BPPT-lock Armor Unit Implementation for Improving Breakwater Sustainability at the Pacitan Power Plant

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Abstract. BPPT-lock was developed by the Agency for The Assessment and Application of Technology (BPPT) and was awarded patent in 2012. The hydraulic stability (K_D) of BPPT-lock armor unit was compared to Tetrapod, Dolos and Xbloc armor units. The results indicate that, BPPT-lock performs far better K_D in comparison to each of these armor units. A comparative analysis on the economical use of material was also carried out among BPPT-lock, Dolos, Tetrapod and rough stone and rounded stones for similar design condition, the armor unit weight is 4.68ton, 4.97ton, 9.95ton, 19.89ton, and 39.79ton respectively, means that BPPT-lock is more efficient in this comparison. Considering its feasible performance, BPPT-lock is designed as the armor units for the maintenance and reparation of the existing rubble mound breakwater of Pacitan Coal Fired Power Plant port. The 110 m parts of the existing breakwater was hardly damaged and the new structure is designed to stand against a 30 yrs RP waves of Hs = 7m. BPPT-lock armor unit of W = 11 ton on the breakwater slope 1:1.5 is implemented. The first phase construction works was completed in December 2018 and visual observation has shown the great integrity and stability of BPPT-lock armor units.

Keywords: BPPT-lock, breakwater, rubble mound, efficient, Pacitan Coal Fired Power Plant.

1. Introduction

Breakwater is a structure that is used to protect the harbor from wave attacks [1]. This structure separates the harbor basin from the open sea to prevent large waves entering the harbor basin. Under breakwater protection, the harbor basin become calm and ships can safely load and unload goods.

Rubble mound breakwater is the most common breakwater used for shore protection [2]. Rubble mound breakwater is made of stone piles, which can be either natural stone or artificial material. The armor layer, i.e. the most outer part of breakwater, is subjected to direct large forces from the wave, and therefore its shape and size must be designed to remain stable at all times.

The shape of an armor unit has a key role because it will affect the stability coefficient (K_D = Coefficient of Hydraulic Stability) of the unit.

There are many types of armor units that can be classified according to the placement method, number of layers, shape, and stability factors. Table 1 shows the classification of armor units.
Table 1. Classification of armor units\(^a\).

| Placement      | No. of Layer | Shape         | Stability Factor |
|----------------|--------------|---------------|-----------------|
|                |              |               | Own Weight | Interlocking | Friction | Manually Bound |
| Random         | Single       | Simple        | Cube, Antifer  |             |          |               |
|                |              |               | Cube, Modified |             |          |               |
|                | Double       | Simple        | Cube          |             |          |               |
|                |              | Double Layer  | Tetrapod, Akmon, |             |          |               |
|                |              | Complex       | Tribar, Tripod |             |          |               |
| Uniform        | Single       | Simple        | A-Jack, Accropod, |              |          |               |
|                |              |               | Core-loc, Xbloc, |              |          |               |
|                |              | Complex       | Stabit, Dolos  |             |          |               |
|                |              | Simple        | Seabee, Hollow, |              |          |               |
|                |              |               | Cube, Diahitis, |              |          |               |
|                |              | Complex       | IAS            |              |          |               |

\(^a\) [3], added with Xbloc, IAS, and BPPT-lock [4].

BPPT-lock is classified as a random, single layer and interlocking armor unit and has been awarded patent by Ministry of Law and Human Rights of Indonesia in 2012.

Breakwater of the Pacitan Coal Fired Power Plant located at Pacitan District is suffered severe damage and even its breakwater’s trunk was cut off about 110 m length. The First Phase damage reparation was carried out by putting BPPT-lock as the armor layer of breakwater (instead of the originally Dolos) on the seaside part that directly receiving large waves attack, whereas for the harbor side parts, that has no large waves attack, Dolos armor units is kept to give protection.

BPPT-lock armor unit is used for the present breakwater reparation by consideration that BPPT-lock has a better performance compared to Dolos, and is a domestic technology product.

2. BPPT-lock Comparison With Others in a Laboratory Test

2.1. Comparison with Tetrapod and Dolos

The Laboratory tests were carried out by comparing BPPT-lock, Tetrapod and Dolos. The slope of breakwater was 1:1 (vertical : horizontal).

![Figure 1. Tetrapod, Dolos, BPPT-lock.](image)

As shown in Figure 2, the transverse slope of breakwater model was divided into 3 sections, from left to right respectively for Tetrapod, Dolos, and BPPT-lock by careful arrangement that each section will provide accurate data. Any single armor unit is placed randomly in its appropriate section layer.
Figure 2. Arrangement of armor units models in the experimental flume [4].

From the hydraulic model tests, the following results are obtained. Figure 3 shows the hydraulic laboratory test result comparison of number of damage (moved) armor units among BPPT-lock, Tetrapod and Dolos. At the left-side, it is shown that BPPT-lock performs better in comparison with either Tetrapod or Dolos. At the right side, the detailed comparison of number of damaged (moved) armor units between BPPT-lock dan Dolos is shown in which BPPT-lock performs much better than Dolos.

Figure 3. Test results comparison of number of damage (moved) units [4].

2.2. Comparison with Xbloc

Figure 4 shows the pictures of BPPT-lock armor unit and Xbloc armor unit as well. Further, comparison of hydraulic stability test results between BPPT-lock and Xbloc for breakwater slope of 1:2 is shown in figure 5, and for the slope of 1:1.5 is shown in figure 6. It is known from the test results that BPPT-lock armor unit performs hydraulic stability better than Xbloc along with the increase of wave height.
2.3. Measuring Hydraulic Stability coefficient (Kd)

Hydraulic stability tests had been carried out to determine the hydraulic stability coefficient (Kd). Kd values are calculated using the Hudson’s formula [5]:

\[ W = \frac{\rho_a H^3}{K_d (S_r - 1)^3 \cot(\alpha)} \]  

where: \( W \) = weight of armor unit, \( H \) = wave height, \( g \) = specific gravity; \( K_d = K_D \) = stability coefficient, \( \alpha \) = slope of rubble mound, \( S_r \) = relative density \( (\rho_a/\rho_w) \), \( \rho_a \) = armor unit density, \( \rho_w \) = density of water.

The calculated \( K_d \) values of BPPT-lock and its related numbers of damaged (moved) armor units during experiment is shown in table 2 and figure 7.

Table 2. Calculated \( K_d \) of BPPT-lock based of hydraulic experimental results [4].

| Slope | Wave Height | \( K_d \) | Nr. of Damage |
|-------|-------------|----------|---------------|
| 1:2   | 5.04        | 1.86     | 0             |
| 1:2   | 8.49        | 8.87     | 0             |
| 1:2   | 12.05       | 25.37    | 0             |
| 1:2   | 15.02       | 49.13    | 1             |
| 1:2   | 17.3        | 75.08    | 3             |
| 1:2   | 19.35       | 105.05   | 7             |
| 1:2   | 21.25       | 139.14   | 200           |
| 1:2   | 6.05        | 3.21     | 0             |
### Table 3. Comparison of properties and number of armor units per square area (for the same armor unit weight).

|               | Number of layers (n) | Coefficient of Stability ($K_d$) | Coefficient of Layer ($K_{\Delta \ell}$) | Coefficient of Porosity (p) | Number of Armor/Square Area |
|---------------|----------------------|----------------------------------|----------------------------------------|----------------------------|----------------------------|
| **BPPT-lock** | 1                    | 17                               | 0.99                                   | 52                         | 1,001                      |
| **Dolos**     | 2                    | 16                               | 1.00                                   | 56                         | 1,495                      |
| **Tetrapod**  | 2                    | 8                                | 1.04                                   | 50                         | 1,696                      |
| **Rounded Stones** | 2              | 2                                | 1.00                                   | 38                         | 2,107                      |
| **Rough Stone** | 2                  | 2                                | 1.20                                   | 37                         | 2,569                      |

3. **Comparison of BPPT-lock Properties to Other Types of Armor Units**

A comparison of BPPT-lock properties to Dolos, Tetrapod, rough stone and rounded stones armor units were conducted. The comparison was made for the number of armor units per square area (table 3) and the weight of a single armor unit for for similar design condition, i.e. slope 1:2 and $H_{\text{design}} = 5\text{m}$) (table 4).

![Graph showing Kd values and number of damage](image)

**Figure 7.** $K_d$ value and the number of damage [4].
Table 4. Comparison of weight of armor unit for similar design condition.

| Armor       | Slope | Design Wave $H_{\text{design}}$ (m) | Armor Unit Weight (ton) |
|-------------|-------|--------------------------------------|-------------------------|
| BPPT-lock   | 1:2   | 5                                    | 4.68                    |
| Dolos       | 1:2   | 5                                    | 4.97                    |
| Tetrapod    | 1:2   | 5                                    | 9.95                    |
| Rough Stone | 1:2   | 5                                    | 19.89                   |
| Rounded Stones | 1:2 | 5                                    | 39.79                   |

Obtained the results from table 3, it is known that the mass porosity of BPPT-lock, Dolos, Tetrapod, rough stone and rounded stones are 50%, 63%, 52%, 37% and 38% respectively, and number of armor unit per square area is 1,001, 1,495, 1,696, 2,107 and 2,569 respectively for BPPT-lock, Dolos, Tetrapod, rounded stones, and rough stone.

Whereas for similar design condition (slope 1:2 and $H_{\text{design}} = 5m$) at table 4, it is found that the armor unit weight of BPPT-lock, Dolos, Tetrapod, rough stone and rounded stones are 4.68 ton, 4.97 ton, 9.95 ton, 19.89 ton and 39.79 ton respectively, means that BPPT-lock is more efficient in this comparison.

4. Implementation of BPPT-lock at the Port of Pacitan Coal Fired Power Plant

4.1. Breakwater of the Pacitan Coal Fired Power Plant Port, its damage and reparation situation.

Location of Pacitan Coal Fired Power Plant and bird-view of the damaged breakwater is shown in figure 8 below.

![Figure 8. Location of Pacitan Coal Fired Power Plant and bird-view of the damaged breakwater.](image-url)
Figure 9. Bathymetry surrounding the Pacitan Coal Fired Power Plant Port

Figure 10. Bathymetry details nearby the damaged breakwater location (before damage situation)
The damage situation of breakwater is described as follows:

a. About 100 m part of the breakwater was partly damaged, where the main armor units were scattered due to large waves attack (Phase 1 reparation was completed);

b. Another 110 m part of the breakwater was hardly damaged by large waves attack, where the broken parts included armor layer, sub layer and part of the core layer.

Figure 11 shows the Google image of damage situation of the Pacitan Coal Fired Power Plant breakwater.

![Figure 11. Situation of damaged at the breakwater trunk of Pacitan Coal Fired Power Plant Port.](image)

4.2. Breakwater Reparation Design.

4.2.1. The 1st alternative design of breakwater

The 1st alternative design consists of BPPT-lock as the armor layer, geobag filled with sand at the 2nd layer, and a pile of stones at the core layer.

![Figure 12. The 1st alternative design of breakwater.](image)
4.2.2. The 2nd alternative design of breakwater
The 2nd alternative consists of BPPT-lock as the main armor layer, the 2nd layer is pile of stones, and the core layer is pile of stones [7].

![Figure 13. The 2nd alternative design of breakwater.](image)

4.2.3. The actual implemented design.
For the Phase 1 breakwater reparation, the actual implemented design was a combination between the alternative 1 and alternative 2, where all the 2nd layer uses pile of stones, but the top part only uses sand filled geobags. This is illustrated in the following figure.

![Figure 14. The actual implemented design in the phase 1 reparation.](image)

4.3. Construction Execution

4.3.1. Mold making
BPPT-lock molds were made of iron, as shown in the following Figure. The mold was completely built up in the workshop and then by using truck car taken to the production site at the Pacitan Coal Fired Power Plant Port.
4.3.2. Area for the production and temporary storage of BPPT-lock
BPPT-lock casting area and temporary storage area (before taken to the breakwater location) is shown in the following figure.

![Figure 15](image1.png)

**Figure 15.** BPPT-lock’s moulding.

4.3.3. Casting
The casting of BPPT-lock was carried at the production site close to the port of the Pacitan Coal Fired power plant. Class K-350 concrete is used. The following is a picture of BPPT-lock casting.

![Figure 16](image2.png)

**Figure 16.** BPPT-lock production and temporary storage area.

![Figure 17](image3.png)

**Figure 17.** BPPT-lock casting.
4.3.4. Transportation
BPPT-lock armor units were transported by using truck car from production sites to the construction site of breakwater. The following Figures illustrate the transportation method of BPPT-lock from the production area to the breakwater construction site.

![Figure 19. Illustration of BPPT-lock loaded by truck.](image)

4.3.5. BPPT-lock Installation
BPPT-lock installation on the breakwater was carried out by using crane car with capacity of 200 tons.

![Figure 20. Illustration of BPPT-lock installation onto damaged breakwater.](image)
4.3.6. Completed Repaired Breakwater

Current Breakwater situation (East side, 100 m’s partly damaged breakwater) after completed reparation is shown in the following figure. Around 720 armor units of 11 tons BPPT-lock were deployed for this reparation works.

Figure 23. Breakwater current situation after completed reparation.
5. Conclusions

The conclusions can be summarized as follows:

1. From the hydraulic stability test results, BPPT-lock has shown the best performance compared to Dolos, Tetrapod, and Xbloc, with a fairly high stability coefficient (17 to 13 for the trunk and head of breakwater).

2. Economically, BPPT-lock also has a good performance, such as saving in the use of concrete compare to tetrapod, dolos, rough stone and rounded stones.

3. The first phase reparation construction was completed and visual observation has shown the great integrity and stability of BPPT-lock armor units.

6. References

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