SCOUR AROUND OFFSHORE STRUCTURES - ANALYSIS OF FIELD MEASUREMENTS

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In this paper analysis results of scour measurements of different offshore structures in the southern North Sea are described. Numerous bathymetry survey charts, underwater videos and spudcan penetration reports were analysed. Observed scour depths and metocean conditions were evaluated to improve the understanding of the scour phenomena around offshore structures.

1 Introduction

Although the occurrence of scour in the marine environment is a well known phenomenon, little has been published on field measurements and practical validation of existing scour prediction formulae for situations with combined waves and currents. The present knowledge on scour development is mainly based on small scale laboratory tests.
In the past, experimental research on combined wave and flow action around single vertical piles has been published for example by Rance (1980), Wang & Herbich (1983), Herbich et al. (1984), Eadie & Herbich (1986), Saito & Shibayama (1992), Katsui & Toue (1993), Sumer et al. (1993) and Sumer & Fredsoe (2001). The most recent work was done by Sumer & Fredsoe (2002) who carried out reanalyses of experimental results, explained hydrodynamic processes and their effect on scour development.

Field measurements on scour have been scarcely reported. Some indications on scour in the North Sea were given by van Dijk (1981) and Dahlberg (1983). However, details on hydraulic conditions, water depths and dimensions of the structure were not published. Measurements on gravity based foundations were published for example by Bos et al. (2002).

In order to improve the understanding of scour processes under field conditions a scour evaluation project was set up by the gas and oil company NAM (Nederlandse Aardolie

Maatschappij), the service contractor AJS and WL | Delft Hydraulics. The study was co-financed by the Dutch Ministry of Economic Affairs.
Field measurements were selected for typical structures and conditions in the North Sea. In the present paper the analysis results are presented for the following field cases:

- Field case 1: a monopile in block N7 in shallow water (h = 7m);
- Field case 2: a jacket structure in block L9 in moderate water depth (h = 25m).

2 Field case 1: Scour around a monopile at location N7 (North Sea)

2.1. Description of the pile and site conditions

The monopile (outer diameter D = 6.0m) was installed in summer 1997. It is located in the coastal zone at about MSL -7m water depth. The absolute water depth can vary between 5.2m (LAT) and 11m (HAT). The depth-averaged current velocity of the tide is in the range between 0.25m/s and 0.75m/s. The tidal currents come from 100 ºN during ebb and 300 ºN during flood. The extreme design conditions for a 100 year storm event are: H_s = 4.6m, T_p = 16.1s and the depth-average current velocity u = 1.3 m/s.

The actual extreme conditions since pile installation were estimated from measurements at a location nearby, indicating the following conditions: H_s = 4.4m, T_p = 14.0s and u = 1.2 m/s.

The seabed consists of fine to medium dense sand. Scour protection was not applied. However, patches of gravel were detected in the area around the monopile.

2.2. Scour measurements

Table 1 contains a summary of maximum scour depths (S_{max}) and mean scour depths around the pile (S_{mean}) as derived from the available survey data.

Table 1. Scour development at the monopile

time after installation (yr)	scour depth	
	S_{mean} (m)	S_{max} (m)
0.0	0.0	0.0
0.05	1.8	2.5
0.16	2.5	3.0
0.24	2.5	2.7
0.39	2.7	3.2
0.72	3.0	3.3
1.76	3.5	4.0
4.73	4.8	6.3

Almost two years after installation the scour hole had an extent of about 200m and a maximum depth of 4.0m (Figure 1).

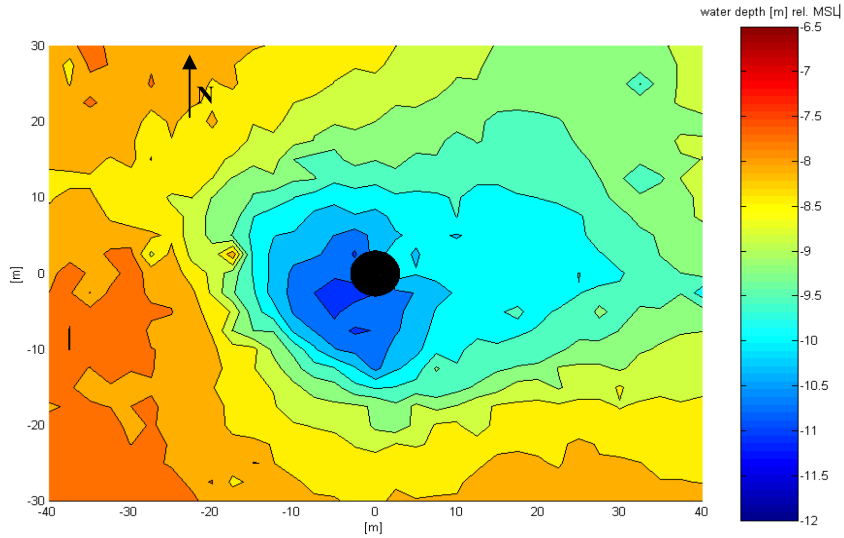

Figure 1. Bathymetry around the monopile, survey 1.76 years after installation.

2.3. Scour analysis

The scour analysis for the monopile focused on the development of the maximum scour depth with time. The development of the scour hole extent was not further considered. In the following, scour measurements are compared with predictions from some scour formulae. From the literature the following formulae were selected:

Nakagawa & Suzuki (1976):

$$S_{\max} = \left(\frac{t}{t_1}\right)^{0.22} \cdot D \tag{1}$$

$$t_1 = 29.2 \cdot \frac{D}{\sqrt{2} \cdot u} \cdot \left(\frac{\sqrt{\Delta \cdot g \cdot d_{50}}}{\sqrt{2} \cdot u - u_c}\right)^3 \cdot \left(\frac{D}{d_{50}}\right)^{1.9} \tag{2}$$

This scour prediction formula was actually derived for tidal flow only. Applying D = 6m, u = 0.5m/s (tidal mean), d_{50} = 0.2mm, u_{cr} = 0.37m/s and t = 4.73 years, the expected scour depth at the time of the last survey yield S_{max} = 4.9m. The scour depth after 25 years would be approximately 7.1m. The difference between the hindcast and the scour measurements might be explained by a slightly higher tidal mean velocity in reality or the occurance of higher flow velocities during storm events.

Breusers et al. (1977):

$$S_{\max} = 1.5 \cdot D \cdot \tanh\left(\frac{h}{D}\right) \tag{3}$$

The scour prediction formula from Breusers et al. (1977) was actually derived for flow only. The maximum scour depth is independent of hydraulic conditions and grain size. Applying D = 6m and h = 7m (depth at MSL), the maximum scour depth yields S_{max} = 7.4m. In the case of a 100 year storm the water depth could become 11.4m (including surge) leading to S_{max} = 8.6m.

Sumer & Fredsoe (2002):
According to Sumer & Fredsoe (2002) it needs to be distinguished between slender piles (ratio between pile diameter D and wave length L < 0.2) and large piles (D/L>0.2). The monopile is relatively large for small waves (L < 30m, T <4.5s). Under storm conditions the pile can be considered as relatively small.

For a cylindrical slender pile (D/L < 0.2), Sumer & Fredsoe (2002) give a design formula for the maximum scour depth (equation 4):

$$\frac{S_{\max}}{D} = \frac{S_C}{D} \cdot \left[1 - \exp\left\{-A \cdot \left(KC - B\right)\right\}\right] \tag{4}$$

With: $A = 0.03 + 0.75 \cdot U_{cw}^{\;2.6}$, $KC = \dfrac{U_m \cdot T}{D}$, $B = 6 \cdot \exp\left(-4.7 \cdot U_{cw}\right)$ and $U_{cw} = \dfrac{U_c}{U_c + U_m}$.

Equation (4) is the only scour formula for cylindrical piles available in the literature which accounts for waves and currents. The range of validity is limited to 4 < KC < 25. All other formulae were developed for currents only.

In the case of a large pile (D/L > 0.2), the Keulegan Carpenter number can be calculated according to the equation above. The scour depth due to waves can be estimated from a graph as presented in Sumer & Fredsoe (2002). The range of validy is limited to KC < 2. Scour depths are generally in the order $S \leq 0.05D$.

According to this approach, the maximum design scour depth was calculated depending on the hydraulic conditions (U_m = 2.1m/s, U_c = 1.15m/s, T = 16.1s). Maximum scour depths were calculated for a ratio of $S_c/D = 1.3+\sigma_{s,d} = 2.0$ and $S_c/D = 1.3+2\sigma_{s,d} = 2.7$. The design maximum scour depth under extreme conditions (100 year storm return period) yields S_{max}=3.7 - 5.0m. For the actual hydraulic conditions since pile installation (U_m = 2.0m/s, U_c = 1.08m/s, T = 14.0s) a maximum scour depth between 2.9 and 3.9 m would have been expected.

Figure 2 shows the development of scour with time. It seems to be likely that the scour equilibrium is not yet reached. The time dependent formula after Nakagawa & Suzuki (1976) showed a good agreement with the measurements of mean scour (averaged around the pile). The other two formulae were time independent. Using the formula of Breusers et al. (1977), maximum scour would be expected between 7.4m and 8.6m. In view of the measurements at the monopile after 5 years ($S_{max,observed}$ = 6.3m) the predictions according to the formulae of Breusers et al. and Nakagawa & Suzuki appear to be in the right order of magnitude. The approach of Sumer & Fredsoe (2002) led to a scour depth prediction of 2.9m to 3.9m, depending on the conservativity for the ratio S_c/D. Compared with the measurements this method indicates an underestimation of the scour depth for both conditions actual scour after 5 years and equlibrium design scour.

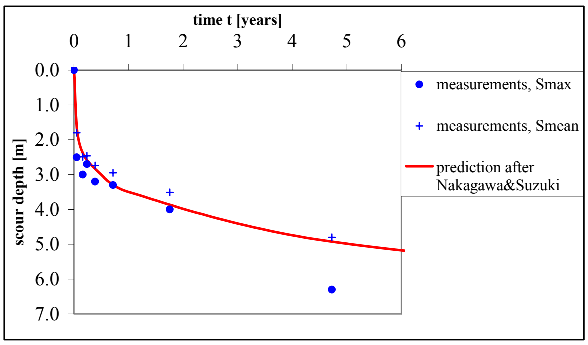

Figure 2. Comparison of measured and computed scour depth in time.

3 Field case 2: Scour around a jacket structure at location L9 (North Sea)

3.1. Description of the structure and site conditions

The considered wellhead and production platforms at block L9 were installed in summer 1997. The bed level is about 24m below LAT. The wellhead is based on a jacket structure with four legs (diameter $D_{leg,well}$ = 1.1 m) with a spacing of 20 m and 17 m, respectively. The support structure of the production platform comprises six legs ($D_{leg,prod}$ = 1.5 m) having spacings of 16 m and 20 m, respectively. At the seabed, all legs are connected to skirt piles (Figure 3). The piles sitting in the seabed have a diameter of $D_{pile,well}$ = 1.2 m and $D_{pile,prod}$ = 1.5 m, respectively. Scour protection was not applied at the jacket structures.

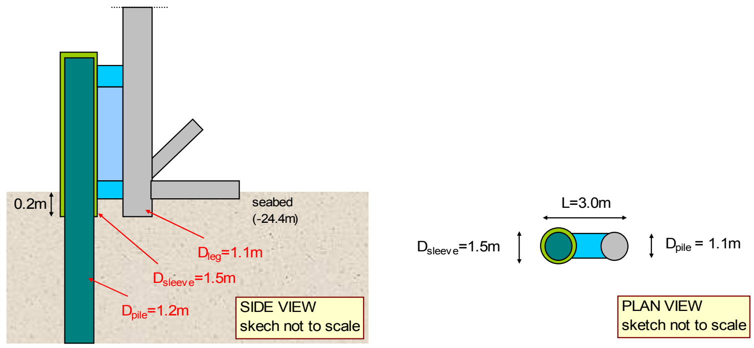

Figure 3. Schematisation of connection between jacket and skirt piles at the seabed (sketch not to scale): side view and plan view.

Typical depth-averaged peak flow velocities are 0.5 m/s during spring tide and 0.35 m/s during neap tides. The estimated depth-averaged mean flow velocity is u = 0.25 m/s. Metocean design conditions for a 100 year storm indicate the following conditions: H_s = 8.8m, T_p = 10.1s and u = 1.2 m/s. The actual wave conditions since installation where estimated at: H_s = 7.8m, T_p = 9.8s and u = 1.0 m/s. The seabed material consists of dense fine to medium grained sand (d_{50} = 0.2mm).

3.2. Scour measurements

Bathymetry charts showed that a wide area around the platforms was affected by scour. The extent of the global scour hole was in the order of 50m in all directions. A typical scour pattern is shown in Figure 4. Maximum scour depths were in the range of 1.5 to 5.0m for both the wellhead and the production platform with most legs experiencing scour in the range of 2.0 to 3.5m.

The global scour hole (extent of bathymetrical changes relative to the undisturbed situation) had a radius of roughly 40 times the pile diameter. This is in the order of magnitude as observed for the monopile at N7 (field case 1).

According to Breusers et al. (1977) the maximum scour depth for a single pile yields $S_{max,prod}$ = 2.3m (production platform) and $S_{max,well}$ = 1.8m (wellhead platform), respectively. Calculation based on the formulae of Sumer & Fredsoe (2002) indicated maximum scour depth of $S_{max,prod}$ = 1.2 - 1.7m (production platform) and $S_{max,well}$ = 1.2 - 1.6m (wellhead platform), respectively (actual conditions).

The difference between the scour for a single pile and the observed scour at the legs is a factor of about 3 to 4. This difference can be explained by the disturbing effect of the jacket structure (pile sleeve construction at the seabed, bracings, pile-pile interactions, Fig. 3). This disturbance effect should be taken into account in the scour design for jackets. The presented field measurements give an idea of the order of maginitude of this effect.

From consultancy projects at WL | Delft | Hydraulics it is known that comparable scour depths were also observed at similar jacket structures in the North Sea. This indicates that measurements at L9 are no exceptions. The same factor (3-4) between measurement and prediction for a single pile was found.

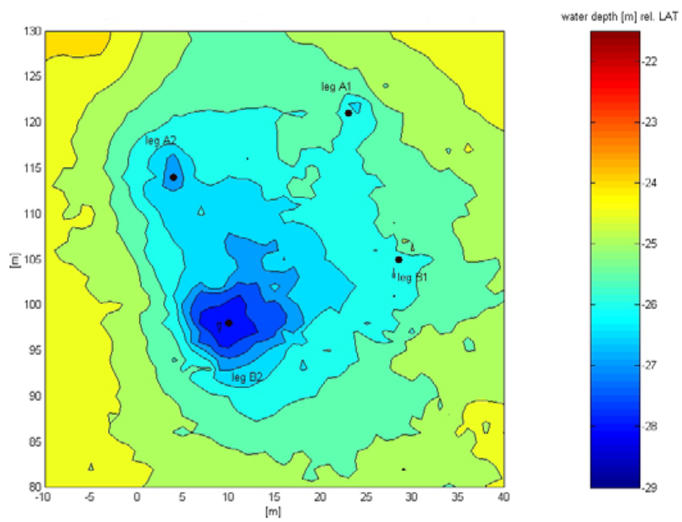

Figure 4. Bathymetry at the wellhead platform, survey after 3 years.

4 Conclusions

The maximum scour depth S_{max} at the monopile with a diameter D = 6m in a water depth of MSL -7m subject to waves and currents was 6.3m after 5 years. The extent of the scour hole was up to 200m. A comparison with three different scour depth prediction formulae was carried out. It was found that good predictions of maximum scour were made using the formula presented by Nakagawa & Suzuki (1976) and Breusers et al. (1977). Regarding the time scale of scour development it was concluded that the equilibrium scour depth had not been reached when the last survey was carried out. Scouring can obviously take much longer in reality than often experienced in laboratory experiments. Using the formula from Nakagawa & Suzuki (1976) it was possible to reproduce the mean scour development with time very well.

Scour around two jacket structures at location L9 were analysed using several field measurements. The global scour hole had a radius of about 50m (40 x pile diameter). Local scour holes reached depths of 5m which is more than 3 times the pile diameter. Scour predictions for single piles provide an underestimation of scour depths by a factor of 3 to 4. This difference can be explained by the disturbing effect of the jacket structure close to the seabed. This disturbance effect should be taken into account in the scour design for jackets.

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