Numerical and Experimental Studies of Soil Scour Caused by Currents near Foundations of Gravity-Type Platforms

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Abstract: The mathematical model using is presented of cohesionless soil scour near foundations of marine gravity-type platforms from currents impact. In addition to this, numerical studies are also performed for different parameters of such impact. Furthermore, experimental investigations are executed in hydrowave basin with a platform model. In this work, scour areas and scour holes depths are obtained near the platform foundation, then comparison is performed of numerical and experimental studies.

Keywords: soil scour; seabed; offshore platforms.

1. Introduction

When using marine gravity-type platforms, it is very important to prevent seabed scour near its foundations. Scour progress and soil washing away from under platform foundation can cause stability loss and disturbances during its exploitation. When using platforms in offshore zones, the impact from currents should be taken into account to make a decision on platform design that ensures its own safety and prevents from soil scour. Results of such studies are presented in [1-6] for different obstacles. In this work, results are presented of experimental and numerical studies of such impact to the concrete model of gravity-type marine platform with foundation close to square.

2. Experimental studies

Experimental studies were performed in hydrowave basin of the 23rd State Marine Design Institute (St. Petersburg, Russia). The test rig is presented on Fig. 1 (all measures are presented in m).

Fig. 1. Test setup (view from above): 1 – wave basin wall; 2 – water supply vacuum pump; 3 – pipeline with plug; 4 – test area; 5 – test section; 6 – platform model; 7 – enclosure; 8 – weir with thin wall (width 1.200 m).

The experimental facility contained the current generation system and was outfitted with sand seabed model placed on the basin floor and mounted with the offshore platform model. The test rig was organized as follows. To study soil scouring near the platform model, the special experimental setup was organized using the enclosing
working area inside the basin (with overall measures 40.0×6.2 m). In the test rig beginning, a pumping system was placed to create currents. It contained 1.055 m³/s centrifugal pump with system of piping and valves. The flow rate was adjusted with a gate valve at the inlet to the test rig. To achieve uniform water flow discharge, a weir with wide crest was used at 40 m from the gate valve. This weir created the area within the limits of the test rig, where the water flow had the necessary depth and velocity. Velocity distribution of current was kept close to uniform along all the depth.

At 17 m from water supply outlet, a test area began in a form of underwater ledge with height from the basin floor equal to 0.4 m and with length equal to 12 m. In the middle of the ledge, a test section was placed measuring 4.0×4.0×0.4 m, which was filled with fine-grained sand with average diameter of particles equal to 0.22 mm. The sand surface top level was constant everywhere and equal to 0.4 m from the basin floor. In the center of the test section, the platform model was placed on rigid base. Its foundation was situated on the level that was accurately equal to 0.4 m with respect to the basin floor. The platform model was made of bakelite plywood (see Fig. 2) and has the form of real platform (in 1:60 scale from natural dimensions). Tightening weight was also used. All of experiments were performed without any sand feeding in the test area.

On Fig. 3, the photo is presented of the test section of the experimental rig with the mounted platform model before experiments.

Parameters of water flow used in experiments and obtained results are presented in Table 1 below. Experiment duration was taken equal to 1.5 hour.

<table>
<thead>
<tr>
<th>No of experiment</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water depth near platform model, ( d ), m</td>
<td>0.336</td>
<td>0.179</td>
<td>0.240</td>
<td>0.281</td>
</tr>
<tr>
<td>Current average velocity, ( v ), m/s</td>
<td>0.072</td>
<td>0.132</td>
<td>0.199</td>
<td>0.242</td>
</tr>
<tr>
<td>Maximal scour depth, ( h_{sc} ), m</td>
<td>0.003</td>
<td>0.025</td>
<td>0.080</td>
<td>0.078</td>
</tr>
</tbody>
</table>
During all experiments, the registration was performed of current average velocity using tensoresistive gauges. The water level was controlled with ultra-sonic distance meter. Acoustic gauges registered seabed profile changing during experiment. After experiment ending and test section drying, the resulting seabed profile was measured with optical surface scanner GOM ATOS 2 Triple Scan.

The results of experiment No 4 (in which impact was studied of current with maximal velocity) are on Figs 4 and 5. From these Figs, it is clear that the maximal soil scour near platform model is located near the interfaces between its upstream face and cut corner faces. The depth of scour holes grows with forcing of water flow velocity near platform.

![Fig. 4. Seabed profile near the platform model after experiment No 4 that was measured with optical scanner GOM ATOS 2 Triple Scan](image1)

![Fig. 5. Seabed profile marks in the test section after experiment No 4](image2)

The resulting scour view near the platform model foundation is presented on Figs 6-8 for different test conditions. We can see that the point, where soil starts getaway, is the point near interface of the platform upstream side and platform cut corner (Fig 6). The further scour evolution from current flow velocity increasing causes the soil transport along the cut corner.
The scour hole has the form like a flame. On the photo of results of experiment No 2 (with middle value of current flow velocities, see Fig. 7), we can see that the scouring direction is close to the axis of platform cut corner projection to the bottom. For further velocity growing (Fig. 8, experiment No 3), we can state that soil transport accumulation, which takes place near lateral platform sides close to its corners, causes changing of scouring direction. We can conclude that scouring direction depends on current velocity. All these effects are also observed in numerical simulations.

Fig. 6. Scour near platform corner between upstream and lateral faces after experiment No 1

On Figs 9 and 10, there are acoustic gauges layout and measurements results of seabed profile dynamics during experiment No 4 that were obtained with these gauges. Positive values on Fig. 10 are corresponded to soil sedimentation in accordance with the unstrained seabed surface. Negative values – to soil scouring. Red vertical lines mark moments of experiment beginning and ending. The resulting level of seabed profile in points, where gauges were mounted, is presented in Table 2 (for experiment No 4).
Table 2. Measurement results for resulting scouring or sedimentation

<table>
<thead>
<tr>
<th>Gauge No</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>( z, \text{cm} )</td>
<td>-5.2</td>
<td>-6.6</td>
<td>-5.7</td>
<td>-5.4</td>
<td>-5.7</td>
<td>-5.7</td>
<td>-0.2</td>
<td>-4.1</td>
<td>-6.1</td>
</tr>
</tbody>
</table>

Fig. 9. Acoustic gauges layout in performed experiments

Fig. 10. Measurement results of soil level changing during the experiment No 4

The data obtained from experimental studies were compared with results of numerical calculations

3. Numerical studies

To perform numerical studies, the model of soil scouring process was used, which is described in [7]. Within its framework, the soil transport was calculated for each cell of computational mesh under the influence of gravity, friction and lifting force that was caused by environment motions. Scouring process was considered as sampled in time. For each discrete time value, the instantaneous characteristics of seabed soil transport were computed, the seabed profile was updated and solution domain was reconstructed respectively. For that, firstly, shear stress was computed of the seabed surface, then the calculation of seabed soil transport was performed and finally the equation of mass balance was solved. Within used numerical model, the seabed was presented as 2D surface and soil particles motion was caused by water current flow impact and resulting seabed irregularity.

To compute currents, the 3D Navier-Stokes model for natural variables was used for viscous incompressible fluid. The current was considered to be caused by given pressure drop [8]: on the flowing boundaries, the conditions were taken for pressure distribution and for tangential component of velocity vector as problem boundary conditions. The difference approximation for the examined problem was used on the so-called “chess grid”, where individual mesh points set was corresponded to each unknown grid function. As a result, system of algebraic equations was derived and solved with gradient iterative method of incomplete approximation [9, 10].

The graphical results of current flow numerical modeling are presented on Figs 11 and 12. The initial condition of simulation data is corresponded to experiment No 4 from the Table 1.
From the results of numerical studies, it can be concluded that: current streamlines near platform went round it, whirl areas occurred near lateral platform sides. On Fig. 12, there are results of numerical computing for conditions of experiment No 4 (its duration was 1.5 hour). Some partial results corresponded to comparison between experimental and numerical studies are in Table 3. Fig. 4 and Fig. 12 illustrate that there is qualitative agreement between results of experimental and numerical studies: the maximal scour is close to platform corners; there are sedimentation areas near it. Velocity increasing causes growth of scour holes.

<table>
<thead>
<tr>
<th>Position on Fig. 12</th>
<th>Numerical result, mm</th>
<th>Measurement result, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>77.75</td>
<td>-75.34</td>
</tr>
<tr>
<td>2</td>
<td>74.64</td>
<td>71.81</td>
</tr>
<tr>
<td>3</td>
<td>31.39</td>
<td>33.09</td>
</tr>
<tr>
<td>4</td>
<td>-34.42</td>
<td>-31.19</td>
</tr>
<tr>
<td>5</td>
<td>10.21</td>
<td>11.17</td>
</tr>
</tbody>
</table>

We can see very good quantitative correspondence (difference doesn’t exceed 10%, average error is close to 6%) for values of final scour depth. We can conclude that numerical model can be used for scour predictions from currents. On Fig. 13, there are results of comparison between dynamical scour and sedimentation behavior during experiment No 4 correspondingly to measurements and numerical results. We see good qualitative agreement. Vertical line marks the beginning of current impact in performed experiment.
As a further research, the influence of other forms of platform foundation on the soil scour near it will be studied experimentally and numerically.

4. Conclusions

In this work, the results are presented of numerical and experimental studies of soil scour near marine gravity-type platform foundation (with form of square with cut corners) caused by current. Obtained results are in a good qualitative accordance.

Acknowledgements

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References