Hydraulic Turbulence Caused by Ship Movement and Slope Stability at the Juncture of Dredging and Reclamation

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Abstract. For accommodating deep drafted vessels dredging at the vessel maneuvering area to the required depth as well as deepening the berth pocket of the upcoming jetty also became necessary. Improvement of strength of the reclaimed ground became essential to cater to the future loads of container stacks, gantry cranes and infrastructure for the upcoming terminal. Simultaneously For design of the dredged slopes the factor of safety became critical at the juncture of reclamation and dredging. In this paper the criticality of submarine slope stability subjected to hydraulic turbulence generated during ship's berthing particularly at the interface of dredging and reclamation are discussed.

Keywords: Reclamation · dredging · interface · slope · stability

1 Introduction

The marine structures within the ports for accommodating ships of multiple variety and sizes vary according to bathymetry, shoreline geometry, geotechnical parameters of the location etc. During development of a deep drafted Terminal at western coast of Arabian Sea a large chunk of area measuring approx. 91 ha of land was reclaimed from sea, at the end of which 1 km long Berth was constructed for accommodating large capacity Container Vessels. In this paper the criticality of submarine slope stability subjected to hydraulic turbulence generated during ship's berthing particularly at the interface of dredging and reclamation is discussed.

2 Reclamation

While augmenting the capacity in addition to the existing terminals the Port has built an additional container terminal through a concessionaire, a sister concern of a renowned

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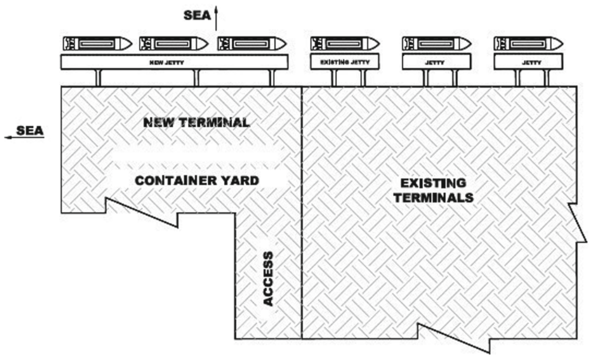

Fig. 1. Plan of new terminal.

international port developer under 30 years' agreed terms for design, finance, build and operate the terminal.

Reclamation of large area from the sea was necessitated for development of the container. Terminal at the coast of Arabian Sea to augment the capacity of a container handling port at west coast of India. Construction in stages for maintaining stability of the edges, followed by ground improvement through installation of band drains and surcharging for calculated pause period became concurrently necessary for consolidation. Improvement of strength of the reclaimed ground became essential to cater to the future loads of container stacks, gantry cranes and infrastructure for the upcoming terminal. Simultaneously for accommodating deep drafted vessels dredging at the vessel maneuvering area to the required depth as well as deepening the berth pocket of the upcoming jetty also became necessary. While designing the dredged slopes the factor of safety became critical at the interface of dredging and reclamation zone.

Due to turbulence expected during berthing of deep drafted 18000 TEU capacity container ships, to be generated by movement of bow thruster and propeller, minimum scouring and stability of the dredged slope was required to be ensured when fluid-soil interaction phenomenon needed to be examined.

The Phase 1 development includes construction of a quay of approximate length of 1 km with suitable approach trestles, dredging of the berth pocket & the maneuvering area including reclamation of around 100 hectares of area from the sea, for development of the container terminal with stacking yard, rail and road accesses with RTGC's and other utilities. The schematic layout of the new terminal is shown in the Fig. 1.

The experiences gathered while executing the Dredging and Reclamation work for the 1st phase of development of the upcoming new terminal for container, in particular the unique critical technical challenges faced at the juncture of reclamation and dredging were unique. The critical importance of Stability of dredged slope including analysis of scour at the interface of reclaimed mass and dredge pocket is worth mentioning.

3 The Phenomenon of Stability

Reclamation of large area from the sea is being necessitated for development of the new terminal. However, considering that construction of the future terminal on the existing

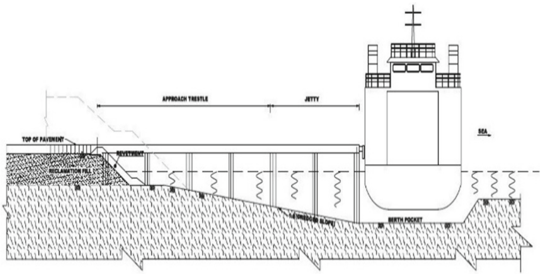

Fig. 2. Cross section of new terminal at the interface.

soft marine clay would certainly invite huge long-term residual settlement as well as differential settlement, measures for adequate ground improvement by installation of prefabricated vertical drains (PVD) up to design level along with putting surcharge load for a designed pause period has been adopted to achieve desired consolidation of the reclaimed mass. For maintaining stability of the edges of the reclaimed area, the reclamation was done by adopting end-on method basis in land mode. For satisfying the desired factor of safety under static and seismic condition adequate ground improvement technique and suitable construction stages were adopted by using PVD.

In addition to above, for accommodating deep drafted vessels, dredging at the vessel maneuvering area up to the required depth as well as deepening the berth pocket of the upcoming jetty also became necessary. The dredge spoil had to be disposed to a designated area at deep sea far away from the existing port. Selection of the disposal area was based on the criterion of large dispersion rate based on hydraulic studies. The soft marine clay being unsuitable for the future terminal, reclamation fill with locally available soil resulted to dispersion of soft marine clay by formation of mud wave, which also had to be removed by additional local dredging near the shore. Quay with approach trestle from the reclaimed area above pile foundation is separately being constructed at place shown in Fig. 2.

During slope stability analysis PIANC guidelines and IIT Kanpur's GSDMA guidelines has been adopted for static and seismic conditions. Considering the effect of critical velocity required for scouring of soil particles from the dredged slope, the stability analysis of eroded dredged slope under the relevant hydraulic conditions has been carried out.

4 The Criticality at the Interface

For availing deeper draft, the jetty had to be planned in a place away from the shore and the area for proposed container terminal covering a distance of more than about a kilometer had to be reclaimed with locally available filling materials. At the location of the berth pocket dredging was required to be carried out at the end of the reclaimed land mass where eventually an interface of 'Dredging' and 'Reclamation' developed as shown in Fig. 2.

At this interface the stability of dredged slope at the end of the reclaimed mass became critical and demanded careful analysis and design to ensure the steadiness of the dredged slope and examining scope for scour on slope in the prevailing dynamic hydraulic conditions particularly during maneuvering of ships.

5 Design Philosophy for Analysis

A slope stability calculation has been carried out for the dredged slope using the analytical method of slices, using SLOPE/W of GEO-SLOPE. The formulation of Morgenstern and Price [1] is used, with a half sine function as interslice force function. The factor of safety has been computed for temporary condition and permanent condition.

Morgenstern and Price opined regarding methods for analysis of stability [1], the equilibrium limits may not necessarily be restricted at the surface of the slip failure shape. The failure surface may diverge suggestively from a circular plane and they thought for arbitrary outline and related research on surface analysis. Details for making the phenomenon statically determinate are elaborated [1]. For generalization of the investigation for any slope the probable gliding body was divided into finite slices by vertical lines with markings X0, X1, X2, … Xn. Such division assumes linear slip-surface and pore pressure zones in each slice considering the moment equilibrium equation depends linearly on x.

The criterion for yield within the soil mass which can undergo sliding would be violated if the shear force calculated at an interface of a slice necessary for equilibrium is greater than the shear resistance which might develop along the interface surface. Calculation of the total force acting as normal on the interface was done considering pore pressures, and strength values along the interface. Determination of the factor of safety of any shape sliding body with varying shear strength and pore pressures was done based only upon limiting equilibrium principles [4]. The equilibrium condition for the boundary conditions were satisfied for the Governing Equation. Computer programming was done for the analysis and other methods of analysis was compared.

Since the soil is cohesive in nature the factor of safety has been calculated under seismic condition as per pseudo- static analysis & the slope analysis has been performed in total stress method (based on undrained shear strength) for both temporary and permanent condition.

Under the prevailing conditions it was envisaged that potential scour can occur at the berth pocket and at the dredged slopes, due to hydraulic turbulence generated under the action of waves, ship wash, currents for both short term and long- term conditions, and also due to rotation of the propeller as well as lateral movement of bow- thrusters during maneuvering of the design vessels.

The importance of the scour of dredged slope due to turbulence expected to be generated by movement of bow thrusters and propellers during berthing of deep drafted 18000 TEU capacity container ships deserve due consideration.

For the purpose of such analyses the largest container ship i.e., Maersk Mc-Kinney Møller (Maersk Triple E-class), having maximum speed of 23 knots, opposed to 25.5 knots of her precursor, the Emma Maersk has been considered.

For the purpose of analysis, the following vessel configuration has been adopted from PIANC guidelines [2].

a. Location of Bow Thruster

(1) The bow thruster is located at a distance of 12.5% of the width from the hull of the shin the middle of the ship
(2) The distance between the tip of the propeller and the keel of the ship is 0.5 m corresponding to the diameter of the bow thruster

b. Location of Main propeller: For the maximum ship the main propellers are 24m apart. The other vessels have a main propeller in the middle of the width of the ship.

On the other hand, the weak geotechnical parameter of the available soil was considered for slope stability analysis for eroded slope. The soft clay has an average cohesion of 9 kPa with a standard deviation of 6 kPa. When assuming a diameter of 2 μm for the soil particles, the critical velocity can range between 0.7 and 1.5 m/s.

In order to determine the effect of the scouring on the slope it can be considered that the toe of the slope after some time might recede while the top of the slope will be affected.

6 Results and Discussion

The berth pocket slope has been dredged in 1 (V): 8 (H) and slope stability has been analyzed for this underwater dredged slope. The factor of safety of initial dredged slope has been calculated using SLOPE/W software. During this operation the hydraulic condition will be turbulent as a result of which the dredged slope will be vulnerable to erosions.

The average critical velocity of 1.15 m/s has been considered in the analysis and it is found that the dredged slope will be eroded at a low rate varying from 0 to 0.1 m/year. Corresponding to the repeated erosion over the period of the anticipated lifetime the eroded slope comes to 1(V):6.5(H). According to hydraulic study, it is also noticed that no further erosion will take place once 1(V):6.5(H) slope is formed. The eroded slope which was modelled under SLOPE/W software brings out a factor of safety of 1.4 & 6.3 under Seismic and Static Condition respectively. Coefficient of horizontal acceleration has been adopted as per IIT Kanpur's GSDMA guidelines [3]. As a result of the erosion, the slope is likely to become steeper but it shall be limited to 1V: 6.5 H only. It is further reconfirmed that although the factor of safety of eroded slope is lesser than that of the initial geometrically demanded slope, such factor of safety of eroded slope technically satisfies the requirement of the intended purpose of short and long-term stability of the dredged slope as well as facilitating safe operation of vessels at the berth.

7 Conclusions

From the forgoing results & discussions, the following inferences are drawn.

a. The interface between reclamation and dredged slope needs to be carefully planned against stability and scour both for temporary and permanent conditions. The potentiality of scour needs to be estimated after thorough examination.

b. In the event of scour taking place due to hydraulic disturbances, stability of the eroded slope is required to be checked under static and seismic condition.
c. If the eroded slope is not safe then suitable protection against scour needs to be done or else the dredged slope needs to be flattened to the required extent.

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