of 0.36 for a B/L of 0.32.

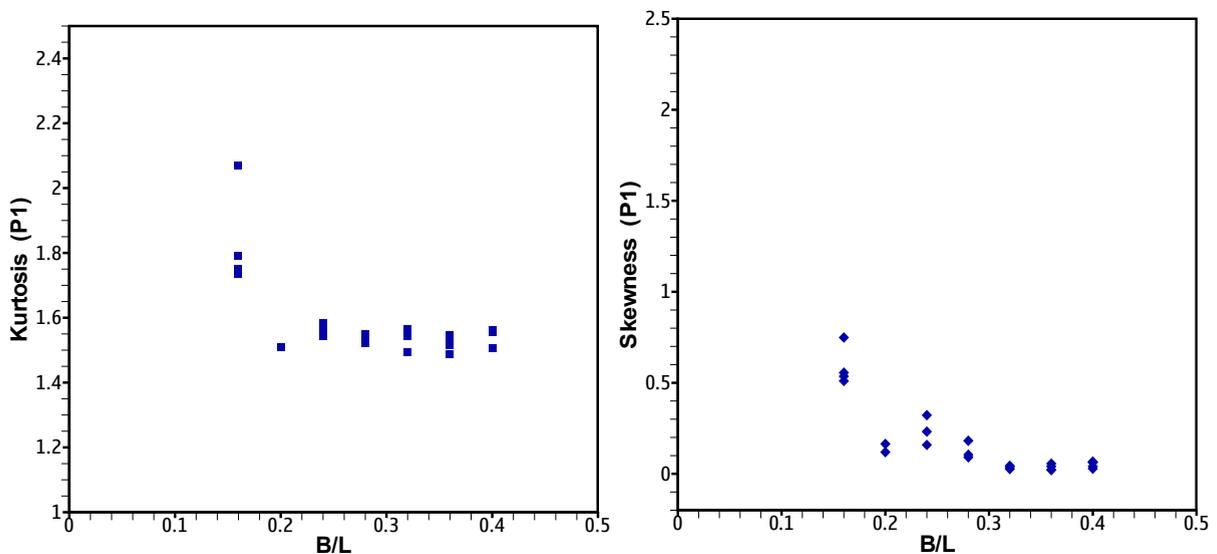


Fig. 5. (a) Variation of Kurtosis Vs B/L for P_1 (b) Variation of Skewness Vs B/L for P_1

The plot in Fig 5 (b) shows the assymetry (in x axis) in the measured pressure record, the effect of skewness is more pronounced beyond B/L of 0.2 which is also due to shoaling effect . The maximum skewness observed is about 0.75 for a B/L of 0.16 and the minimum skewness obseved was about 0.022 for a B/L 0.36.

4. CONCLUSION

The variation of non-dimensional Pressure ($P/\gamma H$) with crest width parameter B/L was discussed for P_1 and P_2 and it was found that the $P/\gamma H$ increases with decrease in B/L, Which implies that pressure increases as wavelength increases.

- Maximum non-dimensional crest pressure observed at P_1 is about 0.64 for a B/L of 0.16
- Minimum non-dimensional crest pressure observed at P_1 is about 0.3 for a B/L of 0.4.
- Maximum non-dimensional crest pressure at P_2 0.74 for a B/L of 0.16.
- Minimum non-dimensional measured crest pressure at P_2 is about 0.23 for a B/L of 0.4.

The theoretical through pressure in the absence of structure is correlated to get the maximum pressure on the structure.

The quantification of pressure may be correlated to stability of GBAR units; as pressure can be related to the force on the structure. The differential pressure between crest and trough were plotted as a function of B/L which may give a better understanding of unbalanced pressure acting on the structure.

Variation of statistical parameters (Skewness, Kurtosis) is made for the measurements pertaining to pressure and studied with respect to B/L. Thus the study gives a good sense of understanding on the pressure variation on the seaward and leeward side of the structure. Plots are plotted showing the correlation between the theoretical pressure distribution and the pressure due to the presence of structure. This information may serve as a good source of know how in designing artificial reefs in the wave environment.

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