Stability of breakwater armour using rock pockets on transition wave

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Abstract. Breakwater, which is one of the coastal protection systems that is often used in Indonesia, has a major component of the armour/protection layer. Breakwater armour on the coast has three possibilities for wave attack, are shallow waves, transition waves, and deep waves. Using rock pockets as armour in transition waves has significant characteristics and influences on the coefficient of damage value. This study aims to obtain the Coefficient of damage breakwater armour using rock pockets in transition wave conditions. This research is experimental with physical tests conducted in the 2-D wave channel at the Laboratory of Marine Engineering, Faculty of Engineering, Hasanuddin University. Making with several waves, and weight of armour configurations. Transition waves are obtained by plotting and eliminating the wave classification graph. The scale model used is 1: 10, with three water depth variations, are 25 cm, 20 cm, and 15 cm. The results showed that coefficient of damage armour at the end (head) of the breakwater for the transition wave for slope device 45˚, coefficient of damage value is 3.92, at the slope device 60˚ Coefficient of damage value is 4.52.

1. Introduction
The Indonesian archipelago is an area that mostly grows and develops starting from the coast. The coastal protection system that is often used is by making breakwaters. At inclined breakwater type, the device is generally made of natural stone piles whose exterior is given armour or a protective layer that serves to withstand wave attacks. Armour made from large stones weighing several tons or using artificial stones such as tetrapod, quadruped, tribar, hexapod, dolos, A-jack and others. This causes breakwater work to be relatively more expensive in construction. In the area around the coast, it is sometimes difficult to find rocks that fill up the technical specifications of breakwater armour. Local materials easily obtained are sand and rock, so that efforts are needed that can fill up the weight requirements of one of breakwater armour using the pocket.

In design the weight of breakwater armour is calculated based on the value of the Coefficient of damage \( C_D \) for various types of armour grains, but until now, there is no coefficient of damage value \( (C_D) \) that can be used to calculate stability for the type of armour that uses rock pockets for various conditions wave.

Several previous studies related to breakwater stability such as the stability character of sandbag armour on submerged breakwaters, the formula stability of breakwater armours on an unbreaking
wave, the stability of roll sandbag armour, the stability of armour on the submerged breakwater, and stability of cube armour, and tetrapod accropode [1-5].

The above makes the writer interested to research the stability of breakwater armour using rock pockets. This study aims to obtain the value of the coefficient of damage (C_D) of breakwater armour using rock pockets that occur on transition waves.

2. Research Methods
The research method used was experimental, carried out in the Hydrodynamics Laboratory of Marine Engineering, Faculty of Engineering, Hasanuddin University.

2.1. Material
The materials used in the study are: pockets of rock and stone with non-uniform gradations

2.2. Equipment
The equipment used in this study is: wave flume, ruller bar to measure wave height, a stopwatch to measure wave period, camera for documentation, tables and stationery, hammers and keys to regulate fully and stroke.

2.3. Procedure
In line with the research procedure as follows: first the model is placed in the middle of the flume, a wave generation experiment is carried out to calibrate the recording tool for wave height, conducting wave observations, the maximum and minimum wave heights in front of the model are measured and recorded in each of the 9 point. Transition waves are obtained by plotting into a wave classification graph, which is not a transitional wave eliminated. After reaching a certain number of waves (N), the wave generator is off, then the model damage is recorded, the model damage is divided into three criteria: not moving, moving but not silt, sift from device position with a certain distance [6], coefficient of damage (C_D) is determined based on the maximum damage criteria on 0 - 5% [7]. The variations in this research were adjusted to the purpose of the study and laboratory conditions, which are shown in table 1.

| Case | Research Parameters       | Variation I | Variation II | Variation III | Repetition |
|------|---------------------------|-------------|--------------|---------------|------------|
| 1    | Slope device              | 01          | 01           |               | 3          |
| 2    | Weight of rock pocket armour | W1        | W2           | W3            | 3          |
| 3    | Wave period               | T1          | T2           | T3            | 3          |
| 4    | Wave height               | H1          | H2           | H3            | 3          |

Table 1. Configuration of research.

The shape rocks pocket similar a pillow bag as shown in figure 1, with size weight W_{100}, W_{150}, and W_{200}. Material Bag is a cloth that is a prototype of geotextile.

Figure 1. The shape of armour rock pocket.
Wave channel with completed a wave generator. The wave channel is made of steel with a length of 1.845 cm, a width of 122 cm and an effective height of 122 cm. as in figure 2.

![Figure 2. Model in the wave flume.](image)

The parameters studied were the wave variables are wave period (T), wave height (H), water depth (d). Material weight consists of gravity (g), rock pocket weight (W), rock specific gravity (γr). The fluid parameter is water specific gravity (γa) and geometry parameters consist of slope device (θ), and model damage (S).

3. Results and discussion

3.1. Wavelength

Determination of wavelength (L) based on the wave period (T) and water depth (d) obtained from the rotation time of the drive generator of the wave generator. The results of the calculation of experimental data plotted into a graph of the use limits of the application of wave theory are based on the comparison value of H/ d and d/ L, as shown in figure 3. Because the airy waves used are in transition conditions, so that waves other than airy transition conditions are eliminated. So that the calculation of the related wave parameters fully uses the Airy wave theory in transition conditions.

![Figure 3. Classification of wave theory functions H/ d and d/ L.](image)

3.2. Wave reflection

To review the effect of wave steepness (Hi / L) with the reflection coefficient (Cr) in the simulation on different breakwater slope and relative water depth (d). Calculation of reflection coefficient (Cr). Each model is plotted in the form of a graph of the relationship of wave steepness (Hi / L) and the
reflection coefficient \( (C_r) \) for the variation of breakwater slope at depth of 15, 20 and 25 cm can be seen in figures 4, figure 5 and figure 6.

![Figure 4](image1.png) **Figure 4.** Plot of \( \frac{H_i}{L} \) and reflection coefficient \( (C_r) \), at \( d = 15 \)cm.

![Figure 5](image2.png) **Figure 5.** Plot of \( \frac{H_i}{L} \) and reflection coefficient \( (C_r) \), at \( d = 20 \)cm.

![Figure 6](image3.png) **Figure 6.** Plot of \( \frac{H_i}{L} \) and reflection coefficient \( (C_r) \), at \( d = 25 \)cm.

The results of testing the trend of the reflection coefficient values increase along with the wave steepness \( (\frac{H_i}{L}) \) up. This caused the incoming waves are breaking before rubbing the breakwater. Friction waves are getting smaller to the device will reduction absorb reflections from incoming waves, so that it will produce a greater reflection wave, which can cause greater armour damage.

Based on the picture, the largest reflection coefficient \( (C_r) \) value of 0.484 occurs at the wave steepness \( (\frac{H_i}{L}) = 0.057 \) and the smallest \( C_r = 0.200 \) at \( \frac{H_i}{L} = 0.012 \). The reflection coefficient \( (C_r) \) gets bigger at water depth \( (d) \) large and the slope of the device \( (\theta) \) is large.

3.3. Stability of armour rock pockets on transition waves

Wave energy is influenced by wave height. Wave height is one of the trigger factors for damage breakwater. According to the law of energy conservation, the higher the wave, then the greater the velocity of the wave. Wave velocity is very influential on the hydrodynamic force. Therefore wave higher there is an increase in the level of damage \( (S) \).

3.3.1. Water depth and wavelength ratio, \( d/L \) to armour damage

The effect of water depth and wavelength \( d/L \) ratio to the level of damage \( (S) \). As shown in figure 7, armour damage increases polynomially with an increase in the \( d/L \) ratio. A high water depth value caused a greater level of damage. A high wavelength \( L \) is caused by the greater wave period \( T \). If a wave travels over an area with a certain depth, with a small wavelength so that the influence of wave high reflections and caused greater value armour damage.

![Figure 7](image4.png) **Figure 7.** Water depth and wavelength ratio, \( d/L \) to armour damage.
3.3.2. Wave height and water depth, H / d ratio to armour damage

The relationship of wave height and water depth ratio H / d to the level of damage (S) with variations slope device (θ) can be seen in Figure 8. Shows the trend level of damage (S) increase polynomially with increasing wave height (H) and accordingly with the law of energy conservation in a wave. The wave height (H) increases with increasing water depth (d) and slope device (θ).

![Wave height and water depth ratio, H / d to armour damage.](image)

Figure 8. Wave height and water depth ratio, H / d to armour damage.

3.3.3. Stability of rock pockets armour on transition waves

When the breakwater is given a wave force, some rock pockets armour move and shift from the construction. The quantity of pocket moves and shifts from its device, which called is the level of damage device. The level of damage is an indicator of stability, where the coefficient of damage (C_D) is determined based on the level of damage (S) 0 to 5%.

In design, the weight of breakwater armour is calculated by equation 1.

\[
W = \frac{\gamma_r H^2}{C_D (\frac{\gamma_r - \gamma_a}{\gamma_a})^s \cot \theta}
\]  

(1)

So the C_D value is calculated by the equation 2.

\[
C_D = \frac{\gamma_r H^2}{W (\frac{\gamma_r - \gamma_a}{\gamma_a})^s \cot \theta}
\]  

(2)

Where W = armour weight (kg), (γ_r) = rock specific gravity (kg / m3), (γ_a) = water specific gravity (kg / m3), H = wave height (m), θ = breakwater slope, C_D = armour coefficient of damage. Calculation Coefficient of damage (C_D), as shown in table 2.

According to the table 2 shows the value of coefficient of damage (C_D) in the transition wave by placement at the end (head) of breakwater, calculated at the level of damage (s) 0-5%, the highest value at slope device 60°, value coefficient of damage C_D 4.52 and at slope device 45° value C_D 3.92. A high coefficient of damage (C_D) will produce high device stability. A high C_D is a function of a small weight (W), a small slope device θ and large wave height (H).
## Table 2. Coefficient of damage calculation.

| No | % Damage | W (Kg) | h (m) | \( \gamma_t \) (kg/m³) | \( \gamma_a \) (kg/m³) | \( \theta \) (°) | C_D |
|----|----------|-------|------|----------------|----------------|---------|-----|
| 1  | 1.27%    | 0.10  | 0.053| 2200           | 1000          | 60      | 3.19|
| 2  | 0.96%    | 0.10  | 0.050| 2200           | 1000          | 60      | 2.76|
| 3  | 0.69%    | 0.10  | 0.048| 2200           | 1000          | 60      | 2.36|
| 4  | 0.41%    | 0.10  | 0.053| 2200           | 1000          | 60      | 3.19|
| 5  | 0.41%    | 0.10  | 0.053| 2200           | 1000          | 60      | 3.19|
| 6  | 4.49%    | 0.15  | 0.060| 2200           | 1000          | 60      | 3.18|
| 7  | 0.77%    | 0.15  | 0.058| 2200           | 1000          | 60      | 3.18|
| 8  | 0.77%    | 0.15  | 0.058| 2200           | 1000          | 60      | 2.79|
| 9  | 0.46%    | 0.15  | 0.058| 2200           | 1000          | 60      | 2.79|
| 10 | 0.52%    | 0.20  | 0.058| 2200           | 1000          | 60      | 2.10|
| 11 | 0.17%    | 0.20  | 0.063| 2200           | 1000          | 60      | 2.69|
| 12 | 2.94%    | 0.15  | 0.068| 2200           | 1000          | 60      | 4.52|
| 13 | 2.63%    | 0.15  | 0.058| 2200           | 1000          | 60      | 2.79|
| 14 | 0.93%    | 0.15  | 0.063| 2200           | 1000          | 60      | 3.59|
| 15 | 0.31%    | 0.15  | 0.063| 2200           | 1000          | 60      | 3.59|
| 16 | 0.31%    | 0.15  | 0.060| 2200           | 1000          | 60      | 3.18|
| 17 | 2.09%    | 0.20  | 0.060| 2200           | 1000          | 60      | 2.38|
| 18 | 4.50%    | 0.10  | 0.068| 2200           | 1000          | 45      | 3.92|
| 19 | 3.29%    | 0.10  | 0.058| 2200           | 1000          | 45      | 2.42|
| 20 | 0.77%    | 0.10  | 0.060| 2200           | 1000          | 45      | 2.75|
| 21 | 0.55%    | 0.10  | 0.063| 2200           | 1000          | 45      | 3.11|
| 22 | 0.33%    | 0.10  | 0.060| 2200           | 1000          | 45      | 2.75|
| 23 | 3.83%    | 0.15  | 0.071| 2200           | 1000          | 45      | 3.04|
| 24 | 3.33%    | 0.15  | 0.070| 2200           | 1000          | 45      | 2.91|

The greatest value at \( \theta = 60° \) 4.52
The greatest value at \( \theta = 45° \) 3.92

### 4. Conclusions

From the results of this study, it can be concluded that the wave reflection, the ratio of wave height and water depth, \( H/d \), the ratio of wave height and water depth \( H/d \) the larger, caused higher armour damage. Thus affecting the coefficient of damage (C_D) value. The results obtained the coefficient of damage breakwater armour using rock pocket at the end (head) of the breakwater construction on transition wave conditions, calculated at the level of damage (s) 0-5%, the largest value at slope device 60°. Coefficient of damage C_D 4.52 and at slope device 45° C_D 3.92. A high Coefficient of damage (C_D) will produce large device stability. A high C_D is a function of small weight (W), a small slope device \( \theta \) and large wave height (Hi).

In this research, not all model parameters are examined, so that it is possible to do further research with various wave classification conditions, and consider lift and drag forces that occur at armour device.

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