Deformation and Stability Analysis of Breakwater Structure in Morosari Coast, Demak, Central Java

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Abstract. Indonesia is an archipelagic country with the second longest coastline in the world. The problem faced by coastal areas in Indonesia is the erosion, mainly due to the development of ponds, as happened in Morosari Demak. Several segments of breakwaters from concrete blocks have been constructed. But it has not been able to withstand erosion-, even the breakwaters were damaged. This study is aimed to evaluate the stability and deformation of breakwaters that have been built. Evaluations include armoring stability, soil bearing capacity, land subsidence, and consolidation. Two segments of breakwaters constructed in different years, 2011 (A) and 2013 (B), are evaluated by measuring cross-sectional, and elevation. Measurements were made twice at different times. Changes that occurred during that period were compared with the difference between the initial condition (as built drawing) and the condition when the measurement was done. The results indicated that the breakwater have been deformed both horizontally and vertically. The breakwater tends to move northwest by 6.662 and 8.330 cm/year for breakwater A and B consecutively, and go down by 5.976 and 4.982 cm/year. There are two factors caused breakwater deformation, soil consolidation, and armoring. The consolidation rate measured in 2016 was 4.234 and 5.040 cm/year for breakwater A and B consecutively. The 300 kg of existing armoring was unstable, the stable armoring should be 365 kg.

1. Introduction

Indonesia is an archipelagic country with the second longest coastline in the world [1]. The problem faced by coastal areas in Indonesia is the erosion, mainly due to the development of ponds, as happened in Morosari, Demak [2]. Several segments of breakwaters from concrete blocks have been constructed. But it has not been able to withstand erosion, even the breakwaters were damaged. This research is aimed to evaluate the stability and deformation of breakwaters that have been built. Evaluations include armoring stability, soil bearing capacity, land subsidence, and consolidation. Two segments of breakwaters constructed in different years, 2011 (A) and 2013 (B), are evaluated by measuring cross-sectional, and elevation. Measurements were made twice at different times [3]. Changes that occurred
during that period were compared with the difference between the initial condition (as built drawing) and the condition when the measurement is done [4].

![Research Location Map](image)

**Figure 1.** Location Map of Morosari

### 2. Methods

The overall procedure of this study is following the flowchart as presented in Figure 2. The study was started by data collection, it consisted of secondary and primary data. The secondary data includes wind data, wave data, tidal data, soil characteristics, and the original breakwater design [5]. The primary data obtained based on field survey and observation. Field survey was conducted twice, June and December 2016. It is mainly the measurement of breakwater cross section, position, and the elevation.

The rate of breakwater deformation was analyzed based on the difference between the two measured results. The deformation analyzed by using congruency analysis and movement analysis. The settlement of breakwater was analyzed by using consolidation formula, while land carrying capacity used by Terzaghi equation. The stability of armoring was analyzed by calculating the required armoring weight compared to the existing armoring [6-9s].

![Flow chart of data processing](image)

**Figure 2.** Flow chart of data processing
3. Results and discussion
The analysis of horizontal movement in this research was carried out in the period of June to December 2016. The results of data analysis give magnitude and direction of horizontal movement as shown in Table 1. The vector of the horizontal movement between June to December is presented in Figure 1. This figure shows the movement pattern of the structure between June to December 2016.

| Points | dX (cm) | dY (cm) | Horizontal movement (cm) | Direction movement (degrees) |
|--------|---------|---------|--------------------------|-----------------------------|
| P1     | 2,891   | -3,353  | 4,428                    | 319,2292                    |
| P2     | -5,185  | -4,818  | 7,078                    | 47,10059                    |
| P3     | 0,982   | -0,131  | 0,990                    | 277,6128                    |
| P4     | 2,303   | 0,969   | 2,499                    | 67,18386                    |
| P5     | 1,718   | -0,305  | 1,745                    | 100,0854                    |
| P6     | 1,866   | 5,439   | 5,750                    | 18,94492                    |

The magnitude of vertical movement is obtained from the difference or high difference between the high ellipsoid in June and the high ellipsoid in December. There are six observed points experienced vertical movement at the Morosari Coast breakwater structure. The magnitude of the vertical movement is shown in Table 2.
Table 2. The magnitude of vertical movement between June and December 2016

| Breakwater 2013 | Points | dh (cm) | Average (cm) |
|-----------------|--------|---------|--------------|
| P1              | -2,459 |         |              |
| P2              | -2,298 |         | -2,491       |
| P3              | -2,716 |         |              |
| Breakwater 2011 | P4     | -2,161  |              |
| P5              | -5,090 |         | -2,988       |
| P6              | -1,712 |         |              |

According to Table 2, the value of the vertical movement is negative, which means that all monitored points are settled down. The average value of vertical movement of the breakwaters built in 2011 is higher than that of the breakwater structure built in 2013, which is 2.988 cm. Furthermore, the movement of movements to determine the pattern of movement up or down. In Figure 4 shows the pattern of vertical movement between June and December 2016.

The value of vertical movement ranges from -1.71 cm to -5.10 cm. Negative value means that both breakwater structures (built in 2011 and 2013) are settled down. The effect of sea level rise was analyzed based on tidal data by using MIKE 2.1 software. The result is presented graphically as shown in Figure 5. Based on Figure 5, it can be seen that the Mean Sea Level (MSL) is 0.0003 m, High Highest Water Level (HHWL) is 0.55 m, High Water Level (HWL) is 0.44 m, Mean High Water Level (MHWL) is 0.32 m, Mean Low Water Level (MLWL) is -0.27 m, Low Water Level (LWL) is -0.37 m, Low Lowest Water Level (LLWL) is -0.41 m.
Figure 5. Tidal level at breakwater site

4. Result of Calculation of Land Carrying Capacity (SF)

The calculation of carrying capacity of the land covering two breakwater structures are breakwater structure in 2013 and breakwater structure in 2011. The following is the result of calculation of land carrying capacity based on data of measurement result of 2016 at breakwater structure in 2013 and 2011 presented in Table 3 and 4 below.

Table 3. Calculation of land carrying capacity in breakwater 2013

| Parameters | Values | Units | Information                      |
|------------|--------|-------|----------------------------------|
| A          | 16,750 | m2    | Area                             |
| P          | 79     | m     | Structure length                 |
| V          | 1,323,250 | m3 | Structure volume                 |
| ρ          | 2,400  | kg/m3 | Concrete cube weight             |
| g          | 10     | m/s²  | Acceleration of gravity          |
| B          | 7,690  | m     | Width of foundation              |
| L          | 79,000 | m     | Length of foundation             |
| D1         | 0,300  | m     | The depth of land                |
| Ø          | 18,266 | °     | Sliding angle                    |
| NY'        | 2,160  |       | Coefficient of Terzaghi          |
| Nc'        | 10,768 |       | Coefficient of terzaghi          |
| Nq'        | 4,713  |       | Coefficient of terzaghi          |
| c          | 0,126  | kg/cm²| Land cohesion                     |
| Po(σo')layer1 | 5,541 | kM/m2 | Pressure overbuden of structure  |
| P=∆σ       | 24,421 | kpa   |                                  |
| B/L        | 0,097  |       |                                  |
| Ysat       | 18,469 |       | Y saturated                      |
| Qult       | 315,935|       | Q ultimate                       |
| SF         | 12,937 |       | Safety Factor                    |
Table 4. Calculation of land carrying capacity in breakwater 2011

| Parameters | Values | Units | Information |
|------------|--------|-------|-------------|
| A          | 16,750 | m²    | Area        |
| P          | 79     | m     | Structure length |
| V          | 1,323,250 | m³  | Structure volume |
| ρ          | 2400   | kg/m³ | Concrete cube weight |
| g          | 10     | m/s²  | Acceleration of gravity |
| B          | 5,270  | m     | Width of foundation |
| L          | 70,680 | m     | Length of foundation |
| D1         | 0,300  | m     | The depth of land |
| Ø          | 18,266 | °     | Sliding angle |
| Ny'        | 2,160  |       | Coefficient of Terzaghi |
| Nc'        | 10,768 |       | Coefficient of terzaghi |
| Nq'        | 4,713  |       | Coefficient of terzaghi |
| c          | 0,126  | kg/cm²| Land cohesion |
| ρc         | 12,580 | kN/m² |             |
| Po(σo')layer1 | 5,541 | kN/m² | Pressure overburden of structure |
| P=Δσ       | 20,069 | kPa   |             |
| B/L        | 0,075  |       |             |
| Ysat       | 18,469 |       | Y saturated |
| Qult       | 268,156 |      | Q ultimate |
| SF         | 13,361 |       | Safety Factor |

5. Result of Breakwater Dimension
Figure 6 and 7 show the design breakwater dimension images of 2011 and the breakwater of 2013 in a row. Figures 8 and 9 show the existing breakwater dimensions of 2011 and the breakwater of 2013 in continued.

![Figure 6](image1.png)
**Figure 6.** Design Breakwater built in 2011

![Figure 7](image2.png)
**Figure 7.** Design Breakwater built in 2013
Based on the figures shown in Figures 6 to 9, there has been a change in the dimensions of the breakwater structure and the elevation elevation of the breakwater structure, both in the 2011 breakwater and the breakwater of 2013. The result of dimensional changes is used to support the calculation of movement, soil consolidation, and power. Support the land that there has been a land subsidence in the breakwater structure at Morosari Coast, Demak District.

### 6. Evaluation of The Relationship Between Land Supporting Capacity with Soil Consolidation

In Table 5 shows the results of comparison of dimensions with carrying capacity and consolidation using data from the measurement results in 2016. Based on the values presented in Table 5 below can be concluded that the value of Safety Factor (SF) structure 2011 is greater than the value of SF structure 2013. This is caused by the value of structure volume and the value of pressure on structures in 2011 is smaller than the structure 2013. Thus, the structure 2011 is more stable than the structure 2013. The volume of structures and pressure on structures greatly affect the value of the Safety Factor (SF).

**Table 5.** Results Comparison of dimensions with carrying capacity and consolidation

| Parameters | Breakwater 2013 | Values | Units | Information |
|------------|-----------------|--------|-------|-------------|
| A          | 8,439           | 4,407  | m²    | Area        |
| P          | 73,250          | 70,680 | m     | Structure length |
| V          | 618,179         | 311,480 | m³    | Structure volume |
| P          | 24,421          | 20,069 | kpa   | Pressure    |
| SF         | 12,937          | 13,361 | Safety Factor |
| Sc         | 1,970           | 1,655  | cm    | Total settlement before loading |
| ∆z         | -0,594          | -0,1210 | cm    | Average of vertical movement |
7. Conclusions
Based on the results of data processing and analysis conducted, it can be concluded the research results are as follows:

The magnitude of movement in the structure breakwater in 2011 has a large average horizontal movement of 3.331 cm and the average vertical movement of 2.988 cm. The magnitude of movement in the structure breakwaters in 2013 has a large average horizontal movement of 4.165 cm and the average vertical movement of 2.491 cm.

The direction of the horizontal movement of the breakwater structure at Morosari Coast (the structures of 2011 and the structures of 2013) tends to the northwest. The direction of the vertical movement has decreased all, both in the structure in 2011 and the structure in 2013.

The amount of land consolidation value based on data from the results of 2016 measurement in the breakwater structure in 2011 amounted to 1.655 cm, after 5 years of land consolidation value of 21,174 cm. The amount of consolidation value of land of the breakwaters in 2013 amounted to 1,970 cm, after imposition of 3 years the value of land consolidation to 15.122 cm. The value of land carrying capacity (SF) breakwater structure in 2011 amounted to 13.361, The value of land carrying capacity (SF) structure breakwaters in 2013 amounted to 12.937.

The result of evaluation of the relationship between the movement size, the value of soil consolidation and the carrying capacity of the soil, shows that between the movement and the consolidated value of the soil have a linear relationship. Furthermore, the relationship between the value of land consolidation with soil carrying capacity (SF) has the opposite relationship. The value of soil consolidation and soil carrying capacity (SF) has the opposite relationship, since the value of SF is influenced by the volume of structures and pressure on the structure. This causes breakwater in 2011 to be more stable than breakwater in 2013, as the volume and pressure value at Breakwater 2011 is smaller than the value of volume and pressure at breakwater 2013. The movement of point and decrease of soil consolidation causes the happening of change or decrease of design structure elevation with structure breakwater currently.

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