# SCOUR AROUND AND SINKING OF SUBSEA STRUCTURES EXPOSED TO CURRENT AND WAVES

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## INTRODUCTION

Many different subsea structures are used in the offshore industry, particularly for floating offshore wind farms, such as gravity anchors, tensioners, clump weights, and chains. Exposure of a subsea structure to currents and/or waves leads to changes in flow around the structure, forming flow contraction at the sides of the structure and secondary flow patterns such as horseshoe vortices, lee-wake vortices, and counter-rotating vortices (Sumer and Fredsøe, 2002). Often placed on erodible beds under current and/or wave action, scouring around these structures are experienced.

Scour process around such a subsea structure may be described as follows (Sumer and Kirca, 2022). With the introduction of the flow, the structure undergoes scouring due to the previously mentioned changes in the flow around structure. As the scour process continues, the scour hole around the structure deepens, and when the scour depth reaches the bottom of the structure, a new process kicks in where the structure begins to get undermined. The undermining of the structure causes its bearing area to get smaller, increasing the load on the soil, and potentially leading to the so-called general shear failure of soil as the bearing capacity of the soil might ultimately be exceeded, which is followed by the sinking of the structure. Depending on the geometry of the structure and the scour hole, the structure during the course of sinking may tilt due to the asymmetry of the scour geometry, or, in the case of spherical structures, it may roll forward into the deeper part of the scour hole (Truelsen et al., 2005). With further undermining, a continuous failure of the soil causes a continuous sinking of the structure. This sinking process stops when the structure sinks to such levels that it is protected against scour, where the sinking of the structure presumably comes to an end (Sumer and Kirca, 2022).

Although there is a well-established literature on scour around common marine structures such as pipelines and surface-piercing piles (see Sumer and Fredsoe, 2002, for a thorough review), scour research on other kinds of subsea structures, particularly those used for floating offshore wind projects such as gravity anchors, tensioners, clump weights, and chains, are relatively fewer.

The present paper presents the early results of an experimental study aiming to investigate the aforementioned scour and sinking processes around cuboid blocks (cubes, rectangular prisms and horizontal cylinders) under the action of waves, currents, and waves combined with currents. In this regard, cuboid structures with different dimensions and orientations are considered to assess the scour depth, scour-induced sinking depth, and time scale of the process. Of particular interest is the equilibrium scour depth and equilibrium sinking depth (if different) as well as tilting of the structure. The scope that shall be presented in this paper covers the early results for the cube shaped blocks, which are representative for several different subsea structures. Different boundary conditions are considered as for the model structure: Free to move, free to move only in vertical direction, and fixed. Results show that scouring and sinking is heavily dependent on the Keulegan-Carpenter number, current to wave velocity ratio as well as the Shields diameter. Observations show that scour is coupled with tilting of the sinking structure in most cases, given the asymmetric scour geometry. Scouring and sinking depths, tilting angles and associated timescales are studied as a function of aforementioned non-dimensional numbers. Earlier results of the study were presented in Kirca et al. (2023).

## MODEL SETUP

Experiments were conducted in a flume located in the Hydraulic Laboratory of Istanbul Technical University (ITU), with dimensions of 1 m width, 1 m depth, and 23 m length. The current was maintained by a re-circulating pump, whereas regular waves were generated via a piston type wavemaker. Water depth was maintained as 40 cm in the flume. A 3-m-long and 0.20-m-deep sand pit was placed at 11 m from the flume inlet in the channel, with a false bottom extending at the two sides of the sand pit. The sediment used in the tests was fine sand with median grain size of $d_{50}$ = 0.16 mm, geometric standard deviation of $\sigma_g = \sqrt{d_{84}/d_{16}}$ =1.37, and angle of repose of φ = 36.5°. The main focus of this research was scour around and sinking of cube structures. These blocks were made of concrete or hard plastic and their dimensions varied between 2 and 6.5 cm. Different boundary conditions for the blocks are considered: Free to move (6 DoF), free to move only in vertical direction (1 DoF), and fixed (0 DoF).

Three types of experiments were performed: current tests (C), wave tests (W), and current plus waves tests (CW). The values of the $KC = U_m T/D$ number varied between 1.25 and 17.5, whereas, the values of current to wave velocity ratio $U_{cw} = U_c/(U_c + U_m)$ varied between 0 and 1. Here, $D$ is the size of the structure, and $U_c$ and $U_m$ are the current velocity and the amplitude of the bed orbital velocity, respectively. Both clear-water and live bed experiments were conducted with the Shields parameter, $\theta$, ranging from 0.015 to 0.22.

## RESULTS

Results on different flow conditions showed that the scour depth and sinking depth depend on the imposed boundary conditions on the structure. The maximum value of the scour depth is observed for the 6 DOF. Figure 1 shows the non-dimensional scour depth (S/D) for waves only case as a function of the KC number. On the same figure the results of Truelsen et al. (2005) obtained for spheres were also given. A strong dependence of the scour/sinking depth on the KC number is evident. Also, the scour/sinking depths of cubes are significantly larger than those of the spheres.

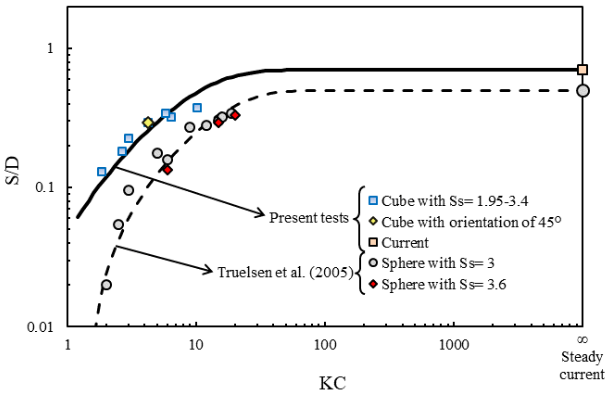


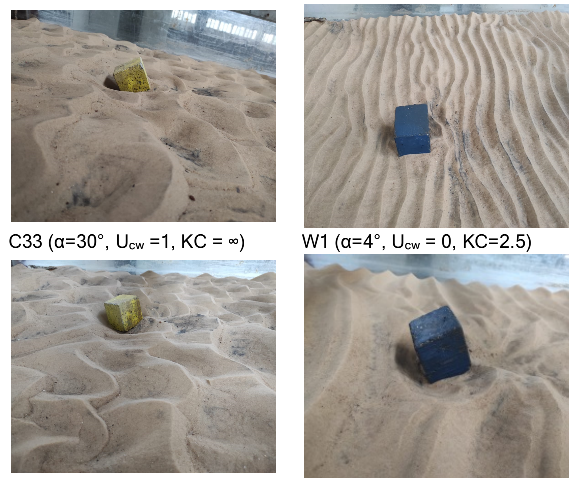

Figure 1 - The non-dimensional scour depth (S/D) as a function of KC number. Wave only case.

Although not given here due to reasons of space, the equilibrium scour/sinking depth for the case of combined waves and current were seen to be a strong function of KC as well as $U_{cw}$, similar to the pile scour case (Sumer and Fredsoe, 2001, 2002).

The tilting of the blocks in the equilibrium scour hole were also monitored in the experiments for the blocks 6 DoF tests (blocks free to move). For current only tests, the scour holes around the blocks were deeper, wider, and much more asymmetric, which resulted with significant tilting of the blocks (up to 40°) towards upstream and slipping into the scour hole. For the combined flow, a general dependence to KC number was also evident. For the waves only tests, tilting was practically zero (always less than 10°). Combined waves and current tests yielded substantial tilting for small $U_{cw}$, which gradually disappeared as $U_{cw}$ increased. Figure 2 shows the after-tests photos of the blocks with the tilting angles (α) for different ranges of the $U_{cw}$. Then, as the current velocity increases, the tilting angle also increases.

## CONCLUSION

In this paper, the early results of an experimental study on the scour around and sinking of subsea structures with different boundary conditions exposed to current and waves were presented. Results show that scour/sinking depth as well as tilting of the blocks are strongly dependent on the KC and $U_{cw}$ numbers. The maximum tilting of blocks (α=40°) was seen in the current only case, which reduced to practically zero for waves only case. The study will further continue to address the following issues: The scour/sinking depth and tilting angles for changing KC and $U_{cw}$ numbers, block geometries, as well as degrees of freedom.



C33 (α=30°, $U_{cw}$ =1, KC = ∞)  W1 (α=4°, $U_{cw}$ = 0, KC=2.5)

C36 (α=34°, $U_{cw}$ =1, KC=∞) Block with orientation of 45°  CW2 (α=20°, $U_{cw}$ = 0.47, KC=4)

Figure 2 - Tilting of free structures under different flow conditions.

## ACKNOWLEDGEMENT

This study was funded by the European Union through the Horizon Europe project INF4INiTY under Grant Agreement No. 101136087. Authors acknowledge ITU ARI Teknokent for their ongoing support under the ITU ARI Teknokent Research and Development activities.

## REFERENCES

Kirca, Ghasempour, Sumer (2023): Scour Around and Sinking of Subsea Structures Under Current and Waves. In. Proc. of 11th Int. Conf. on Scour and Erosion, Cph.

Sumer, Fredsøe (2001): Scour around pile in combined waves and current. Journal of Hydraulic Engineering, ASCE, vol. 127, pp.403-411.

Sumer, Fredsøe (2002): The mechanics of scour in the marine environment. Advanced series on ocean engineering, Vol. 17. WORLD SCIENTIFIC, Teaneck, N.J., USA.

Sumer, Kirca (2022): Scour and liquefaction issues for anchors and other subsea structures in floating offshore wind farms: A review. Water Sci. and Eng., 15(1), 3-14.

Truelsen, Sumer, Fredsøe (2005): Scour around spherical bodies and self-burial. Journal of waterway, port, coastal, and ocean engineering, ASCE, vol. 131, pp.1-13.