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Grabe, Jürgen; Kinzler, Steffen; Miller, Carol J.

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J. Grabe*, S. Kinzler* and C. Miller **
* Technische Universität Hamburg-Harburg, Hamburg, Germany
** Hamburg Port Authority, Hamburg, Germany

The present paper reflects the new development of a scour monitoring system. The basic idea is to install two buoys, one has a density between the base failure load and fuidized soil "sink", the other between fluidized soil and water "float". The design of shape, guideway and data-logging will be illustrated.

I. INTRODUCTION

Container handling in the large sea and domestic ports is increasing very fast during the last years. In the wake of this evolution the ship size is also accretive. The growing engine power entail an accession of stress of wharfage and seabed as a result of docking and undocking maneuvers. This problem is especially relevant for self-docking ferries, RoRo ships and container cargo ships, which dispose normally high capacity bow stream or stern stream rudders.

During application of the propellers appear special erosion appearances at the seabed which are called *scours*. Scouring is the result of local raising stream velocity which disperse soil substratum. The result is a residual deepening of the seabed.

Extent, depth and durability of scouring are not known a priori. Based on the mechanism of bed erosion caused by exceedance of a critical shear stress by taking the *Bernoulli* equation [1] for the stern drive respectively according to *Römisch* [8] for the bow drive the scour mechanism can be calculated approximately. This computation should be judged critically because the empiric nature of equations is not considering specialized constraints.

To prevent endangering of water structures different strategies exist:

- Securing of seabed using scour protection systems: Scour protection systems are composed of loose or composite embankments. Accepted constructions prevent the erosion only by using large stone diameters;
- Integration of jet disposers in quay constructions Application of steam disposing elements as components of the sheet piling or installation of an erosion decreasing bed slab;
- Allowance of scour depth during design During the static design process a scour depth, based on careful estimates, is considered.

All strategies have in common that they require significant capital appropriations and, caused by the estimation on the safe side, seem inefficient.

It is necessary to develop a scour monitoring system to get to cost-effective and safe quay constructions. The monitoring system needs to be able to verify and examine the basis of the statical calculation. The monitoring system enables the observing engineer to log the characteristics of scouring during the whole docking and undocking maneuver. Subsequently the critical case can be certified or modified.

The Technical University Hamburg-Harburg, Institute of Geotechnical and Construction Management has developed such a monitoring system after observing scour procedures and has proved its effectiveness under laboratory conditions. Presently it will be installed together with the Hamburg Port Authority at berth 1, Hamburg Predöhlkai.

II. SCOURS

A. *Formation of scours*

Cause of the formation of scouring are high flow rates at the seabed. Especially drifts induced by engine propellers or bow stream rudders form finite but considering nearby standing harbor constructions like quay walls or dolphins particularly observant exposures.

Estimations for calculation of scour depths are given in the corresponding literature [4], [7].

Appearance of scours can lead to a local instability of a line shaped construction (e.g. a quay wall) or to global loss of stability of a point shaped construction (e.g. a monopile foundation). The loads are transferred on line shaped constructions in longitudinal direction. Scours occurring repeatedly on the same location can highly constrict the serviceability of the structure because deformations accumulate during each load relocation.

As avoidance of endangerment of water constructions by scours protection systems shall be provided. An exact acquaintance of the local conditions together with monitoring of the effective arising mechanisms permits an exact planning and dimensioning of scour protection systems and in the course of the structural analysis an accurate estimation of scour depths.

B. *Experiences at Hamburg Port*

At Hamburg port scours were discovered the first time during the bearing of the sea bed in front of quay walls 15 years ago. These scours were refilled with sand or flint.

A systematic investigation of the scour situation was made from 1988 until 1993 at one specific berth. On-site varying scour depths from about 2 meters up to 4 meters were observed in the monitoring time. Penetration tests result significant lower stabilities of the seabed until a penetration depth of 6 meters.

There upon reduced static soil parameters were estimated in the design process of quay walls.

Advanced and more comprehensive studies and their results were performed during the years 1994 – 1996 and described below.

C. Experiments at Leichtweiß and Franzius Institute

Within the framework of an advice, commissioned by Hamburg Port Authority, in investigation of arrangements against slip stream erosion at ship berth, Leichtweiß-Institute of hydraulic engineering at Technical University Braunschweig as well as Franzius Institute at Technical University of Hanover have analyzed scour formation at harbor bed in the front of quay walls [3]. By means of a three-dimensional physical model the flow caused by stern propeller bow propeller were watched and analyzed.

Via hydraulic models under variation of definite hydrological and ship conditional framework, structural alteration of quay walls as well as characteristic situations of ship movement specific nature alike simulations accomplished. The model ships used to accord in their measurements and regarding the equipage with propulsion oars to modern container ships of 4. generation scale 1:45, geometry and flow conditions were given following similar laws. The Material of the bed was set to d_{85} = 0,04 m under consideration of scaling laws so that it suits the in-situ material at 5. and 6. berth of Burchardkai, Hamburg.

By varying significant parameters like machine speed or under keel height the dependency no the scour process is determined. The analysis of these experiments enables an estimation of the scour depth by known bed velocity.

By investigation of scour stability of unsecured seabed the bow stream induced scours are located directly at the quay construction while the stern stream induced scours occur minimum 5 meters away. It is imperative that static loads lead to larger scour depths than intermitting load.

Based on the enforced analysis a qualitative prediction of appearing scours is possible. A substantiated determination of scour depths depends on geometric boundary conditions, subsoil and flow behavior and thereby in particular case not or only approximately possible.

Taking the model scale under consideration the scour depth straight in front of the quay construction can reach slightly several meters. Scour depths in these categories lead to a decrease of bearing strength of wharfage and therefore to an exposure to loss of stability. A permanent control of scour depths is essential for apprehending specific arrangements of scour covering or scour reconstruction.

III. New Monitoring System

Already acquainted procedures used for measuring scour depth during scour formation like e.g. sonar methods and optical systems are inapplicable due to occurring turbulent particle streams of whirled sediments. Supersonic measurements are not applicable because of the air bubbles running by screw cavitation. A demand for a new measurement and monitoring system for investigation of changes in seabed profiling is immanent.

Beside the ascertainable depth of seabed before the beginning and after ending the docking respectively the undocking maneuver using existing methods it is obvious that the critical load case of wharfage arises during interstages. Alterations in compactions of packing in subsoil located in scour and backfilling areas are due to comprehension of soil static approaches in the calculation of stability will be of great interest. Results of the in situ measurements could be adducted to control the *Froude* similar criteria which forms the basis of the model experiments.

In combination with an online protocol about the characteristics of scouring and a transmittance to the bridge of the docking or undocking ship the scour monitoring system can be used as assistance in maneuver free of failure for self landing ships. Concerning commitment liabilities the documentation of the scour logging may be helpful for allocate the scour origin to a certain ship or maneuver.

A measurement system that meets the requirements was developed at the Technical University Hamburg - Harburg, Institute of Geotechnical and Construction Management and applied for a patent [2].

A. Description of the system

The evolved system used for scour monitoring consists of two positively-driven swim respectively sink parts which measure the depth of the seabed at least at one measuring point close to the considered construction. The simple mechanic design of the procedure enables the operator to achieve reliable results under difficult conditions like turbulent flow an contrary weather.

The gained results depend of the specific weight of the measurement buoys. To make safe predictions concerning the stability of the considered construction a system with two buoys is recommended.

The two buoys differ in their specific weights. If the bulk density of the corpus is chosen superior than the density of the sediment it sinks downwards during the scour progress at the regarded location and rests at the maximum scour depth, unattached of an eventual refill of the scour. This compound is called “sink” hereafter. During the dimensioning of the sink the base failure load is to be considered.

If the specific weight is chosen between the weight of water and the weight of the mixed water soil suspension, originated by the turbulent flow at the seabed, the measuring result is the particular depth of the refilled seabed. If additional soil material sediments the buoy remains above the seabed. The illustrated body is called “float” hereafter because it floats on the seabed.

The described construction is illustrated in Fig. 1. The sink is working as drag indicator which shows the maximum scour depth ever whilst the float indicates the actual depth of the seabed at each measuring time step.

Shape and specific weight of the buoys are significant factors which are decisive for calibration of the mechanisms described above. Regarding the shape a double cone characteristic especially for the float is proved particularly favorable because bodies shaped that way will lift easier from the sediment.

An evaluation unit to record, analyze and/or indicate the actual scour depth in combination with a wireless transmission unit enables a monitoring of the docking and

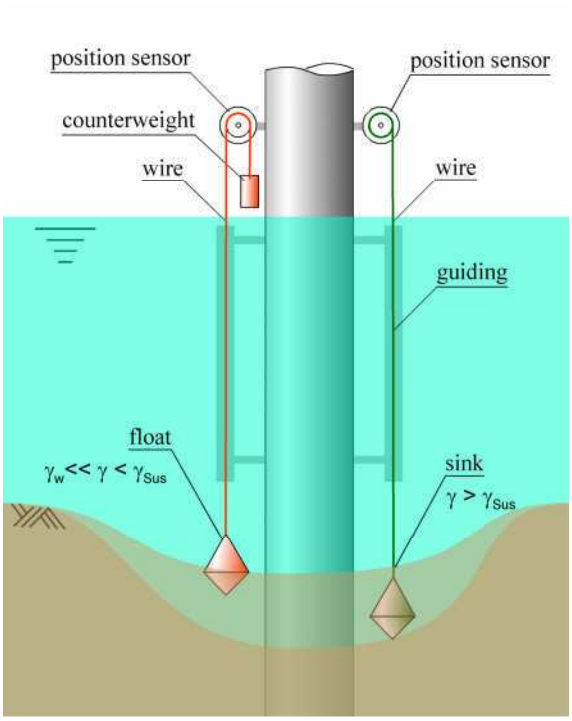

Figure 1. Schematic depiction od the measuring system

undocking maneuver. Among taking preliminary thresholds as a basis immediate protection arrangements can be taken. For an additional measurement of the extents of the scours it might be reasonable to collocate multiple scour measure units in a row . In this manner it is possible, assumed an appropriate concentration of measurement points, to gather the scour formation alongside a quay wall.

B. Design of the float

The scour monitoring system described in the section above was tested and precised under laboratory conditions. Beside the tests described hereafter some experiments with rings, bars, cuboid and cylindric shaped buoys were made. The most satisfactory results have been achieved with the double cylindric float thus only these tests will be described in detail.

Determining regarding the shaping of sink and float are slight penetration an lifting in respectively up from the suspension or sediment. The lowest resistance shows the double cylindric shaped buoys, whose base areas are directed against each other. All further geometries prove themselves as improper.

The laboratory buoys were turned out of different kinds of wood which possess varying densities, see Fig. 2.

The type of wood was chosen by assuming that the specific weight of the floats lies between the density of water and the density of the water soil suspension. We used olive, which has a density under laboratory conditions from 1,05 kg/dm3. The sinks are wooden, too. Therefore we choosed Cocobolo. It has a density of 1,1 kg/dm3 under laboratory conditions.

Figure 2. Investigated geometries for the floats

IV. Proving the Scour Monitoring System

A. Laboratory tests

In the course of the developing of the scour monitoring system the Technical University Hamburg - Harburg Institute of Geotechnical and Construction Management performed small scaled model experiments. The results of these tests are listed in [5], [6].

The scour measuring system was tested in a box with dimensions h / w / d = 40 / 20 / 10 cm. The box is filled with water and up to the half of its height with soil. Using an inlet at the bottom of the box we derive a vertical flow, directed from bottom to top. Therefore the soil in the top layer is existent as suspension. A scour is generated.

The measurement buoys are fixed on bars which are moveable in vertical direction. In the initial state both matters rest on the seabed. As the tests are performed in a geometric tight box the whirling soil material sediments at the original place. The procedure is equivalent to the real maneuver operation and has nothing in common with the static loading. A respective test passage is shown in Fig. 3.

The sequence shows clearly the desired behavior of the measurement device. During the initial situation both buoys are lying on the seabed in the same depth. After finishing the experiment the sink is out of sight in contrast to the float which lies still on the top of the newly formed water bed. The maximum scour depth during the trial is shown by the sink position; an indication to the final depth of the sea bed after ending the maneuver could be given by regard the position of the float.

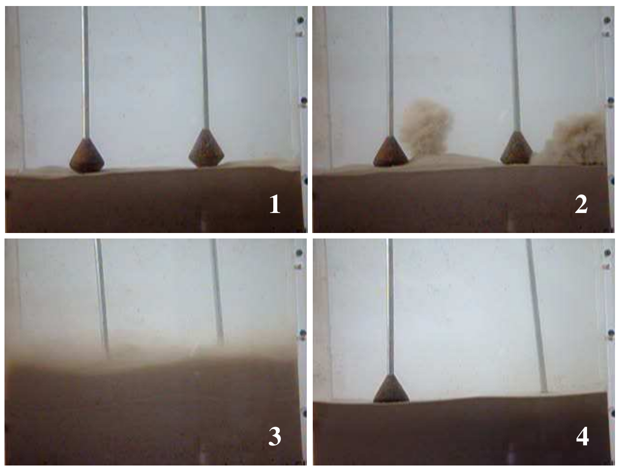

Figure 3. Experiment sequel scour measuring

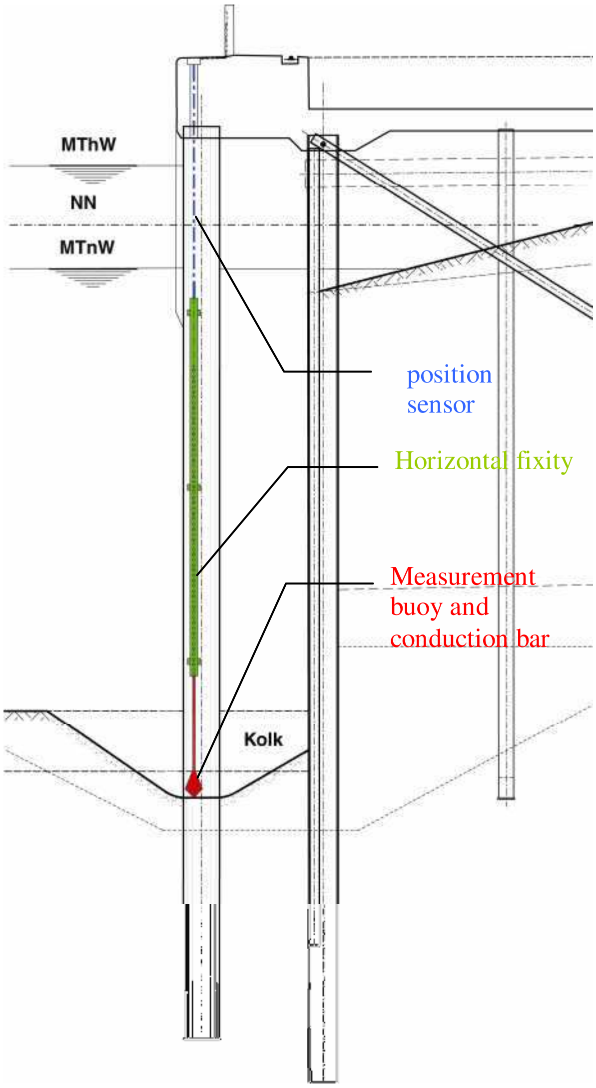

Figure 4. Installation of the scour monitoring system at Predöhlkai, Hamburg

B. Planned measuring program at Predöhlkai, Hamburg

The container handling in Hamburg is increasing very fast. Additional to the fairway deepening of the river Elbe and the construction of the 1.4 km long container terminal Altenwerder Hamburg Port Authority intends to build three new large ship berths for containerships with an overall length of 1035 m at Predöhlkai.

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During the first phase of construction the executive company Hochtief, Hamburg Port Authority and Technical University Hamburg - Harburg agreed upon the installation of the described scour monitoring system. The berth is operating since November 2005. Because disturbances are feared during ice drift in winter it is planned to install the scour monitoring system in spring-time 2006.

The measurement buoys are manufactured in steel and are fixed to a conduction bar. The bar is vertical free and horizontal fixed via plates in the other directions on the friction pile. Using a cable winch coupled with position sensors the measure signals will be submitted to a data logger and recorded with a frequency between 20 Hz and 2 kHz. Thus a complete and real time documentation of scour formation during docking and undocking maneuver is possible.

A graphic of the planned installation is shown on Fig. 4.

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