Experimental Study on Destroy of Dolos Armored Breakwater, Pacitan in Indonesia

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***Abstract*— the breakwater armored with 15 T Dolos block had destroyed several times during constructing even the section verified by experiment study in wave flume, and it was destroyed again after the repair design and test verification. The damage phenomena were compared between on site and in the lab. In the third model test study, it proposed the problems of rod broken caused by block shaking and rolling impact, as well as overall sliding caused by small block supporting the big block. The stability of the repair plan was verified again by increasing the block weight, and the section was verified under the wave impact after on-site implementation. The study also revealed the fact that shaking led to the broken of the rod and the breakwater failure.**

Keywords— breakwater, blocks, destroyed, experiment, shaking, wave flume.

I. INTRODUCTION

In past decades, lots of port were constructed around JAVA island. During the construction of breakwaters for several terminal projects, the south coastal of JAVA island is faced to India Ocean and with strong swell, especially as the PACITAN power station terminal project, ADIPALA coal-fired power station terminal project, Cilacap power station breakwater terminal project, and KARANG TARAJE terminal project. The major waves in the sea area all have a period of 15~18 s, accompanied by huge wave energy swells, which bring great difficulties to the design and construction of the breakwater. The experience and lessons learned from multiple breakwater damage [1-3] were summarized, and the breakwater section structure was continuously designed and optimized. The physical model test was used to verify the design characteristics of the breakwater structure under the action of this type of wave. In order to understand the process of project optimization design, here takes the PACITAN power station terminal project as an example to illustrate that the breakwater has obtained a stable designed breakwater through scale model test. However, during construction, due to the lack of understanding of wave characteristics in the project area and the limitation of construction machinery, failure to reach the designed breakwater during the construction period has already occurred [4-5]. For the third time, combined with the damage phenomenon occurred in the site and the phenomenon observed in the model, the differences were comprehensively analyzed, and the stability scheme was proposed in the test, and the breakwater project was finally completed. In the process, it was also revealed that there are relatively thin and long rods similar to Dolos artificial block, which is also not suitable for use in the sea area with long period swells, and it is easy to be broken rods when encountering heavy waves [6-7].

Indonesia PACITAN (2 × 315 MW) thermal power project is a national key project in Indonesia. The project is located on the south coast of East Java, about 30 km east of PACITAN City. The supporting coal unloading dock of the project is located on the top of an arc-shaped bay and faces the Indian Ocean in the south. Two breakwaters are set up in the wharf project, which are east and west breakwaters respectively. The maximum water depth of the breakwater head is - 20 m. See Figure 1 for the project layout. This paper

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mainly discusses that after the east breakwater is damaged during the construction period, repair tests will be carried out until a stable breakwater section is finally obtained. As for the structural type of breakwater armour block, due to the large waves in the project site, it is not appropriate to select block stones or four legged hollow blocks. If the Accropode block is selected, the local government will charge a patent fee, and the Dolos block is selected based on comprehensive consideration. The elevation of the sea bed in front of the breakwater is -18.5 m, and the elevation of the top of the breakwater is+8.984 m. At the inner and outer sides of the breakwater, from the elevation of -8.35 m to the top of the breakwater, 15.0 t Dolos blocks are used for surface protection, and the weight of the cushion block is 750 ～ 1500 kg; 4.0t Dolos blocks are used for surface protection both inside and outside below the elevation of -8.35m. The weight of cushion block stone is 150-300kg, and the slope is 1:1.5; In addition, 100~300 kg rubble is used as riprap prism at the toe of 4.0 t Dolos slope; The inner and outer bottom protection shall be made of 100~150kg rubble, and the end slope shall be 1:2. The core stone weighs 10~1000 kg. According to the Standard calculation, the stability weight of the Dolos block is 8.95t. Considering that the weight of a single block at the breakwater head of a sloping building should be increased by 20%~30%, the weight of the block is 11.64t. Considering the impact of reflection in front of the breakwater on the wave height, the design weight is 15.0t, meeting the stability requirements.

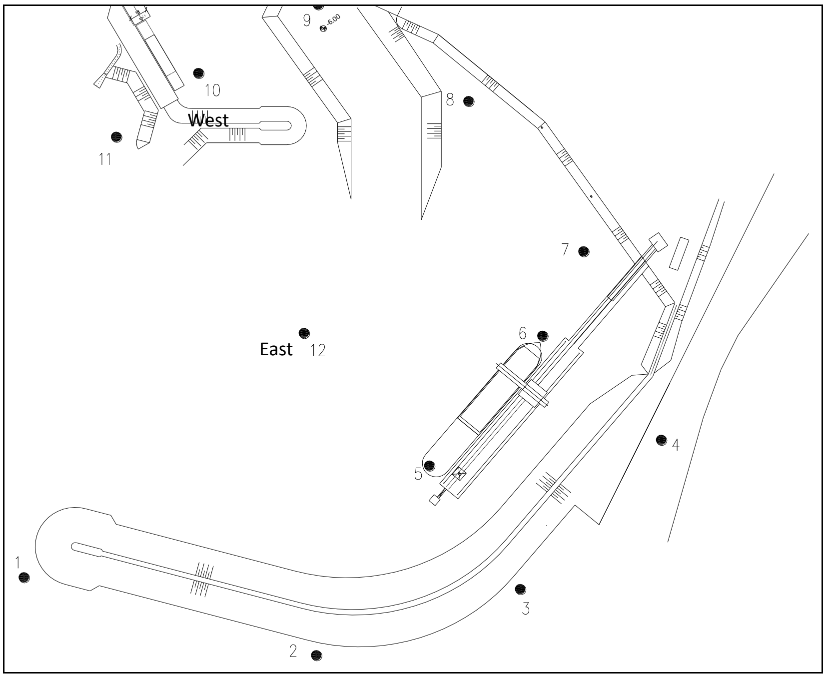


Figure. 1. The project layout

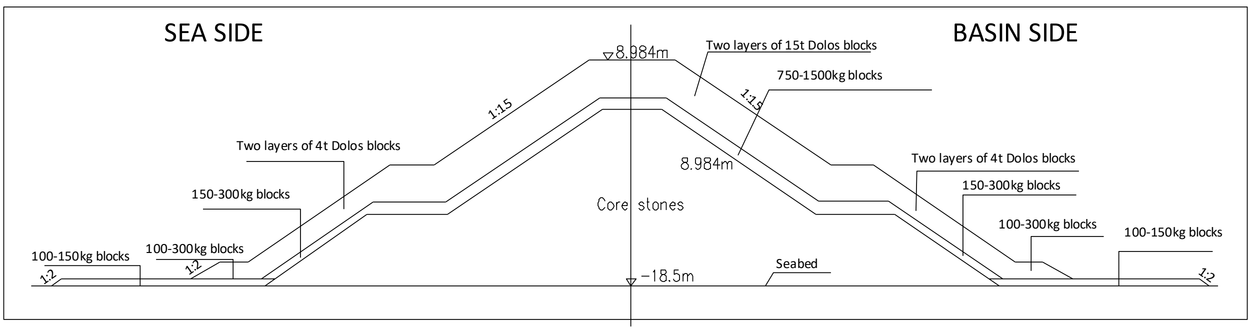


Figure. 2. Typical Section of Breakwater

II. METHOD

The experiment was carried out in a wave flume. The test model was designed according to the gravity similarity criterion, and the structural section size met the geometric similarity. According to the test site, the existing block mass and the test requirements, the geometric scale of the model was 39.3, the time scale was 6.27, and the force scale was 60698.5.

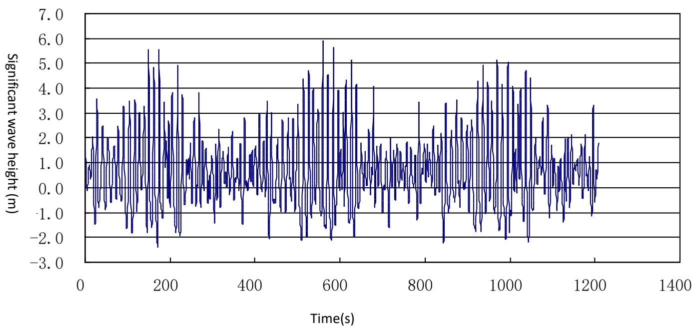
Irregular waves are used in the test, and the wave spectrum is JONSWAP spectrum. For the action of long-period waves, an absorbable wave maker is used in the water tank.

The whole wave elimination principle is to use a wave height sensor to collect the wave signal in front of the wave making plate in real time, and input it to the computer to compare with the target wave, so as to extract (separate) the reflected wave signal, and add the signal to the control signal in an inverse form, make the movement of wave making plate add a displacement movement that can eleminate the secondary reflection wave, and realize the wave making function that can absorb the secondary reflection wave. See Table 1 for the test wave elements, and see Figure 3 for the wave surface duration hydrograph and wave spectrum under the action of the designed high water level wave.

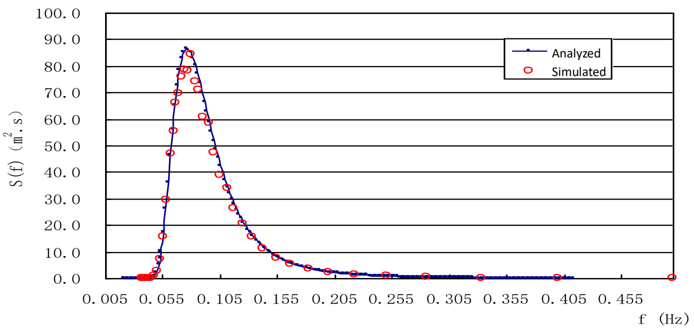
The 15 t and 4 t torsion I-blocks in the section model are prepared with special materials, and the weight deviation and geometric dimension error meet the requirements of the test specification. The judgment of the stability of the twisted I-block armor is to observe its displacement. Under the action of waves, the accumulated displacement of the Dolos exceeds its maximum geometric scale or it slips or jumps out, which is judged as instability.

TABLE 1.
WAVE TEST CONDITIONS

Breakwater section	**Water level**	**Test wave elements**		
		$H_{1\%}$ (m)	$H_{13\%}$ (m)	Ts (s)
East breakwater Typical section	Extreme high water level 3.46m	8.28	5.87	18.0
	Design high water level 1.92m	7.69	5.45	
	Design low water level 0.20m	7.16	5.08	



(a) Design high water level wave surface hydrograph



(b) Wave spectrum corresponding to design high water level

Figure. 3. Wave surface process and corresponding spectrum of design high water level

III. RESULTS AND DISCUSSION

A. Mode test results for the designed breakwater

The model verifies the stability of the design section of the breakwater. Action by wave of 50 years return period, and several water levels as the design low water level, the design high water level, and the extreme high water level ,there is displacement of 15 t and 4.0 t Dolos blocks at the connected position of different size block, the 15 t and 4.0 t Dolos blocks are rolling down under the wave trough action, the displacement rates are less than the allowable values, it is determined that the 15 t and 4.0 t Dolos blocks are critical stable, and other parts of the section can remain stable. See Table 2[8] for test results.

TABLE 2.

TEST RESULTS OF DESIGN SECTION

<table>
<tr><th rowspan="3">Water level</th><th colspan="7">Stability of each part of breakwater</th></tr>
<tr><th colspan="3">Sea-side</th><th>Crest</th><th colspan="3">Rear-side</th></tr>
<tr><th>100~150 kg bottom protection rubble</th><th>100~300 kg riprap prism</th><th>4.0 t dolos armor</th><th>15.0 t dolos armor</th><th>4.0 t Dolos armor</th><th>100~300 kg riprap prism</th><th>100~150 kg bottom protection rubble</th></tr>
<tr><td>Design low water level</td><td colspan="2" rowspan="3">Block stones roll down without losing their functional stability</td><td>Shake</td><td>Stable</td><td>Stable</td><td>Stable</td><td>Stable</td></tr>
<tr><td>Design high water level</td><td>One piece rolls off, the instability rate is less than the allowable value, and it is critical stable.</td><td>No displacement , shaking</td><td>Stable</td><td>Stable</td><td>Stable</td></tr>
<tr><td>Extreme high water level</td><td>Two pieces roll off, the instability rate is less than the allowable value, and the critical stability is</td><td>Two pieces roll off, the instability rate is less than the allowable value, and the critical stability is</td><td>Stable</td><td>Stable</td><td>Stable</td></tr>
</table>

B. Project Site construction of design breakwater

During the construction of the design breakwater, because the site construction is subject to 10~20 s long period waves all the year round, the change of wave period is abrupt. The sea area is calm the day before, and the next day there may be strong waves. The wave period can change from 10 s to 20 s within 24 hours, and then the wave height can change from 1 m to 3.5

m. At the same time, the long period environment makes the water dumping and filling machine usually used for the construction of the breakwater unsuitable for this project, large construction ships and machines are unable to carry out the dumping and filling construction on the water, and can only be pushed on the road. Due to the lack of accurate sea wave forecast due to local conditions, the head of the embankment is washed out more than 10 times under the construction state, and the riprap core stone formed in the daytime may be washed out the next day, and the Dolos block may have a broken rod (see Figure 3), so the construction of the designed breakwater cannot be successfully completed, The actual section formed on site is shown in Figure 4 below, that is, the elevation of the embankment top is about +5.70 m, two layers of 4t Dolos blocks are placed below the sea side elevation of - 4.0 m, and two layers of 15t Dolos blocks are placed at the corner of the embankment top above the sea side elevation of - 4.0 m. Due to the sea conditions in the project area, no cushion block stone is laid under the armour block, and the armour block is directly placed on the 10~1000 kg embankment core stone. The port side of the section and the sea-side block armour are basically symmetrically placed.

Figure. 3. Rod Fracture of armour block on site

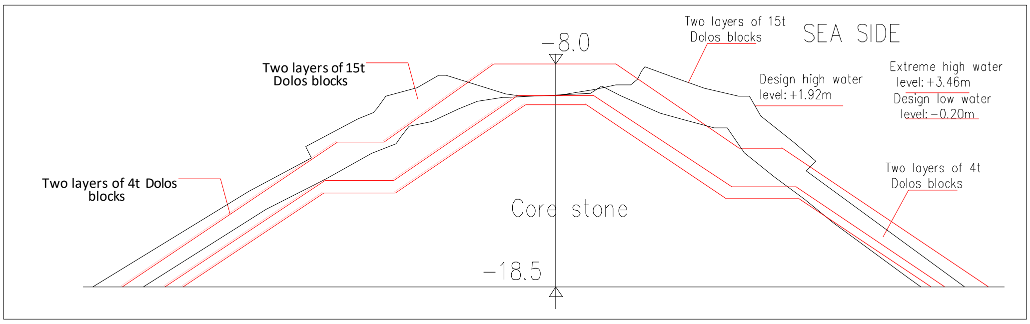


Figure. 4. Breakwater section at project site

(The red line is the original design section, and the black line is the current section)

C. Model test results for breakwater section at project site

On the model, the stability of breakwater section at project site(shown in Figure 4) is directly verified by using wave elements (3.5m wave height) during the construction period. The test shows that under the wave action of the design high water level, due to the lack of hook up of the embankment top block, the instability will soon occur under the wave action, as shown in Figure 5 (b).

According to the above test results, the damaged section is improved, that is, a layer of 4t Dolos blocks is added to the foundation of two layers of 4t Dolos blocks below the sea side elevation of -4.0m (that is, three layers of 4t Dolos blocks are used to protect the surface), and 200~400kg riprap prism (15.4m long and 5.0m thick) is added at the foot of the slope. The other structures are the same as the original design; At the same time, 15 t Dolos blocks are placed on the top of the breakwater.

For the improved section, under the wave action with a return period of 50 years, the 15t and 4t Dolos block breakwater on the sea-side did not slip, and the riprap prism slope became slower, without losing its function. After the breakwater top is protected by 15 t Dolos blocks according to the design, the section is generally stable. See Table 3 [9] for test results.

The test results show that after the failure, riprap should be added to the sea-side as soon as possible to form bottom protection and riprap prism to support the surface protection block. When the top of the breakwater is not protected, the upper part is seriously damaged under the action of strong waves. It is necessary to speed up the placement of 15 t Dolos blocks on the top of the breakwater according to the project progress to prevent the 15 t Dolos blocks on both sides from being washed away by waves after the core stones on the top of the breakwater are brushed.

(a) Place the current section before test (b) Destroy the current section after test

Figure. 5. Mold test Results for breakwater section at project site

TABLE 3.
TEST RESULTS OF EACH PART OF BREAKWATER AT PROJECT SITE

Water level	Stability of each part of breakwater section					
	Seaside			crest	Rear side	
	200~400 kg riprap prism	4 t Dolos block	15 t Dolos block	15 t Dolos blocks	15 t Dolos blocks	4 t Dolos blocks
Design low water level	A little roll off without loss of prismatic function, stable	stable	One piece rolls off, the displacement rate meets the requirements and is stable	Stable	Stable	Stable
Design high water level	Stable	Stable	Stable	Stable	Stable	Stable
Extreme high water level	Stable	Stable	Stable	Stable	Stable	Stable

D. The second intallation and damage of the breakwater

Although it is proposed in the above repair plan that when the top of the breakwater is not protected, the upper part is seriously damaged under the action by strong waves, and the placement of 15 t Dolos blocks on the top of the breakwater needs to be accelerated according to the progress of the project. However, due to the large waves during the construction, the installation can only be carried out on the road. In order to ensure the construction completed, if the top of the breakwater cannot be protected in time, the breakwater will be damaged again (see Figure 6). The final failure section is shown in Figure 7. The whole breakwater forms a large gentle slope.

Figure. 6. Site damage of section after the second repair

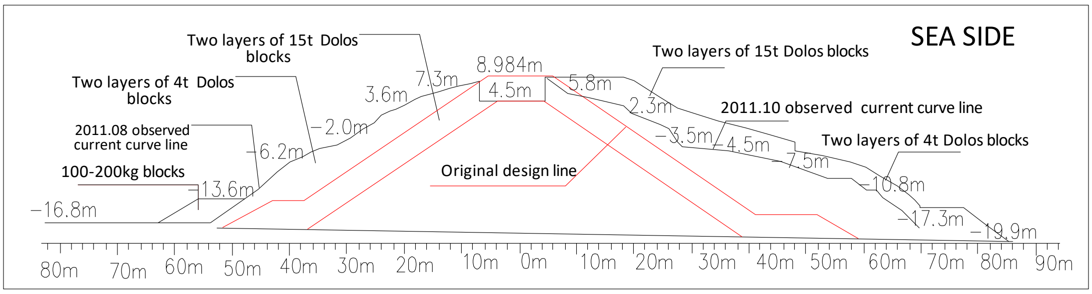


Figure. 7. Shape of the second damaged breakwater section at project site

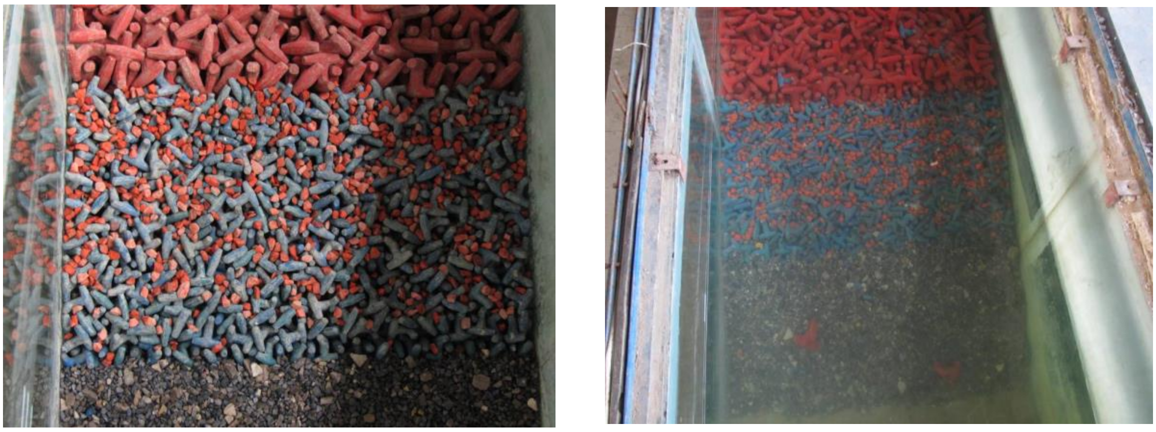
E. Model test results for the second damaged breakwater section

The second destruction prosess of the breakwater was verified again in the wave flume. It is known from the test that due to the gentle slope and poor connectivity of the armour block, the breakwater was unstable under the impact of strong waves, as shown in Figure 8.

For the section form of breakwater failure on site, the section is modified and improved according to the instability situation and previous research results[10]. The mixed prism combination of block stone and Dolos block is adopted. The results show that the section instability rate and block shaking are improved. The main reason is that the block stone has a good squeezing and embedding effect on the block after all or most of the blocks are embedded in the prism block stone, limiting its displacement, thus ensuring the stability of the whole slope. However, during the test, it was found that under the action of strong waves, the block stones rolled up and down on the surface of the armour block along with the waves. Therefore, the specifications should be strictly controlled during the construction to prevent damage to the protruding block bars due to the overweight of the block stones, and the block stones could not fall into the gaps between the blocks, thus weakening the function of the mixed prism. In addition, the mixed prism of block stone and Dolos block is: 200~600 kg block stone and 4 t Dolos block are combined, and the amount of block stone thrown within 22 m of 4 t Dolos block armour is distributed differently, that is, 9 m^3/100 m^2 block stone is thrown randomly from the junction of 15 t and 4 t Dolos block to 7 m, 6.3 m^3/100 m^2 block stone is thrown randomly at 55 m~62 m (see the abscissa of Figure 7, the same below), 2.7 m^3/100 m^2 block stone is thrown randomly at 62 m~70 m, and the test results are shown in Figure 9.

(a) Before test (b) After test

Figure. 8. Model test results for the second damaged breakwater section , instability



(a) Before test (b) After test

Figure. 9. Test Results of Final Perfection Section

F. Breakwatre construction progress at project site

The breakwater improvement scheme proposed in the test is adopted, combined with the experience of breakwater destroy during the previous construction, so the Dolos protection will be timely followed up during this construction, and the distance between the construction of breakwater core stone, cushion block stone and block construction will be shortened, so that the protection can be done in time when the strong wave comes; Do a good job of wave prediction, establish a set of intuitionistic research results of wave change laws in the engineering sea area, directly guide the site construction, and timely achieve wave prediction and prevention; Accelerate the construction progress and reduce the times of protection during construction; Timely guide the construction through wave prediction during the construction, and finally the construction of the breakwater is successfully completed.

IV. CONCLUSION

(1) According to the comparison between the model test and the stability of the site construction section, attention should be paid to the collection and sorting of hydrological data in the early stage in the port engineering design, which will provide guidance for design and construction.

(2) The shaking of the block is unfavorable to the stability of the strength controlled Dolos block, which is easy to be broken. Therefore, it is recommended that the status of the armor block be regularly inspected and maintained or modified into a sturdy manual armor block with support rods.

(3) The main reasons for the instability of the repair scheme are analyzed as follows: the armor on the section adopts a variety of Dolos blocks, and the connection positions between different Dolos blocks are weak in wave resistance, which are easy to separate from each other to form a single body, thus being impacted by waves to destabilize; The overall weight of the block is light; The cushion stone under the armor is missing, and the internal embankment core stone is easy to be brushed and lose its support.

(4) The section is designed with the mixture of stone and block, which can decrease the section instability rate and block shaking. However, during the test, it is found that the stone rolls up and down on the surface of the armour block with the wave under the action of strong waves. Therefore, the specification needs to be strictly controlled during the construction to prevent damage to the convex block bars due to the weight of the stone, and the stone can not fall into the gaps between the blocks, this reduces the mixing function.

(5) Long period swell has its particularity, and the design should be combined with construction experience to improve the section optimization control and conform to theory and practice. In combination with the engineering construction practice, under the condition of long period swell, the construction should

adopt a process different from the traditional one. Especially for the breakwater design under the open sea environment of the Indian Ocean, this project is typical and representative, and it is believed that it can provide a good reference for other similar projects.

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