THE DESIGN AND CONSTRUCTION OF BREAKWATER ON BAMBOO PILE FOUNDATION AT PATIMBAN PORT DEVELOPMENT PROJECT

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INTRODUCTION

The Patimban Port Development project is stipulated in Presidential Regulation No.47 the Year 2016 as one of National Strategic Projects. The New port which is located in Subang, West Java Province, 100 km from Jakarta Metropolitan (Fig1) is expected to boost up the economic growth in West Java and to help improving the logistic efficiency at the Jakarta Metropolitan area where severe congestions often occurred at its sole international gateway: the Tanjung Priok Port.

The project is planned to handle 7.5 million TEUs by 2036 (Fig 1, left cropped image) and will be developed in 3 phases: Phase I will establish the entire breakwater and vertical seawall bounding the port and construct three terminals and associated facilities as well as channel and basin dredging (Fig 2); Phase II and Phase III will expand the number of terminals and deepen the draft of the channel and basin (Fig 1, right cropped image). This paper describes the extensive studies during the design and the construction works of the breakwater which was completed in Phase 1-1 of project (Fig 2 and Fig. 3) with focus on the Bamboo Pile Raft Foundation.

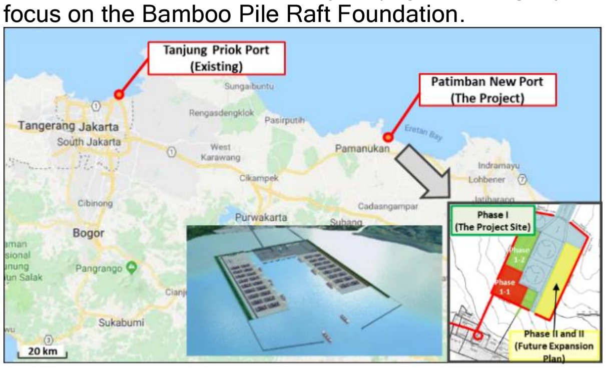

Fig.1 Location of Project and scope of Phase I, II and III

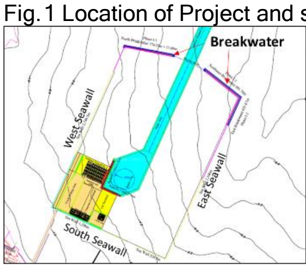

Fig.2 Phase I-1 scope Fig.3 Completed Breakwater

THE DESIGN WORKS

Among various soft soil treatments adopted in the project, bamboo pile raft (bamboo cluster of 7 piles + mattress) was adopted to strengthen the foundation for the Patimban breakwater (Fig.4 and Fig 5). The use bamboo pile foundation as a soil improvement method for coastal revetment and breakwater has a long application history in Indonesia. However, there is no industrial guideline available elsewhere making the design of bamboo pile foundation is rather difficult and less practical. As a result, the height of coastal embankment seating on bamboo pile foundation is often limited to 4-5m as the local practice based on past successful experiences. The natural depth at Patimban breakwater (-8mCD, Fig 4) creates a challenging task for the design team as the rubble height of the Patimban breakwater need to be raised more than 10m. This doubles the height of similar structures has been built anywhere in Indonesia. In the following part, detail of design process will be presented and discussed.

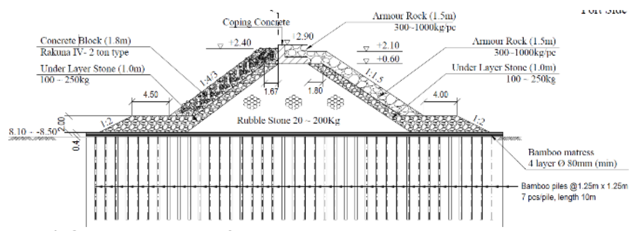

Fig 4 Cross-section of breakwater

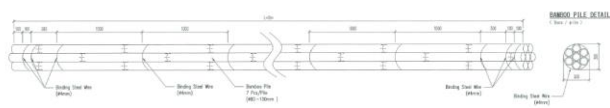

Fig 5 Bamboo pile cluster

Soil conditions.

Soil investigation (20 boreholes) conducted at the breakwater location reveal that the site is predominantly underlain by very soft to soft marine clay (N=0-5) extended up to 10-12m below ground level (Fig 6, layer 1 and layer 2). Underneath this layer is stiff to very stiff clay (N=5-15) with thickness of 5 to 10m (layer 3, Fig 6). Though not shown in Fig 6, hard to very hard clay layer (N>30) are consistently found below these layers.

Laboratory test results also reveal that the thick soft clay near the seabed is very weak (low shear strength, Fig 6) with high compressibility and high level of plasticity. This indicates a highly unstable characteristic.

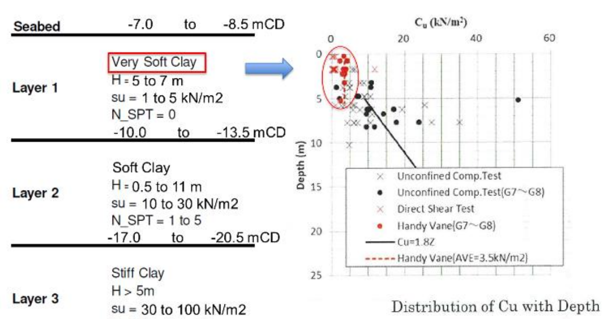

Fig 6 – Typical soil layer at breakwater. Handy Vane & Unconfined Comp. Test (G7~G8) are tests at breakwater.

Hydraulic performance vs settlement consideration

The hydraulic performance of a breakwater is its capacity of reducing wave-induced discharge overtopping structure. In general, it depends on the elevation of breakwater's crest, its permeability as well as the smoothness of its seaside slope.

Due to the existence of thick soft soil layer, it is preferable to have breakwater's crest as low as possible to reduce excessive burden stress on the foundation whilst minimum hydraulic performance criteria still need to be achieved. A random double layer armor blocks is also desirable for better adaptation with settlement since double layer block will be re-interlocked easier than that of a single block. The downside is that they are much heavier than the single layer block type and thus might increase the risk of deep circular failure. A recent invented RAKUNA-IV block was adopted as the armor block for the breakwater. The advantage of this block is that the density per meter long of armor layer is about 20% lighter than the conventional Tetrapod block thanks to its higher porosity (56.5%).

The breakwater section was then designed to limit the overtopping discharge to 200 l/s/m. Deterministic design formula in EurOtop, 2007 was used to assess the overtopping volume at preliminary design state and it was confirmed by hydraulic tests at the facility of National Laboratory of Agency for the Assessment and Application of Technology (BPPT). The final design elevation of breakwater at completion was then raised by about 80cm higher than the required height from physical modelling test to compensate for consolidation settlement which might occur during its 50 years design life.

Procurement consideration

The maximum bamboo pile length that can be procured in large quantity in Indonesia is 12m. Lessons learned from actual experience on both successful and failure bamboo pile foundation projects in Indonesia suggest that the bamboo piles should not be floated on very soft clay layer or in other words it need to be embedded at least to the medium stratum (N>5). Fortunately, the very soft and soft clay layer at Patimban (N<4) is limited to less than 12m and thus there should have no issue with material availability if bamboo pile foundation can be adopted.

Bamboo foundation assessment

Rahardjo. P.P (2005) listed three different methods that often used to assess the bamboo foundation in Indonesia, namely, the method of additional resisting moment by piles (method 1), method of soil cluster with increased shear strength (method 2) and FEM analysis (method 3).

In the method 1, resisting moment by piles shall be added into a limit equilibrium formula (i.e., Bishop Method) to assess the overall stability of foundation. The added resistance moment by piles can be calculated by either Poulos & Davis (1980) method (lateral resistance of piles x moment arm) or Broms & Wong (1985)'s approach (axial resistance of piles x moment arm). The application of this method is however, quite difficult and with high uncertainty if it is involved a large number of piles (as it is the case in Patimban breakwater). Therefore, it was not adopted in our analysis.

More popular in Indonesia, method 2 assumes that treated soil by bamboo pile can be modelled as soil cluster with increasing shear strength (Rahardjo, 2005) and then any circular slip methods can be used. For simplicity, the increment of shear strength is quantified as H_{ult}/s where H_{ult} is ultimate lateral resistance of bamboo cluster, s is unit treated area, $s=a*b$ where a and b are the bamboo intervals in horizontal and lateral direction, respectively.

In this method (and also method 1), ultimate lateral resistance of bamboo cluster must be quantified, however it is not well documented. The study team has carried out an intensive study on lateral capacity of bamboo cluster and it was found that the analytical solution based on the theory of pile on elastic foundation using P-Y curve for soft clay (Matlock, 1970) can reasonably reproduce the load-settlement curve experimented by actual field load tests by Brotodihardjo et.al (1991) in West Java (Rahardjo, 2005) (Fig 7, left). Similar approach is used to determine the ultimate lateral resistance of bamboo piles at Patimban site (Fig 7, right). Physical and mechanical properties of bamboo as required input of modelling were not tested at the time of design work, but was referred to literature (i.e., Abdullah et.al, 2014). The output from PY pile model was then given as the input for our circular slip surface examination by COSTANA software (Modified Fellenius's method) (Fig 8).

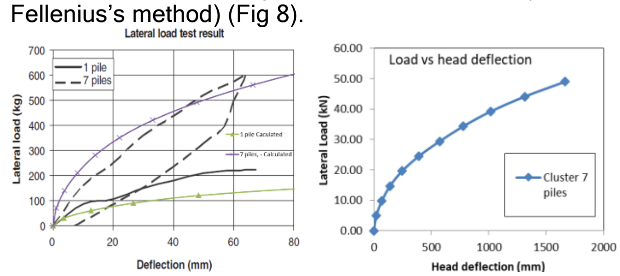

Fig 7 – Load – deflection curves of bamboo pile and cluster at field test (left) and calculated for Patimban site (right)

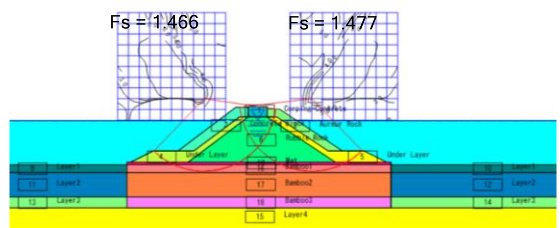

Fig 8 – Circular Slip Surface at East breakwater Bamboo interval @1.25m x 1.25m for Ordinary Condition

2D FEM analysis for Patimban breakwater was carried out by using well-known commercial software (Bentley system's Plaxis 2D model). Bamboo cluster and mattress were modelled as embedded pile row and plate element, respectively. At first our model set up was validated using settlement monitoring data recorded at North Kalibaru's breakwater where similar bamboo piles and mattress arrangement was successfully built. Then similar bamboo piles and mattress input was used to assess the performance of Patimban breakwater.

Plaxis 2D model further confirms the result from circular slip surface method that the breakwater can be buildable (Fig 9). However, due to the existence of very soft-high viscosity clay layer, it is expected that at the end of construction, the center part of breakwater shall be settled more than 2m (point A, Fig 10) whiles in contrast a similar magnitude of up heave can be seen at the toe (point S, Fig 10). Such opposite movement can be explained by the fact that the very soft marine clay will experience large horizontal movement from the center of the breakwater toward the edge of its footprint. The Plaxis model also predicts that settlement in the future will be much less than during construction with only 15cm settlement is expected to occur in the next 2 years (result is not shown here). A closed monitoring program during and after construction would be necessary to validate those findings from modellings.

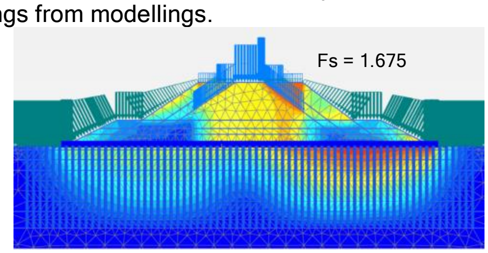

Fig 9 – Factor of safety derived from Plaxis 2D

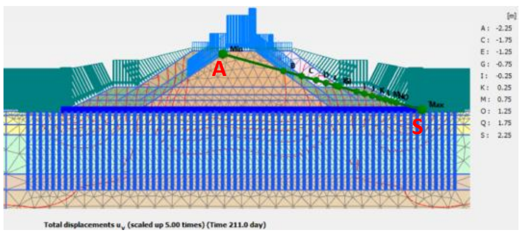

Fig 10 – Vertical deformation contour of breakwater at completion

CONSTRUCTION WORKS

The construction of breakwater started in early 2020 and successfully completed in November 2021.

Preparation works

As part of quality control, bamboo from several sources were collected and shear and bending tests were performed to confirm their physical strength as prescribed in the technical specification. Physical properties and grading of rock was tested twice, once at quarry prior to delivery, and randomly at delivery on site. Bamboo piles and mattress was fabricated and stored at the nearby coastal beach and towed to installation location by tug boat (Fig 11). RAKUNA-IV block and coping concrete was also fabricated and stored in the back up area at nearby beach and transferred to the installation area by large barge (Fig 12)

Fig.11 Piles & Mattress fabrication and transportation

Fig.12 RAKUNA-IV Fabrication and Transportation

Installation works

Prior to the construction of bamboo pile driving, trial driving test was carried out at several locations closed to the explored boreholes to establish a standard penetration per blow for driving control (i.e, 30cm/blow). Bamboo piles shall be driven after being carefully positioned by Real Time Kinematic (RTK) GPS mounted on driving barge and location will be fixed by a four-anchor point mooring system (Fig 13). Similarity, bamboo mattress will be positioned precisely into the placement location (also by RTK-GPS) and six steel piles will be driven as a holder of the mattress and to keep mattress balance during the dumping process by gradually placing rock onto it (Fig 14). Core rock and under layer placement will be carried out at least 2 months after mattress installation to allow some sort of soil recovering (Fig 15). Seaside RAKUNA-IV block will then be installed (Fig 16). Trimming or additional rock placement to compensate settlement will be carried out before coping concrete and top RAKUNA-IV blocks are installed (Fig 17, left and middle picture). Finishing on the rear side block will be carried out at last (Fig 17, right picture).

Monitoring works

Equipment for monitoring the ground movement of breakwater (piezometer, differential settlement gauge, and inclinometer) was installed and continuous monitoring is scheduled for 2 years after completion. Back analysis of monitoring data during and post construction are expected to provide valuable information which can greatly benefit the design of similar structure in the future.

Fig.13 Bamboo piles driving

Fig.14 Mattress installation

Fig.15 Rock placement

Fig.16 Seaside RAKUNA-IV

Fig.18 Installation of Coping, top RAKUNA-IV and rear rock

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