Scour development and conceptual scour protection layout at OHVS HKN and HKWa

Deltares

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Deltares

Title

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Summary

TenneT is planning to develop a grid connection for the "Hollandse Kust (noord)" (HKN) OWF, which will include one Offshore High Voltage Station (OHVS). In addition, another OHVS is planned to connect the northern part of the "Hollandse Kust (west)" (HKW) OWF, namely HKW-Alpha, to the grid.

A desk study has been carried out to assess the scour development and conceptual scour protection layout at both offshore high voltage substations (OHVS), as well as the amplification of the hydrodynamic load in the cable areas in the vicinity of the structures. For the jackets a similar design is considered as the base design of the Borssele and HKZ platforms. In 2016 Deltares performed physical model tests to address the scour development and flow amplification for the Borssele jackets, while in 2017 a desk study was performed to address these topics for the HKZ jackets. Because of the similarity in the design of the jackets, these studies are used as the basis of the present desk study. By comparing the hydrodynamic conditions at the sites, as well as the effects of (small) differences in the design of the jackets, required alterations in the expected scour development, conceptual scour protection layout and flow amplification could be determined.

Both the undisturbed hydrodynamic conditions as well as the local amplification due to the presence of the HKN and HKW Alpha platforms are not expected to differ much from the situation at the Borssele Alpha and Beta platforms and the HKZ platforms. Consequently, the best-estimate for the scour development, the conceptual scour protection and flow amplification at HKN and HKW Alpha is similar to the outcome of the previous studies. For the cable areas to the north, west and south of the platforms the maximum near bed flow velocities close to the structure are expected to be in the order of 7 to 9 m/s (excluding a 10% accuracy band) during extreme conditions. In the far field these flow velocities are expected to be in the order of 5 m/s (excluding a 10% accuracy band). An armour layer consisting of a 3-9" HD grading is expected to show limited deformation under the design storm condition (RP100yr).

References

Proposal: Deltares, *"11202943-001-HYE-0001-o-Scour protection layout - OHVS HKN and HKWa_SIGNED.pdf"*. Dated 20 June 2018.

Award: Tennet, "*Contract letter to purchase order T294253 for Scour Protection Study HKN and HKW Alpha.pdf*". Dated 29 June 2018.

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Contents

1 Introduction

TenneT is planning to develop a grid connection for the “Hollandse Kust (noord)” (HKN) OWF, which will include one Offshore High Voltage Station (OHVS). In addition, another OHVS is planned to connect the northern part of the “Hollandse Kust (west)” (HKW) OWF, namely HKW-Alpha, to the grid. On 4 June 2018, Deltares was contacted by TenneT with a request for a proposal regarding several scour- and hydrodynamic-related consultancy tasks. A quotation was provided by Deltares on 21 June 2018 and Deltares was given a notice to proceed according to TenneT’s Purchase Order received 17 July 2018, which was signed 29 June 2018 (PO T294253).

1.1 Objectives

The objective of this study is threefold:

1. to provide an indicative estimate of the scour that could occur over the lifetime of the jacket in case of an unprotected jacket.
2. to estimate the local amplification of the flow around the platform and the resulting flow velocity profile along the route of the export cables.
3. to develop a conceptual loose rock scour protection layout. The scour protection should (1) prevent erosion around the legs of the jacket or restrict erosion around the legs in such a way that the stability of the jacket is not compromised and (2) prevent or restrict erosion below the J-tubes in such a way that the integrity of the cables going into the J-tubes is not compromised due to free spans exceeding the allowable length.

1.2 Methodology

In the summer of 2016 a physical model test campaign was executed by Deltares in which the scour development and required scour protection around another OHVS was simulated, namely OHVS Borssele Alpha and Beta (Deltares, 2016b). The local amplification of the hydrodynamic loads in the cable areas was also determined in this test campaign (Deltares, 2016a). In a similar study as the one presented here the numerical modelling of the flow amplification was performed on the Borssele and HKZ Alpha and Beta jackets to determine the local amplification of the hydrodynamic loads in the cable areas (Deltares, 2017). Calculations performed in that study are also used as reference for the present study.

Because of the similarity between the design of the Borssele OHVS and HKZ OHVS and the presently considered OHVS jackets, the results of the physical model test campaign and numerical simulations are used as a starting point for this desk study. By comparing the hydrodynamic conditions at the sites, as well as the effects of (small) differences in the design of the jackets, alterations in the expected scour development, local amplifications of the hydrodynamic loads and a conceptual scour protection layout are suggested.

The assessment therefore consists of the following steps:

1. The undisturbed hydrodynamic conditions, local amplification of the hydrodynamic conditions and the morphology at HKN and HKW Alpha are compared with the conditions at Borssele OHVS and HKZ OHVS.
2. The comparison of hydrodynamic conditions and local amplification are used to determine the amplifications of the hydrodynamic loads, including the amplification of the loads in the cable areas for HKN and HKW Alpha.

3. Based on the comparisons of the scour development, amplification of the hydrodynamic loads and the physical model tests results for the conceptual scour protection of Borssele, the scour development and conceptual scour protection layout for HKN and HKW Alpha are assessed.

1.3 Structure of this report

Chapter 2 presents a description of the HKN and HKW Alpha platforms and the metocean conditions. In Chapter 3 the comparison between the hydrodynamic conditions and morphodynamics Borssele Alpha and Beta and HKN and HKW Alpha (this is point 1 of the abovementioned approach) is discussed. Chapter 4 presents the maximum flow velocities in the cable areas around the HKN and HKW Alpha platforms (point 2 of the abovementioned approach). The expected scour development and conceptual scour protection layout for HKN and HKW Alpha is presented in Chapter 5 (point 3 of the abovementioned approach), followed by the conclusions presented in Chapter 6.

2 System understanding

2.1 The HKN and HKW Alpha OHVS

The Dutch Ministry of Economic Affairs presented a road map outlining how the Government plans to achieve its offshore wind goals in accordance with the timeline agreed upon in the Energy Agreement. The road map set out a schedule of tenders offering an additional 7 GW split over five new wind parks by 2023. In the context of this road map, a new tender will open for wind farm zone Hollandse Kust (noord) (700 MW) and Hollandse Kust (west) (1.400 MW) in 2019 and 2021 respectively. TenneT will build grid connections and construct OHVS in the wind farm zones.

In 2016, TenneT has developed a jacket foundation design for the Borssele OHVS, see Figure 2.1. In view of cost reduction, it is the intention to apply a similar jacket design in the HKN and HKW offshore wind farms for the two offshore substations HKN and HKW Alpha.

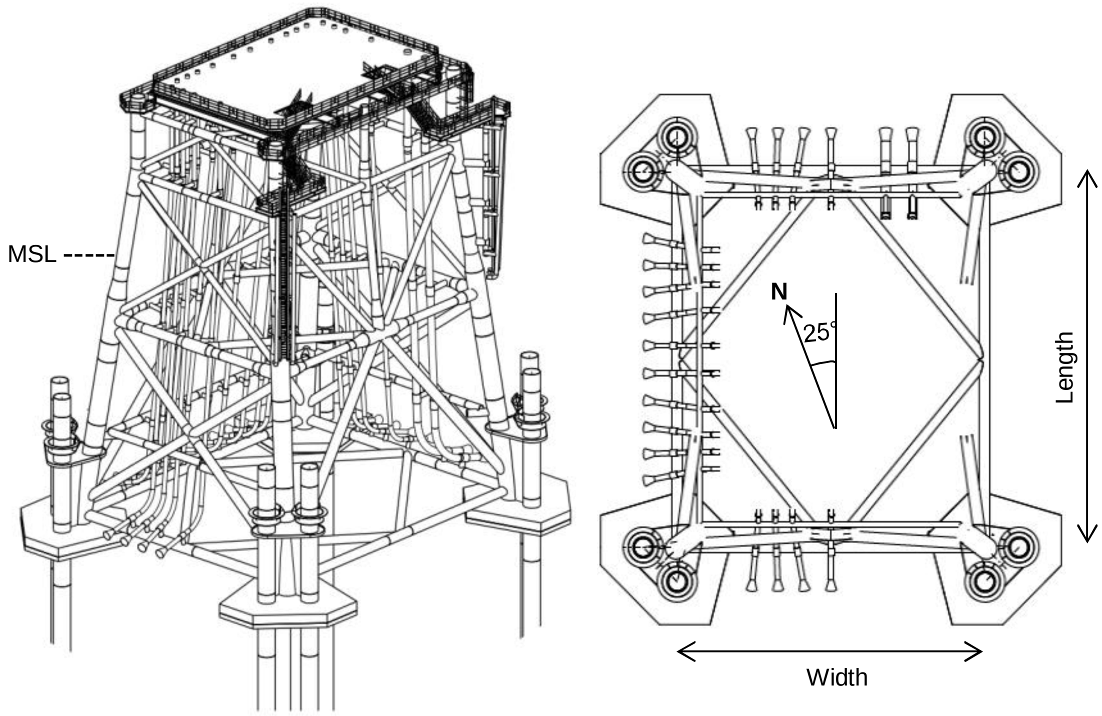

Figure 2.1 Borssele Alpha jacket design (provided by TenneT). Left: three-dimensional overview. Right: plan view.

Similar to the Borssele platforms, the HKN platform will be placed under a 25 degree angle with respect to the true North. For the HKW Alpha platform the orientation is not yet selected. In consultation with TenneT it is assumed the platform is aligned with the main tidal current direction, similar to the HKN platform. Therefore a similar 25 degree angle orientation with respect to the true North is assumed. The J-tubes, where cable connections will be made are located on the north, west and south sides of the platform, as can be seen in Figure 2.1. Please note, that the presence of J-tubes is incorporated in this study as this large amount of J-tubes has an influence on the flow around the platform.

The wind farm areas and the locations of the platforms are depicted in Figure 2.2. Note that a search area is given for the HKW Alpha platform as the location is not yet decided on. For this study representative water depths and hydrodynamic conditions in the search area are considered.

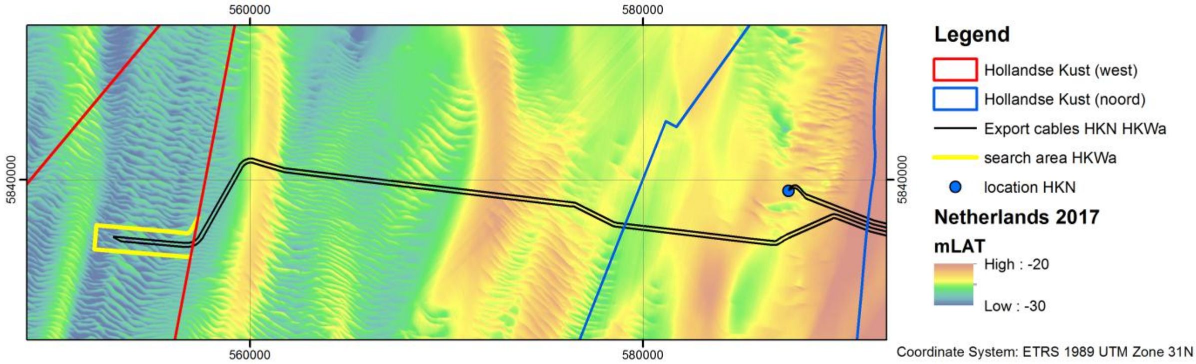

Figure 2.2 HKN and HKW wind farm sites with the location of the HKN platform and a search area for the HKW Alpha platform.

The dimensions of the jacket structures are optimised for local hydrodynamic conditions. For now, a linear scaling of the footprint with the water depth is assumed in consultation with TenneT. The footprint of the Borssele Alpha and HKN and HKW Alpha jackets are presented in Table 2.1. This table shows that the expected footprint of the HKN, which is similar to the HKZ platform, is smaller than the footprint of the Borssele Alpha platform. The HKW footprint will be almost equal to or slightly smaller than the Borssele Alpha footprint depending on the water depth at the selected location. The range of water depths in the search area of 26 to 30 m is taken into account in this study. Apart from the footprint, the exact dimensions of the HKN and HKW Alpha platform are unknown.

Table 2.1 Footprint of the Borssele Alpha and HKN and HKW Alpha jacket structure, where the length and width are indicated in Figure 2.1 and the scale is the size of the footprint relative to the footprint of Borssele Alpha.

Parameter	**Borssele Alpha**	**HKN**	**HKW Alpha**
Water depth, h_w [m LAT]	30.7	24.0	26.0 – 30.0
Length, L [m]	35.0	27.4	29.6 – 34.2
Width, W [m]	29.0	22.7	24.6 – 28.3
Apparent scale, S [%]	100	78	85 – 98

2.2 Hydrodynamic conditions

The metocean conditions for the HKN and HKW site are obtained from the metocean report (DHI, 2017). The sites are characterised by a moderate tidal current, with a dominant direction in the ENE – WSW axis. Furthermore, it is noted that the flood currents, going towards Northeast are usually stronger than ebb currents. Waves are predominantly coming from the northerly to south-westerly direction. This is in line with the direction of the strongest winds. The most predominant wave directions are NNW and SW.

In the relatively shallow water depths considered here, extreme storm events generally result in larger flow velocities at the bed than a tidal condition. However, in these storm events the flow patterns that result in the local scour holes around the foundation piles are continuously broken up due to the reversal of the flow. The formation of local scour holes is therefore generally dominated by tidal conditions. Extreme storm conditions are used to evaluate the stability of the scour protection.

Based on these considerations a set of tidal and storm conditions are selected and evaluated for the HKN and HKW Alpha locations. For the tidal conditions an average tidal flow velocity and a

90% upper limit value were selected. The storm event is based on one of the Ultimate Limit State (ULS) conditions presented in the guidelines by DNV GL on load combinations (DNVGL-OS-C101), see Table 2.2. This ULS condition is referred to the RP100yr condition in the remaining part of this document.

Table 2.2 Return periods of environmental load incorporated in one of the ULS conditions mentioned in DNVLGL-OS-C101.

Limit state	Waves	Current	Water level
ULS	10^{-2}	10^{-1}	10^{-2}

Two extreme storm events are evaluated: the high water and low water conditions with corresponding wave characteristics and water levels. Although the differences are small, the high water condition was found to be normative and will therefore be used. This condition combines the high water wave characteristics with the mean still water level (MSL). Note that this condition is slightly conservative as the high water wave characteristic is generally accompanied with a setup of the water level (storm surge). For the tidal conditions, the water depth is also based on a water level equal to MSL.

An overview of the metocean conditions is presented in Table 2.3 (tidal conditions) and Table 2.4 (storm conditions). The variations in the wave and current conditions found in the search area for HKW Alpha are within the accuracy of this study and therefore a normative representative condition is selected. The maximum and minimum water depths in the search area, represented by HKWa_1 and HKWa_2, are considered in this study.

Table 2.3 Summary of the mean and maximum tidal conditions at HKN and HKW Alpha (DHI, 2017).

Load case	Environmental conditions		
	$U_{c\_mean\ (50\%)}$ [m/s]	$U_{c\_max\ (90\%)}$ [m/s]	Water depth [m MSL]
HKN	0.43	0.64	25.1
HKWa_1	0.42	0.63	26.8
HKWa_2	0.42	0.63	30.8

Table 2.4 Summary of the storm conditions (RP100yr) at HKN and HKW Alpha (DHI, 2017).

Load case	Environmental conditions			
	H_{m0} [m]	T_p [s]	U_c [m/s]	Water depth [m MSL]
HKN	7.7	14.7	1.1	25.1
HKWa_1	7.9	14.5	1.1	26.8
HKWa_2	7.9	14.5	1.1	30.8

2.3 Soil conditions

For the scour analysis the characteristic medium grain diameters of the top sand layer were extracted from DINOloket on February 10th, 2017 (the Geological Survey of The Netherlands | TNO www.dinoloket.nl). This showed that the grain diameter on the HKN platform location is expected to be approximately 310μm. The grain diameters in the search area for the HKW Alpha platform are expected to be in the range of 260 to 300μm. In the present study 260μm is adopted for the calculations of the mobility of the sand at HKW Alpha, see Section 3.3. This value will give a conservative estimate for the mobility; the difference however falls within the accuracy with which this desk study is performed.

3 Comparison of the hydrodynamic and morphological conditions at HKN and HKW Alpha with Borssele

This chapter presents the comparison of the hydrodynamic and morphological conditions at the HKN and HKW Alpha platform with Borssele and HKZ. First, a summary of the physical model test for Borssele is provided in Section 3.1. Second, a summary of the flow amplification studies for Borssele and HKZ is presented in Section 3.2. The undisturbed hydrodynamic conditions are discussed in Section 3.3. The amplification of the hydrodynamic conditions due to the presence of the structure is presented in Section 3.4. Finally, a description of the large scale morphodynamics at the platform locations is given in Section 3.5.

3.1 Summary of physical model test Borssele

Prior to comparing the hydrodynamic conditions at the Borssele site to the HKN and HKW locations, a short summary of the physical model test campaign for the Borssele OHVS is presented. Here the considered metocean conditions, conceptual scour protection layout, the observed scour development and the observed scour protection deformation are discussed.

Metocean conditions

Prior to the execution of the physical model test campaign it was concluded that the conditions at Borssele Alpha and Beta were very similar. Moreover, it was assessed that the conditions at Borssele Alpha were normative. Based on this assessment the physical model test campaign included loading cases related to the Borssele Alpha location. These are presented in Table 3.1. Please note that the load combinations are defined in a similar manner as described in Section 2.2.

Table 3.1 Load combinations considered in the Borssele OHVS physical model test campaign (field scale).

Load case	Environmental conditions			
	H_{m0} [m]	**T_p [s]**	**U_c [m/s]**	**Water depth [m]**
Tide mean (50%)	-	-	0.7	32.3
RP100yr	8.9	12.5	1.2	30.0

Conceptual scour protection layout

The test performed in the Borssele OHVS physical model test campaign were aimed at simulating the external stability of the armour grading; a 3-9" high density (HD) rock grading[1]. Other failure mechanisms, such as winnowing and failure due to edge scour, were not considered.

Based on the selected armour grading, three different scour protection concepts were considered prior to the execution of the tests: (1) a single layer system, with post-installed jacket; (2) a two-layer system, with post-installed jacket and (3) a two-layer system in which the armour is installed after the installation of the jacket. All are visualised in Figure 3.1. It was assessed that concept 3 would be most unfavourable for the armour layer stability. A schematisation of this concept (without including the filter layer) was therefore tested, see Figure 3.2.

[1] *Please note that high density rock relates to a rock density of approximately 3050kg/m^3, as opposed to normal density rock, which generally has a density of 2650kg/m^3.*

Figure 3.1 Schematisation of scour protection concepts.

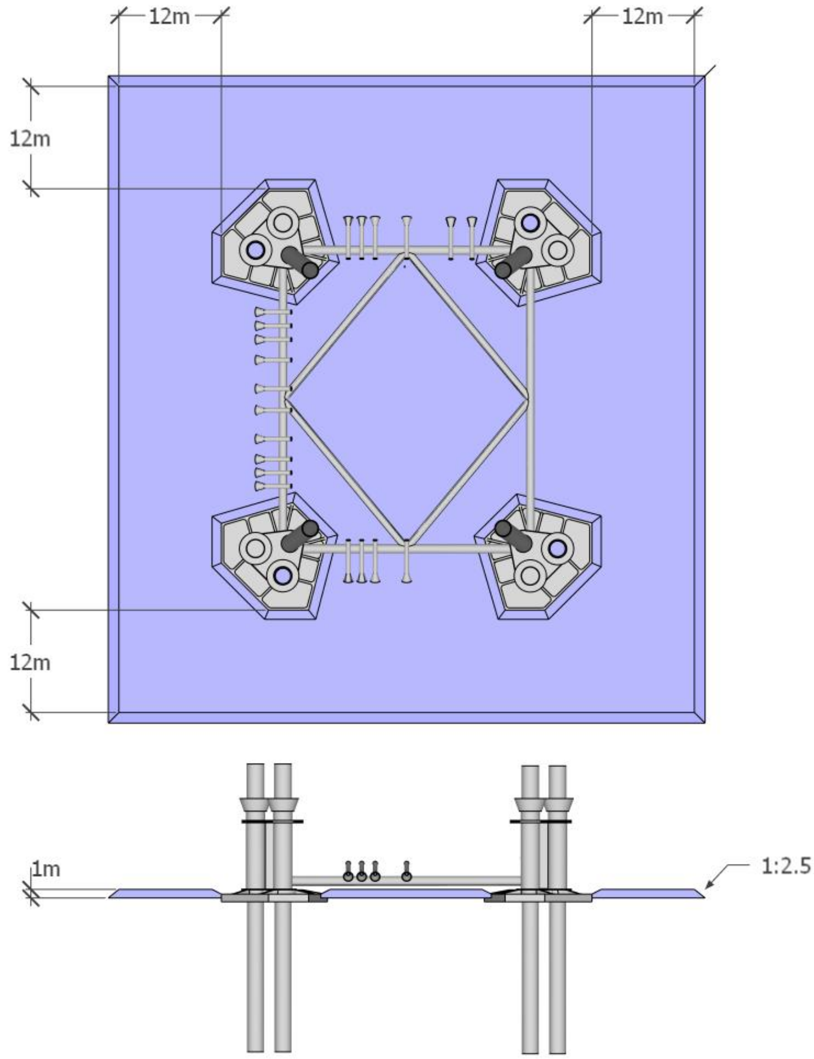

Figure 3.2 Tested scour protection layout.

Scour development observed

The scour development was simulated in tidal conditions, as such conditions general result in the deepest scour holes at the foundation piles. After a mean tidal condition two storm conditions (RP10yr and RP100yr) were run consecutively. Please note that in this desk study only the design condition, RP100yr storm event, is evaluated. Consequently, the conclusions drawn in this study relate to the design condition, but do not give further information on the possibly required maintenance.

The test clearly showed that the tidal conditions are governing for the development of scour holes around the foundation piles (local scour) and for the extent of scour hole around the whole jacket (global scour). In mean tidal conditions equilibrium depths of approximately 7m are found around the foundation piles (including local and global scour). In more severe tidal conditions the scour holes are expected to deepen. In storm conditions or less severe tidal conditions these scour holes around the foundation piles are expected to experience backfilling.

Scour protection deformation
A RP10yr storm and RP100yr storm were run consecutively during the physical model test programme. After the 100yr storm limited movement of the rock was observed; some rock moved on top of the mud mats. This occasional movement did not result in significant deformation during the RP100yr storm.

Based on the outcome of the tests it was assessed that the 3-9" HD grading would be very stable, either when applied as a pre- or post-installed layer. When applied as a single layer, the thickness of the layer should be sufficient to prevent winnowing. When applied in a two-layer system the thickness of the armour layer should ensure a good coverage of the filter layer; a minimum value of 0.5m was advised for the latter.

Based on the expected (expert judgement) edge scour hole development of 3m, a similar extent as incorporated in the conceptual layout (12m, see Figure 3.2) was advised for a single layer system. For a two layer system the extent of the armour grading might be optimised, but the extent of the filter layer should then be sufficient to prevent undermining of the armour layer due to edge scour.

3.2 Summary of flow amplification studies for Borssele and HKZ

Prior to comparing the local amplification of hydrodynamic conditions at the Borssele and HKZ platforms to the HKN and HKW Alpha platforms, a short summary of the physical and numerical modelling for the flow amplification around the Borssele and HKZ platforms is presented.

The flow amplification is defined as the maximum instantaneous flow velocity relative to the undisturbed velocity. The flow amplification in the cable areas around the jacket structures supporting the Hollandse Kust Zuid (HKZ) Alpha and Beta OHVS was assessed using numerical simulations. The numerical model was validated against physical model experiments performed for the Borssele OHVS (Deltares, 2016a). For this similar structure the validation showed that the numerical model is capable of reproducing results from physical model experiments with an error of less than 10%.

Results of multiple numerical computations were combined and presented in a map of the expected maximum flow amplification, see Figure 3.3. The generated maximum flow amplification map shows that the flow amplification is highest in the cable areas to the North and the South of the structure. In these areas the flow amplification factor is estimated to be 2.8. The flows along the North-South axis contribute the most to the flow amplification in the cable areas. This is mainly caused by interaction of vortices being shed from the up- and downstream legs of the platform. A strong dependency on the relative size of the platform is seen and it is stressed that results should not be extrapolated to other geometries. Computations with oscillatory flows with a mean drift indicate that interaction of wave and currents may, under certain conditions, cause unfavourable situations. However, it is argued that these situations are highly idealized and effects such as wave-current misalignment and wave directionality are likely to reduce the observed flow amplification. Combined with undisturbed flow velocities, the map can be used to derive maximum flow velocities required for the design of the cable protection systems.

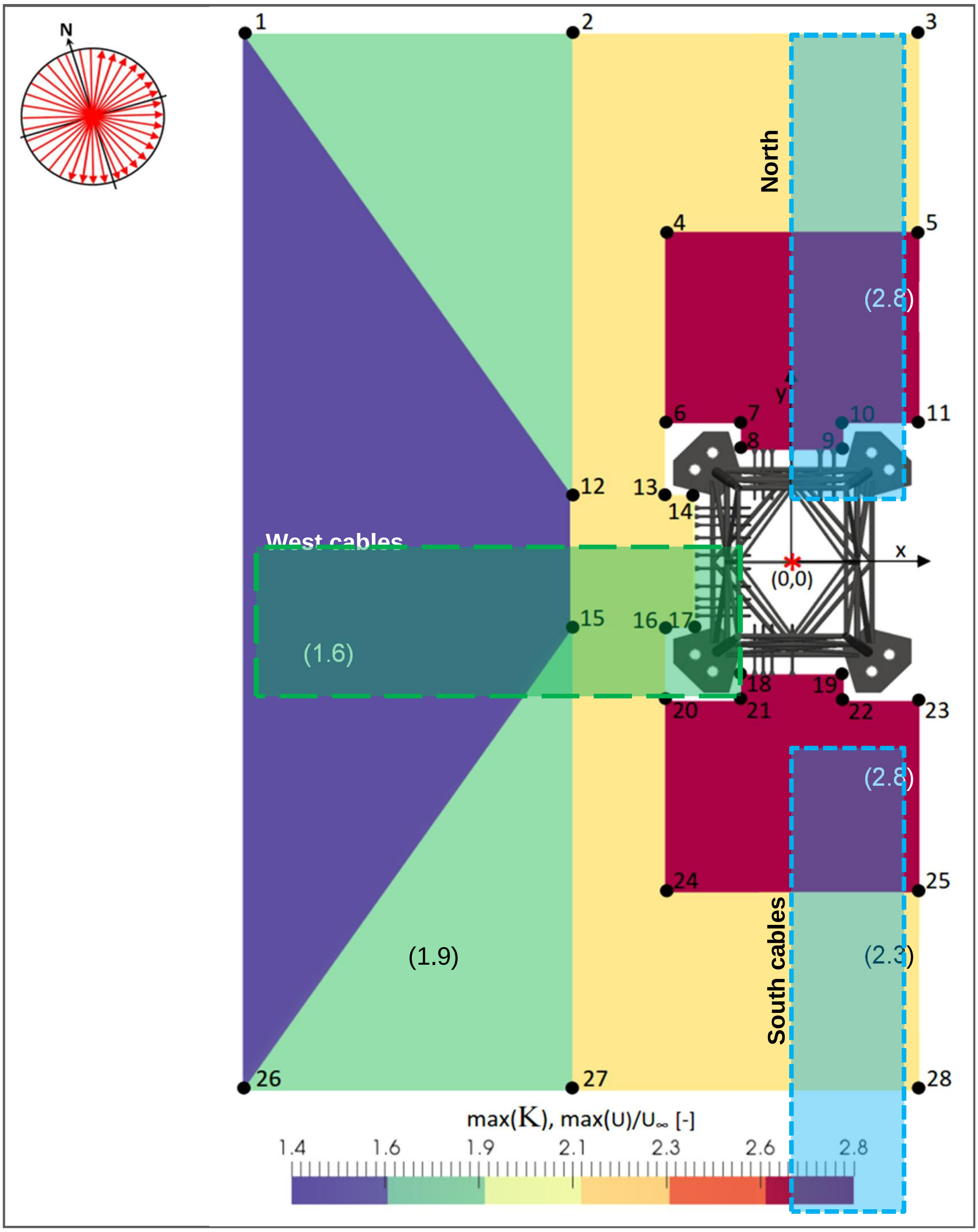

Figure 3.3: The map for the estimated maximum flow amplification. The highest flow amplification is applicable for a particular colour field. The north, west and south cable areas are indicated with the dotted green and blue rectangles. Appendix A presents the coordinates of the points with respect to the displayed coordinate system, which has its zero (0,0) point in the centre of the footprint of the jacket and is rotated 25 degrees with respect to the true North.

3.3 Comparing the undisturbed hydrodynamic conditions

As mentioned in the methodology, see Section 1.2, the first step in the comparison between the Borssele OHVS and the HKN and HKW Alpha OHVS, includes the comparison between the undisturbed hydrodynamic conditions. In order to evaluate the combined effect of the differences of all hydraulic parameters, the relative mobility is considered. The relative mobility is defined as:

$$MOB = \frac{\theta}{\theta_c} \tag{3.1}$$

where θ is the Shields parameter [-], θ_c is the critical Shields parameter [-] and *MOB* is the ratio between them [-]. A relative mobility value larger than 1 indicates that a particle is likely to be entrained or unstable, while with a relative mobility value smaller than 1 little to no movement is expected. Please note, that this is related to the undisturbed relative mobility (without the presence of a structure). In the vicinity of a structure the load can be increased by the structure and particles can become unstable at lower undisturbed relative mobility values. Table 3.2 presents an overview of the undisturbed relative mobility values for the tested conditions for Borssele OHVS and the design conditions for HKN and HKW Alpha.

Table 3.2 Overview of hydraulic parameters for Borssele OHVS and HKN and HKW Alpha.

Tested load cases	**MOB [-]**		
	Sand*		**3-9" HD****
Borssele OHVS	2.67		0.74
Design load cases	**Sand*** (mean current, 50% value)	**Sand*** (max current, 90% value)	**3-9" HD****
HKN	1.02	2.27	0.75
HKWa_1	1.00	2.26	0.73
HKWa_2	0.98	2.21	0.63

** the mobility of the seabed is determined based on tidal conditions*
*** the mobility of the 3-9" HD grading is determined based on a RP100yr storm event.*

From Table 3.2 it can be concluded that the sand is expected to be slightly less mobile compared to the tests at Borssele. The stability of the 3-9" HD rock grading is expected to be equal at HKN and HKW Alpha locations compared to the tests for Borssele OHVS.

3.4 Amplification of hydrodynamic conditions around the platforms in the cable areas

Based on the similarity of the magnitude and directions of the undisturbed hydrodynamics and the linear scaling of the design of the Borssele, HKZ, HKN and HKW Alpha jackets, the local amplifications are expected to be very comparable as well. Within the accuracy with which a desk study can be performed, it is concluded that the differences are negligibly small. Therefore, the flow amplification map presented in Figure 3.3, is also valid for the calculation of the maximum local flow velocities in the cable areas, see Chapter 4.

3.5 Comparing the large scale morphodynamics

Large scale morphodynamics like sand banks and sand waves can cause the seabed at the location of the platforms to raise or lower. Especially a lowering of the bed might threaten the integrity of a scour protection and should therefore be accounted for in the design. Please note that for cables connected to the platform also an increase in bed level might be important to consider. For the present study we focus however on the maximum expected lowering.

In the morphology and morphodynamics study performed for the Borssele Wind Farm Zone the maximum expected seabed lowering and rise were predicted until 2046. Here a maximum seabed lowering of -0.7 m was found for the Borssele Alpha and Beta.

The morphology and morphodynamics of the HKN and HKW areas were studied in Deltares (2018). Although no future predictions of the seabed are performed in this study, the migration speeds and the sand wave heights provide a reasonable idea of the seabed dynamics in the areas. Figure 3.4 and Figure 3.5 present respectively the estimated migration speeds and heights of the sand waves in the area around the HKN platform (bottom figures) and in the search area for the HKW Alpha platform (top figures).

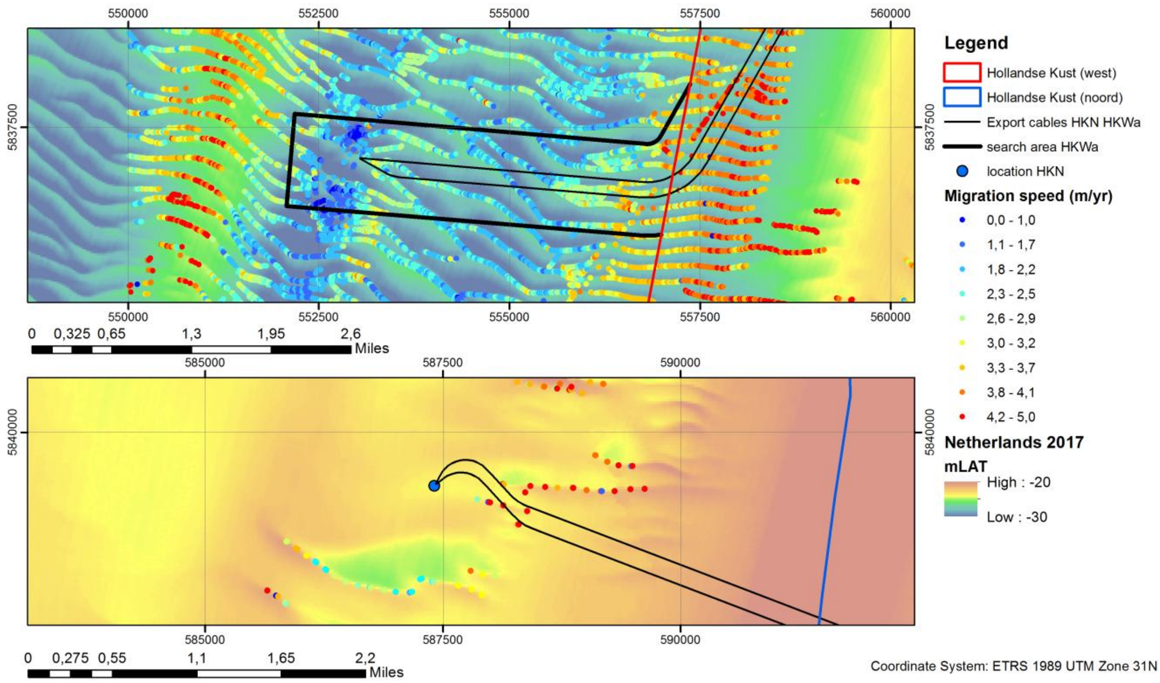

Figure 3.4 Mean migration speeds found in the vicinity of HKW Alpha (top) and the HKN platform (bottom).

In both figures the sand waves are identified and indicated by the dots. The colour of the dots present the migration speed (Figure 3.4) and sand wave height (Figure 3.5). Both Figure 3.4 and Figure 3.5 show that in the direct vicinity of the HKN platform sand waves are absent. Regarding the seabed dynamics the situation at the HKN platform is therefore very comparable to the situation at Borssele Alpha and Beta.

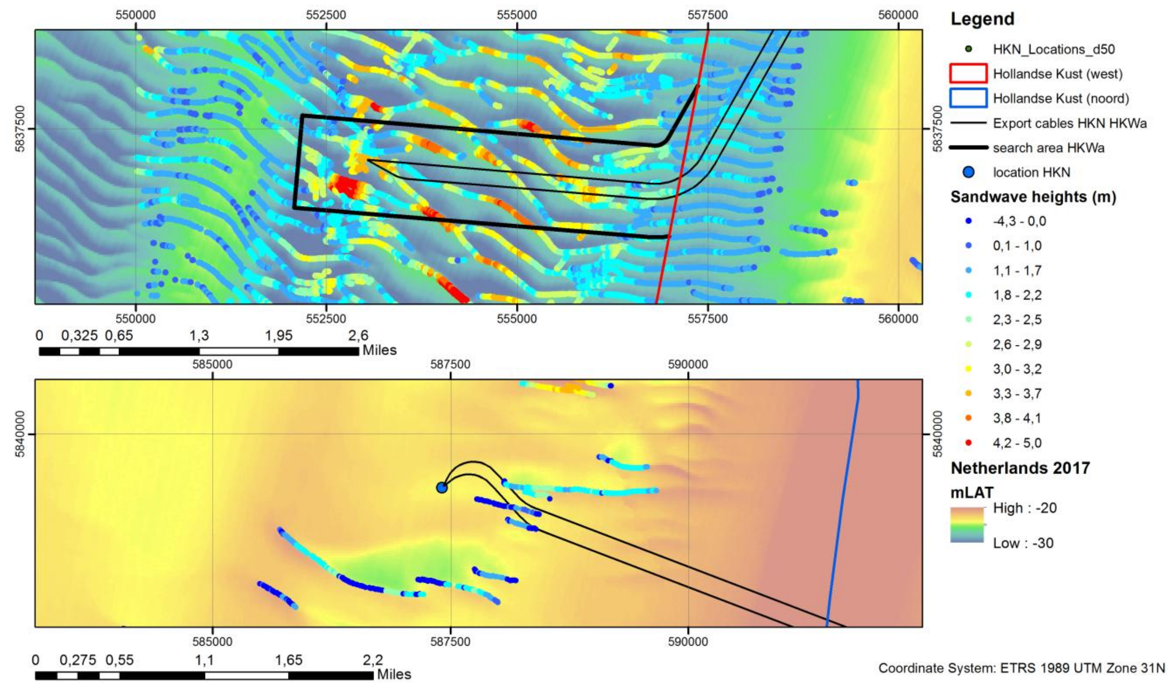

Figure 3.5 Sand wave heights in the vicinity of HKW Alpha (top) and the HKN platform (bottom).

In and around the search area for the HKW Alpha platform more morphodynamic activity is seen. Please note that in the east part of the search area, overlapping surveys made the analysis of the sand waves less accurate. The sand wave heights in the search area range in the order of 1 to 5 m and they move with 1 to 3 meter per year towards the north east. With wave length of 250 to 400 m, the maximum sea bed lowering that the platform might encounter during its lifetime (50yr) is approximately 3 m, which is significantly larger than expected for Borssele Alpha and Beta. Favourable placement can decrease or even dismiss this expected lowering.

4 Amplification of hydrodynamic conditions in the cable area

Figure 3.3, in Section 3.2, presents the maximum expected flow amplifications in the north, south and west cable areas of the HKN and HKW Alpha platforms. Appendix A presents the coordinates of the points in the field map for HKN and HKW Alpha with respect to the displayed coordinate system.

In order to estimate the maximum flow velocities at the cables the maximum undisturbed horizontal velocity at 1 m above the seabed is determined. These near bed velocities can be multiplied with the respective wave and current amplification factors to obtain the maximum expected amplified flow velocities. For an elaborate description of this approach the reader is referred to the numerical flow amplification study for the HKZ Alpha and Beta platforms (Deltares, 2017).

The maximum undisturbed velocities are based on a 100 year design storm for which the wave and current directions are aligned. The maximum near bed horizontal velocity as a result of the orbital wave motion is calculated with stream function wave theory (Rienecker & Fenton, 1981). The velocity is determined using the 100 year maximum wave heights and corresponding periods from the metocean database (DHI, 2017).

In agreement with Section 9.3.4 of the metocean report (DHI, 2017), the 95% maximum depth average current velocity corresponding with the 100 year storm is used to determine the current velocity at 1 m above the seabed using the power law profile:

$$U_c(z) = \frac{8}{7} U_{c,avg} \left(\frac{z}{h} \right)^{1/7}, \text{for } z < 0.33h \tag{4.1}$$

These extreme values from the metocean database and the calculated maximum undisturbed horizontal velocity at 1 m above the seabed are presented in Table 4.1.

Table 4.1 Extreme values of H_{max} and conditioned periods for 100 yr events at HKN and HKW Alpha (DHI, 2017) and the calculated maximum horizontal wave velocity at 1 m above the seabed.

	Environmental conditions				Maximum undisturbed flow conditions	
Load case	**H_{max} [m]**	**T_{Hmax} [s]**	**U_c [m/s]**	**Water depth [m MSL]**	**U_{wave} [m/s]**	**$U_{current}$ [m/s]**
HKN	15.1	12.9	0.8	25.1	3.51	0.58
HKWa_1	15.4	12.8	0.9	26.8	3.44	0.64
HKWa_2	15.4	12.8	0.9	30.8	3.17	0.63

Figure 4.1 presents the maximum expected flow velocities for the north, west and south cable areas, as indicated in Figure 3.3, for the HKN, HKW Alpha 1 (small footprint) and HKW Alpha 2 (large footprint) for the extreme storm conditions. The values are based on the engineering interpretation as described in the numerical flow amplification study for HKZ Alpha and Beta (Deltares, 2017). These values are subject to inaccuracies in the order of 10% corresponding to the inaccuracies found in the numerical model with respect to the physical model tests, see Deltares (2017). From the figure it can be observed that close to the structure maximum flow velocities in the order of 8 to 9 m/s are expected to occur during extreme conditions, while further from the structure the expected velocities are in the order of 5 m/s.

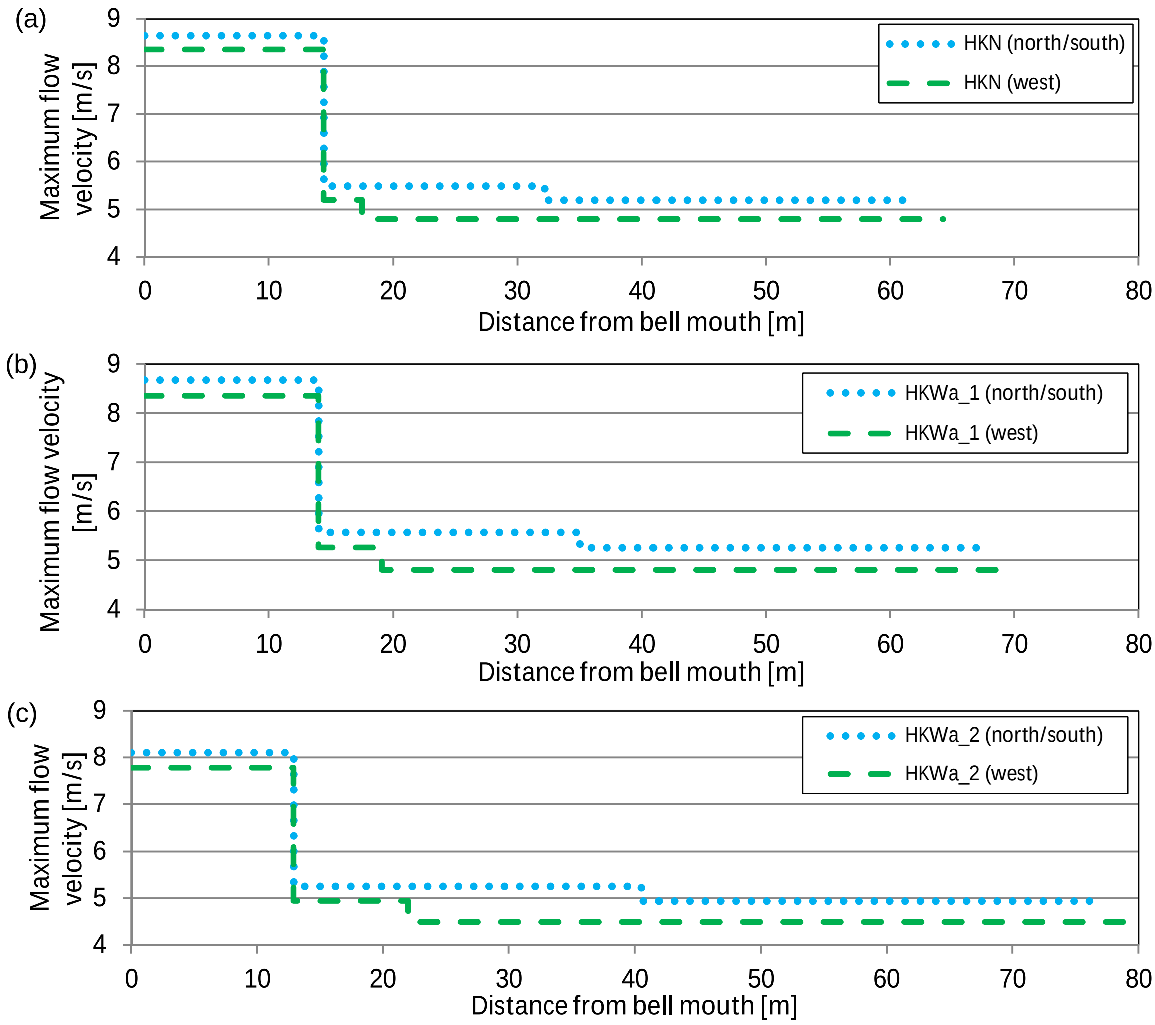

Figure 4.1: The estimated maximum flow velocities in the generalised cable areas: (a) HKN, (b) HKW Alpha 1 and (c) HKW Alpha 2. Note that these values are subject to inaccuracies in the order 10% corresponding to the inaccuracies found in the numerical model with respect to the physical model tests, see Deltares (2017).

5 Scour development and conceptual scour protection at HKN and HKW Alpha

Scour development

For the Borssele Alpha and Beta platforms for the mean tidal conditions an equilibrium scour depth of approximately 7m was found around the foundations. The comparison of the tidal conditions, which are generally governing for scour development, showed that the undisturbed mobility at HKW and HKN was slightly smaller than at Borssele. However, the flow amplification around the platform is expected to be very comparable to Borssele. Consequently, the scour development at both HKW Alpha and the HKN platform is expected to be slightly smaller than simulated for Borssele Alpha and Beta. For the design of the platform it might therefore be considered to let scour develop and adjust the design of the jacket to be able to accommodate this. Note that a detailed scour assessment is needed to optimise for this and that dismissing a scour protection might not be desirable because of the effect on the cables connected to the platform.

Conceptual scour protection layout

Regarding the required stone grading of the conceptual scour protection, we use the comparison of the undisturbed hydrodynamic conditions, presented in Table 3.2, and the comparison of the flow amplification. For both HKW Alpha and the HKN platform these parameters are not expected to differ much from the tested conditions of Borssele Alpha and Beta. Consequently, we recommend a 3-9” HD grading for the scour protection at HKW Alpha and the HKN platform. If applied as a single grading a minimum required thickness of 1 to 1.5 m is recommended to ensure sand-tightness. If combined with a filter layer (1-3” or 1-3” HD), this thickness might be optimized.

Regarding the required extent of the scour protection the expected edge scour and morphodynamic development is important to consider. For the HKN platform it was concluded in the previous chapter that both do not differ from Borssele Alpha and Beta. Consequently, an extent of 12m for a single layer 3-9” HD protection is expected to be sufficient. For HKW-Alpha an additional bed level lowering up to 3 m might occur due to sand wave migration. To deal with this lowering an additional extent up to 2.5 m is recommended. Please note that if HKW-Alpha is favourably placed with respect to the sand waves, on a location with negligible bed level lowering, this additional extent 2.5 m can be dismissed.

If a two layer system is applied, the mentioned extents might be optimized. Note that bed level lowering can influence the hydrodynamic load on your scour protection, this effect can be studied in a more detailed study but is outside the scope of the present research.

6 Conclusions and recommendations

The undisturbed hydrodynamic conditions at the HKN and HKW Alpha platforms is very similar to the conditions at the Borssele Alpha and Beta platforms.

Flow amplification
The flow amplification around the HKN and HKW Alpha platforms is expected to be similar to the amplification around the Borssele and HKZ platforms. For the cable areas to the north, west and south of the platform the maximum near bed flow velocities close to the structure are expected to be in the order of 7 to 9 m/s (excluding a 10% accuracy band) during extreme conditions. In the far field these flow velocities are expected to be in the order of 5 m/s (excluding a 10% accuracy band).

Scour development
The best-estimate for the scour development at HKN and HKW Alpha is similar to the outcome of the physical model tests performed for Borssele Alpha and Beta: 7 m.

Conceptual scour protection
An armour layer consisting of a 3-9” HD grading is expected to show limited deformation under the design storm condition (RP100yr). When applied as a single layer system, an extent of 12m (measured from the contour of the mud mats) is advised. For HKW-Alpha an additional bed level lowering up to 3 m might occur due to sand wave migration. To deal with this lowering an additional extent up to 2.5 m is recommended. Please note that this additional extent can be dismissed if the jacket is location on a position where no bed level lowering is expected. Based on expert judgement a minimum required thickness of 1-1.5m is expected to be sufficient to prevent winnowing.

When applied in a two-layer system, both the extent and thickness of the 3-9” HD grading can probably be decreased. In such a two-layer system a 1-3” or 1-3” HD filter layer should be included to prevent winnowing and undermining due to edge scour.

Please note this is a conceptual scour protection and that both extent and thickness of the armour layer as well as the stability and extent of the filter layer should be further verified.

7 References

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A Coordinates for the flow amplification map around HKN and HKW Alpha

Table A.1 Coordinates for the current-only maximum flow amplification map presented in Figure 3.3. Please note that the coordinates are described with respect to the orientation of the axes presented in the figure.

Location	HKN		HKW Alpha 1		HKW Alpha 2	
	x-coordinate [m]	y-coordinate [m]	x-coordinate [m]	y-coordinate [m]	x-coordinate [m]	y-coordinate [m]
1	-78.0	78.0	-85.0	85.0	-98.0	98.0
2	-31.2	78.0	-34.0	85.0	-39.2	98.0
3	18.0	78.0	19.7	85.0	22.7	98.0
4	-18.0	48.8	-19.7	53.1	-22.7	61.3
5	18.0	48.8	19.7	53.1	22.7	61.3
6	-18.0	20.5	-19.7	22.3	-22.7	25.7
7	-7.3	20.5	-8.0	22.3	-9.2	25.7
8	-7.3	16.6	-8.0	18.1	-9.2	20.8
9	7.3	16.6	8.0	18.1	9.2	20.8
10	7.3	20.5	8.0	22.3	9.2	25.7
11	18.0	20.5	19.7	22.3	22.7	25.7
12	-31.2	9.8	-34.0	10.6	-39.2	12.3
13	-18.0	9.8	-19.7	10.6	-22.7	12.3
14	-13.7	9.8	-14.9	10.6	-17.2	12.3
15	-31.2	-9.8	-34.0	-10.6	-39.2	-12.3
16	-18.0	-9.8	-19.7	-10.6	-22.7	-12.3
17	-13.7	-9.8	-14.9	-10.6	-17.2	-12.3
18	-7.3	-16.6	-8.0	-18.1	-9.2	-20.8
19	7.3	-16.6	8.0	-18.1	9.2	-20.8
20	-18.0	-20.5	-19.7	-22.3	-22.7	-25.7
21	-7.3	-20.5	-8.0	-22.3	-9.2	-25.7
22	7.3	-20.5	8.0	-22.3	9.2	-25.7
23	18.0	-20.5	19.7	-22.3	22.7	-25.7
24	-18.0	-48.8	-19.7	-53.1	-22.7	-61.3
25	18.0	-48.8	19.7	-53.1	22.7	-61.3
26	18.0	-78.0	19.7	-85.0	22.7	-98.0
27	-31.2	-78.0	-34.0	-85.0	-39.2	-98.0
28	-78.0	-78.0	-85.0	-85.0	-98.0	-98.0