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Improving Resiliency and Minimizing Coastal Impact of Rock Mounds Oyster Bed Breakwater System

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Abstract: Structures built along nearshore tend to disrupts coastal processes at different levels depending on the type and manner of construction. This disruption will result into poor water circulation which may affect biological activities, sediments dynamics and coastal protection from inclement weather. Breakwaters are often constructed to minimize impact of stronger waves. Rock mound oyster bed was proposed to help rock oyster producer improve their production, however some environmental issues were noted such as uneven oyster density distribution and sediments accumulation which are associated to water circulation/movement disruption and more importantly the resilience of the mounds itself from stronger waves. This paper explores proposed strategy how the environmental impact to the rock mounds can be enhanced using a laboratory model of a typical coastal zone where rock oyster mounds can be established.

Keywords: impact, sediment dynamics, mariculture impact, water circulation, coastal zone

1. Introduction

Rock oyster farming has been part of the livelihood in Samar. In other countries, different techniques on artificially culturing of rock oyster are being practiced. These techniques sometimes utilize nets as an oyster bed and most commonly through piles of rocks known as rock culture method which is unique in Southeast Asia (FAO, nd.). Rock mounds as oyster bed use natural rocks as a substrate for spat settlement and growth until harvest. The rocks are usually piled in groups and spread in rows in each direction to facilitate management and harvest like the one described in the study of Racuyal (2016). This technique is best used in areas with hard, sandy or sandy-mud bottoms firm enough to support the rocks (FAO, nd.)

In Racuyal's (2016) rock mounds, it was observed that oyster growth was uneven on all sides, has trapped some sediment and was affected heavily by strong waves due to inclement weather. The uneven distribution of oyster on the mounds suggests problems on water circulation. Galtsof (1964) says that larvae are carried by currents and at the time of setting are brought in contact with clean and hard surfaces. The sediments trapped are also attributable to free movement of water along the coast. Structures built in the coast like breakwater prevent sediments from being transported to the area (Vaselali and Azaarmsa, 2009). The excessive sedimentation, as well as dead water, will affect oyster growth. Sediments may burry oyster beds, smother the organisms and increase oyster population mortality (Easter Oyster Biology Review

Team, 2007). Sediments with large quantities of organic matter can deplete oxygen levels through decay (Jones et al., 2012). Water flow is the single most important element of sediment transport (McNally and Mehta, 2004). The rock mounds constructed in the study of Racuyal (2016) was severely affected by waves. According to the University of Hawaii, the amount of energy in a wave is proportional to the square of the height. Any structure built along the coast must be strong enough to face strong waves during inclement weather.

One of the negative impacts of breakwater or any structures built along the coastal waters is its disturbance of the natural processes. As oysters grow on the manufactured reef like the rock mounds, it reinforces its structural integrity, as well as increases, wave energy dissipation improving shoreline protection (Risinger, 2012). The disruption of water movement due to the artificial structures will affect the sediment dynamics in the area (Airoldie et al., 2005) which may alter the coastal configuration. Ordinarily, in a wave dominated shoreface and nearshore environment, fine sediments remain suspended and are winnowed away into the deeper waters where the bottom is slightly stirred by the waves, leaving the coarse sand on shore (Karl, 2000; CU, nd). Fine sediments like silt and clay may come from runoff waters carried by rivers and streams especially during rainy days.

It is therefore important to design the rock mounds that are more resilient to stronger waves but at the same time minimize the disturbance on water and sediments movement.

2. *Objective*

The study explored the redesigning of rock mounds oyster bed as breakwater system. The design also takes into consideration improving water circulation and reducing sediment entrapment for optimal functionality.

3. *Methodology*

3.1 Research Design

The study utilizes the experimental research design with model mounds considering shape and arrangement. Engineering analysis was also included to describe physical performance observed. The research was performed at the Hydraulics Laboratory of Samar State University.

3.2 Research Instrumentation

3.2.1 Physical Model

The model breakwater system was tested using a laboratory wave set-up simulating a typical tidal flat exposed to

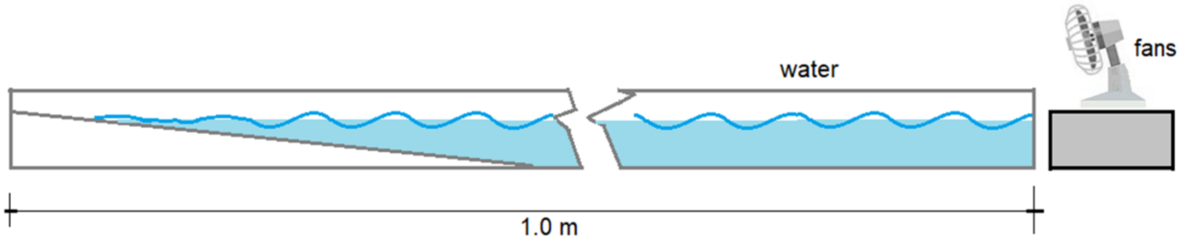


Figure 1. Wave Model

waves and surface runoff from the mainland. Waves were generated using fans blowing at 25 m/s. Wave properties such as height and length and its frequency were not included in the calculation. The model mounds were just exposed for 10 minutes for each setup. For water circulation observation, a blue-colored dye was used. The sloping portion of the physical model is about 1:4.

3.2.2 Rock Mounds and Placement

Scaled rock mounds made of cement mortar were used in the study. The study of Racuyal (2016) made use of longitudinal and cubical formation. For this study, three shapes were considered namely; cube, cylindrical and droplet-shaped and arranged in columnar and staggered formation. The mounds weigh between 5.5 to 7.7 grams. The mounds are assumed to be in-tacked or bonded together like a concrete.

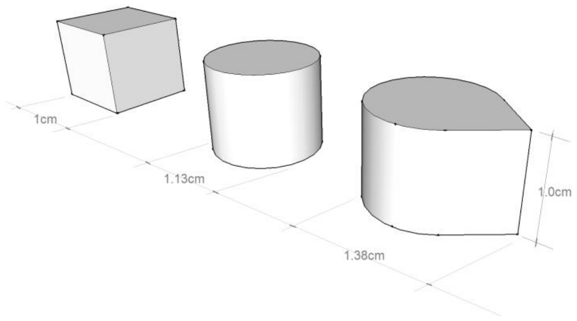


Figure 2. Model Rock Mounds Used in the Study

a) One Row b) Two Rows/Columnar c) Two Rows/Staggered

Figure 3. Rock Mounds Arrangement

3.2.3 Resistance to Waves

Resistance to waves was measured through model mounds displacement. The further it is displaced suggests higher impact, and for stability, it also requires stronger support or anchorage system. The model mounds were arranged in a marked position and later exposed to simulated waves for about 10 minutes. After the exposure, the displacement from the initial position was recorded. The measurement of mounds resistance is aligned to its additional purpose, that is to serve as an effective breakwater system.

3.2.4 Water Circulation

Water circulation was visualized using a blue-colored dye. The flow of water as illustrated in the dye was observed from various trials. Video and still camera shots were used to generalize movements. The free movement of water not only will improve the productivity of the rock mounds as an oyster bed but more importantly is its ability to allow movements of sediments through and through the rock mounds set-up.

3.2.5 Sediment Entrapment

Sediments may come from the sea (leeward) and or towards the sea, usually from runoff waters carrying sediments due to erosion mostly from rivers, streams or canals. For leeward sediment direction mounds were lined-up about 2 cm from the group of the mounds and waves pushed the sediments upward for about ten minutes. For seaward event (see Figure 4), sediment-rich water was poured on the elevated portion of the model and allowed to flow towards the sea. The simulated waves were halted during the process to zero-in the behavior to the run-off water movement only. Amount of sediments transported and trapped inside the area as shown in Figure 4 was determined in terms of area covered with sediments. The volume of sediments was not determined.

Figure 4. Trapped Sediment Estimation Zone

3.2.6 Statistical Treatment of Data and Presentation

Mounds displacement and sediment transported was subjected to a one-way Analysis of Variance (ANOVA) and followed with a post hoc analysis to determine what treatment is statistically different. Other data were presented in tables and graphs as well as pictures.

4. Results and Discussion

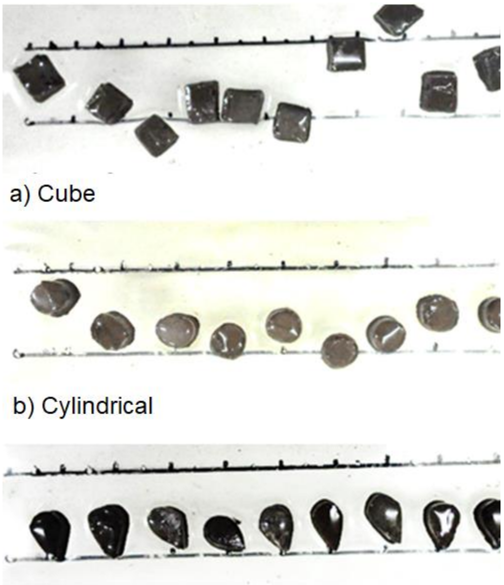
The study looks into ways to improve rock mounds resiliency to stronger waves, enhanced potential oyster productivity and at the same time reduce the impact to coastal process.

4.1 Resistance to Waves

The test examines the mounds resistance to waves not just for it to be resilient to inclement weather farming technique but to examine if it can also serve as a breakwater set-up. Breakwaters are built to reduce wave action in an area in the lee of the structure. Wave actions are reduced through a combination of reflection and dissipation of incoming wave energy (PIANC, 2011).

Failures of breakwaters are categorized into three by Oumeraci (1994), namely; a) inherent to the structure itself, b) the hydraulic conditions and loads, and c) the morphology of the base of the seawall and the seabed. In this paper, observation is limited to sliding or overturning (simple displacement) of a block in a laboratory setting. Rock mounds are piles of rocks grouped into one but are not bonded. The rock mound is assumed to be one and cannot fail individually.

Model rock mounds were prepared and arranged in one line in a wave model. As mini waves impact the model mounds, it is displaced. The farther the displacement, the stronger is the impact. Anchorage or ways to make the mounds more resistance to wave is higher for mounds receiving higher impact. The preceding are the observations made from three trials performed.

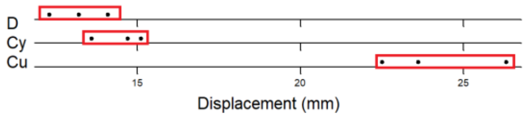


a) Cube

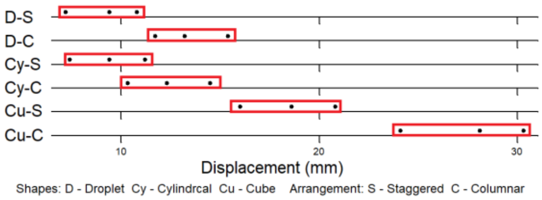
b) Cylindrical

c) Droplet-shaped

Figure 5. Displacement of Model Rock Mounds After Wave Exposure (One Row)



A) Rock Mounds in One Row



B) Rock Mounds in Two Rows

Figure 6. Dot Plot on the Displacement of Mounds

There were three scenarios tested for the test on resistance. First is a one-row mounds arrangement and two rows of mounds arrangement (columnar and staggered placement). The displacements of mounds in one and two rows are the same. The farthest displacement was exhibited by cubic mounds followed by cylindrical, and the least is the droplet shape.

It appears that cubic mounds experience stronger impact from waves. In a single row of mounds, the displacement of cubic and cylindrical mounds is 82.6% and 9.8% farther than the droplet-shaped mounds respectively. On the other hand, the displacements of the first line of mounds in a two rows arrangement are larger by 16.4 for cubic mounds, but it's smaller for cylindrical by 28.5% and 11.2% for droplet shaped. The average displacement has increased instead of decreased because of a larger number of mounds resisting the forces from the crashing waves. Closer observation on the cubic mounds reveals that the ripple effect of the crashing waves from the second

Table 1: Turkey HSD Results for Displacement of Mounds (One Row)

Shape	Average Displacement mm	SD	p-value	
			Cylindrical	Droplet
Cubic	24.13	1.95	**0.001	**0.001
Cylindrical	14.47	0.78		0.509
Droplet	13.20	0.90		

**significant (0.05) ** significant (0.01)*

Table 2: Turkey HSD Results for Displacement of Mounds in the First (Two Row)

Shape - Arrangement	Average Displacement mm	SD	p-value				
			Cu-S	Cy-C	Cy-S	D-C	D-S
Cu-C	27.5	3.14	**0.003	**0.001	**0.001	**0.001	**0.001
Cu-S	18.47	2.40		0.053	**0.003	0.137	**0.003
Cy-C	12.38	2.08			0.570	0.900	0.514
Cy-S	9.33	1.90				0.288	0.900
D-C	13.44	1.85					0.247
D-S	9.13	1.81					

Shape: Cu – Cubic; Cy – Cylinder; D-Droplet *Arrangement: C – Columnar; S – Staggered*
**significant (0.05) ** significant (0.01)*

row pushed the first row blocks farther. The second rows for all type of shapes have lesser displacement than the first.

Post-hoc Turkey HSD calculation reveals that cylindrical and droplet-shaped mounds have similar performance in terms of its resistance to displacement while cubic appears receiving more force attributable to its shape. The cube is like a vertical wall while the droplet and cylindrically shaped blocks are like the inclined wall in the report of Okamura (1993) who studied the impact of waves on vertical walls. He indicated that the pressure gets higher as the wall becomes near vertical. Illustrated in Figure 7, the shape of the cylindrical and droplet mounds diverts the impact to sides while cubic receives the entire wave strength.

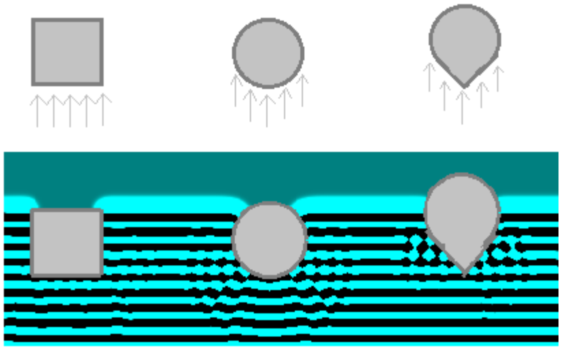


Figure 7. Wave Force Visualization

The total force acting on the wall is dependent on the wave parameters such as speed and height and the area in contact with the wave. For the cubic mound, the entire frontage of the mound receives the pressure, larger contact area, larger driving force Fh. What makes the mound stable against sliding and overturning is its weight and the frictional resistance between the sea floor and the base of the mound as shown in Figure 8. On the other hand, circular frontage will have lesser impact area as presented in Figure 9.

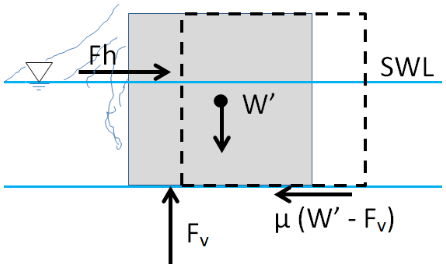


Figure 8. Failure Mode by Sliding (Oumeraci,1994)

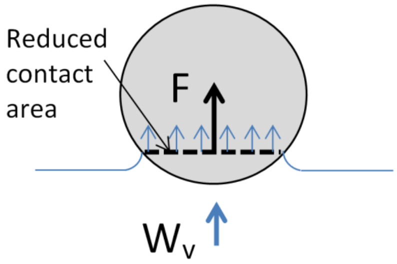


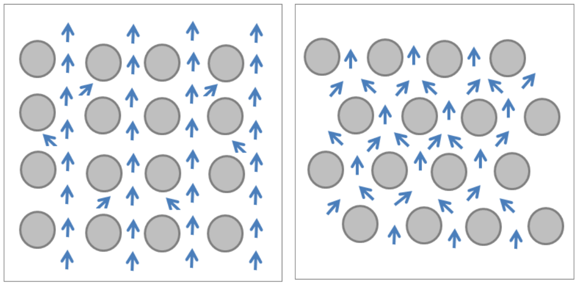
Figure 9. Top View of a Cylindrical Block Facing a Rushing Wave (W_v)

4.2 Water Circulation

Dyed water was used to facilitate observation of water flow. The experiment aims to describe the free exchange of water through circulation which could affect the growth of rock oyster and at the same time the transportation of sediments to and from the sea. It was revealed in the study of Racuyal (2016) that growth density in the mounds was not uniform. This suggests that water circulation is not uniform. Galtsoff (1964) reported that surfaces would have oysters if larvae carried by the currents and in time of setting brought in contact with the mounds.

Observation of the movement of the dye suggests that there are fewer surfaces in the columnar arrangement that is exposed to the dye. The movement appears more linear than disturbed in the columnar arrangement for all shapes tested. The dye comes in contact with the leeward and seaward surface specifically when the water moves up and back as waves disturb the waters.

The behavior of the water with dye is quite different for mounds arranged in staggered form. Majority of the surfaces were regularly exposed to the dyed water. The exposure was higher when the waves further disturb the water due to the waves.



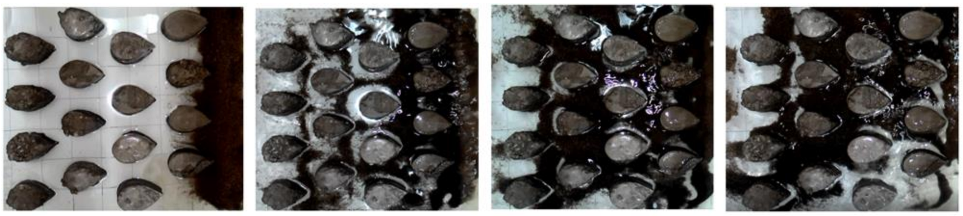
a) Columnar Arrangement *b) Staggered Arrangement*

Figure 8. Movement of Water

4.3 Trapped Sediment

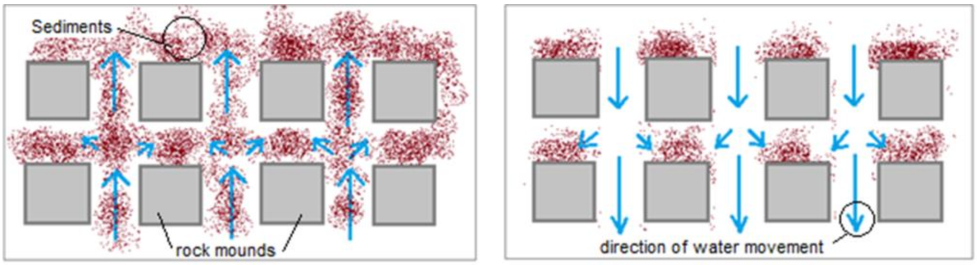
One of the weaknesses observed in the rock mounds in the study of Racuyal (2016) was the trapped sediments inside the experimental site. This characteristic not only poses a threat to the sustainability of the mariculture project for growing rock oyster but also suggests coastal process disturbance. Any barrier along the coast like breakwater or rock mounds may disrupt sediments movement. A disruption of sediments movement results in altered coast characteristics and processes (Woodroof, 2008).

Shown in figure 9 is the test for sediments moving leeward. The waves forced the sediments positioned about 2cm from the mounds to move upward. After 10 minutes of wave exposure, the number of sediments in the pre-identified zone was noted. It showed that the sediments were distributed evenly as wave's forces it to



0 min 3 min 6 min 10 min

Figure 9. Leeward (R to L) Movement of Sediments



(L) Sediments carried by water moving landward (R) Sediments carried by water moving seaward

Figure 10. Sediment Movement

move. On the other hand, as the water recedes, the sediments carried upward were also drawn back to the water. This behavior suggests that sediments do not settle permanently as it is carried back and forth as longshore drift does. As sediments are washed by the waves, erosion or scouring in other parts of the coast supplies the same zones vacated by the washed sediment. In this experiment, sediments are coming from the sea and not from the shore.

The behavior in the cylindrical and droplet-shaped mounds is different. The rounded surface of the mounds allowed sediments to slip over as water recedes to the sea. Shown in Table 4 and 5 are the statistical tests for the percent of the area occupied by the sediments. For the seaward movement, the cubic mounds arranged in a columnar manner received lower value than the staggered arrangement. The area covered with sediments is different for cylindrical and droplet arrangement. There are lesser sediments trapped in the staggered arrangement than in the columnar arrangement.

In this experiment, it appears that cylindrical and the droplet-shaped mound arranged in staggered formation is preferred as it accumulates a lesser amount of sediments than the other set-up, may it be for seaward movement or leeward movement of sediments. The rounded surface allows better flow of water, and so is the sediments carried by it.

5. Conclusion and Recommendation

The better type of mound is the droplet-shaped arranged in a staggered

Table 4. Trapped Sediments (Seaward movement)

Shape - Arrangement	Percent of Area Covered with Sediment	SD	p-value				
			Cu-S	Cy-C	Cy-S	D-C	D-S
Cu-C	55.00	5.00	**0.001	**0.001	0.309	**0.004	**0.009
Cu-S	73.33	5.77		**0.009	*0.022	0.864	**0.001
Cy-C	86.67	2.89			**0.001	**0.002	**0.001
Cy-S	61.67	2.89				0.138	**0.001
D-C	70.00	5.00					**0.001
D-S	41.67	5.89					

Shape: Cu – Cubic; Cy – Cylinder; D-Droplet *Arrangement: C – Columnar; S – Staggered*
**significant (0.05) ** significant (0.01)*

Table 5. Trapped Sediments (Leeward movement)

Shape - Arrangement	Percent of Area Covered with Sediment	SD	p-value				
			Cu-S	Cy-C	Cy-S	D-C	D-S
Cu-C	81.67	2.89	**0.001	**0.001	**0.001	**0.001	**0.001
Cu-S	58.33	2.89		**0.001	**0.001	**0.001	**0.001
Cy-C	31.67	7.64			**0.005	0.900	0.620
Cy-S	16.67	2.89				*0.012	**0.001
D-C	30.00	5.00					0.354
D-S	36.67	2.89					

Shape: Cu – Cubic; Cy – Cylinder; D-Droplet *Arrangement: C – Columnar; S – Staggered*
**significant (0.05) ** significant (0.01)*

manner in terms of its resistance to waves, better water circulation, and lesser sediment entrapment characteristics. The cylindrical mound is comparable but is a little lower in terms of resisting waves, the tapered head facing the wave appears effective in reducing the strength of the wave. The droplet shape and the cylindrical mounds will have lesser environmental impact than the cubical mounds.

The cubical type is not ideal as it is more prone to damage during inclement weather or occasions with strong waves. It also allows larger accumulation of sediments and poorer water circulation.

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