Scour Protection for Subsea Structures

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ABSTRACT: Scour around subsea structures is an ongoing issue for the oil and gas industry. The design of effective scour protection systems is important for the integrity of the subsea structure. This paper presents a methodology for the design of scour protection systems for subsea structures, discussing different options and the difference between static and dynamic stability design approaches. A case study is presented which has utilised this design methodology in order to assure the design will meet the required design criteria.

1 INTRODUCTION

Scour of erodible seabed materials around subsea structures is a common design issue in the offshore industry. Scour changes the seabed profile, burying or uncovering pipelines and creating scour holes around the foundation of subsea structures.

For dynamically stable subsea pipelines, which allow for some movement within the design, scour may be less of a concern. However; where stability of a structure is critical, for example platform footings or subsea manifolds, scour has the potential to cause ongoing issues during operation. Several studies have been conducted in recent years to understand scour around offshore structures, with work focusing on simple structures, such as cylindrical piles and triangular structures (Rudolph et al 2009, Haerens et al 2012, Hogedal & Hal 2005 and Stahlmann and Schlurmann 2011).

On the North West Shelf (NWS) of Western Australia (WA) scour is highly likely due to tropical cyclone activity, which can cause extreme hydrodynamic conditions at the seabed resulting in the seabed material becoming mobile. This has been shown using physical model testing in Jas et al (2012). Unfortunately field measurements of scour have rarely been published for this region thus making a comparison between the theoretical information and actual scour difficult. This results in design uncertainty of sour protection methods and the use of large safety factors.

This paper discusses scour protection methods for subsea structures, focusing on areas where the erodible seabed material is mobile. Numerous scour protection options are available and the choice of a particular solution is based on many factors. To illustrate this, a case study of a fixed offshore platform positioned on a foundation of graded rock material on an erodible seabed is presented.

2 SCOUR

Scour is classified as a natural phenomenon caused by the erosive action of flowing water on the seabed (Khwairakpam & Mazumdar 2009). Scour removes sediment around and near subsea structures and occurs when the near bed shear stress exceeds the critical shear stress at which the bed material starts to move (Hogedal & Hald 2005).

Scour can be a high consequence design issue with significant costs associated with the inspection, and rectification of scour holes, and where structural failure results in facility shutdowns and/or loss of containment, loss of production revenue, environmental harm, health and safety hazard, and adverse reputation impacts can be very damaging to the operator of an offshore submarine oil and gas facilities.

Scour around a pipeline has the potential to cause a scour hole leaving the pipeline suspended above the local seabed surface. If the scour hole propagates along the pipeline then freespans will develop, this is where extended sections of the pipeline no longer touch the seabed (Figure 1). Freespans can increase the hydrodynamic loading on a pipeline, causing increased fatigue and stresses. In some instances, the freespan reaches a critical length and the pipeline will slump into the scour hole, reducing the hydrodynamic loading on the line. However, if a freespan exceeds the design maximum allowable length for Vortex Induced Vibration (VIV), and the

pipeline has not slumped in the scour hole, then remediation may be required if the freespan is demonstrated to be at risk of fatigue failure .
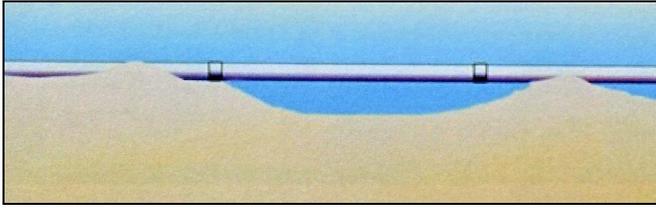

Figure 1 – Freespanning Pipeline

Scour around a subsea platform or manifold type structure is potentially more problematic. Once a scour hole develops around the footing it can propagate along the edge of the footing, causing stability issues and result in subsidence. Scour propagation around a subsea platform or manifold type structure has the potential to be accelerated by the increased seabed shear stress caused by the structure (Cheng et al, 2014)

3 PROTECTION METHODS

As stated in Whitehouse et al (2008), where scour is anticipated to be sufficiently severe to cause problems of structural stability or other related damage, scour protection is required. There are a number of different scour protection options available, with a range of applicability.

To mitigate against scour around a subsea structure a number of scour protection options are available, either as a stable or dynamic system. A stable scour protection system permits no movement of the scour protection system for a given design criterion. These are often used in situations where ongoing maintenance of the scour protection system is not feasible or does not align with operating philosophies, for example in deep water and/or around sensitive equipment. Although the requirement for ongoing maintenance has been designed out, monitoring will still be performed after extreme events i.e. in the NWS of Western Australia this is typically after any large cyclone.

A dynamic scour protection system is designed to erode to a certain extend during the design event, therefore requiring some level of maintenance to restore design capacity. One example of a dynamic scour protection system is engineered rock in a rock berm where some of the exterior material may scour but the main berm structure remains. This is also know as a maintenance design approach. A dynamic scour protection system requires inspection following design events with the expectation that maintenance to restore any loss to the original protection structure will be required.

Typically within the oil and gas industry subsea mattresses, engineered rock, geotextile, or grout bags are used to mitigate scour. Other options such as frond mattresses and steel skirts have been used as scour protection systems; however, these are not discussed within this paper.

3.1 Engineered Rock

Engineered rock is chosen for scour protection because it is versatile in application. Furthermore, installation of engineered rock is a common operation within the oil and gas industry and can be placed with high accuracy. As such a high level of expertise exists as well as availability of suitable installation vessels such as side dump or fall pipe vessels, Figure 2.

Engineered rock works by interlocking the rock particles within a berm, thus providing increased stability, allowing the rock berm to resist degradation (CIRIA et al 2007). As stated in Whitehouse et al (2011) the 'management of scour can be achieved through placement of protection such as rock engineered with appropriate grading to resist the locally enhanced flow and turbulence around the structure.'

Figure 2 – Side Dump Vessel with Engineered Rock

Engineered rock is graded using a nominal D_{50} and maximum l/t ratio (the maximum ratio of length to thickness of a rock particle) (CIRIA et al 2007). The nominal D_{50} and l/t ratio are used to determine the stability and minimum required size of the rock berm.
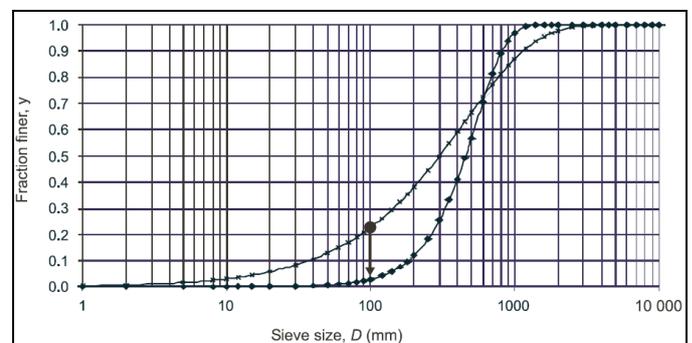

Figure 3 – Rock Grading Curve (CIRIA et al, 2007)

Engineered rock is an effective scour protection option around subsea structures; however installation considerations need to be made if there are delicate components (risk of damage from rock impact during installation) or future inspection and/or ac-

cess requirements for the subsea structure. Furthermore, proximity restrictions for rock dumping vessels around structures need to be assessed and can impact installation methodology and vessel selection which may result in cost escalation.

Engineered rock is usually placed around a subsea structure in an engineered slope. Depending on the design considerations of the project engineered rock berms are typically at least two times the height of the rock grading D_{50} (CIRIA, 2007), to allow for adequate interlocking of the rock particles.

Engineered rock is often chosen for dynamically stable systems for a number of reasons:

- Individual rock particles may degrade under design conditions but do not result in system failure.
- Engineered rock can be replaced in the event that the berm degrades more than the design limit.
- The rock berm particles typically embed into the seabed, increasing the stability of the berm.
- Mobile seabed material becomes trapped within the berm structure, increasing its stability.
- Engineered rock can be installed in a variety of conditions and situations.
- Engineered rock is generally readily available from most quarries providing the rock meets specification.
- Engineered rock has a proven track record.

A variation to a standard rock berm is a falling apron (Van Velzen 2012). This system allows the underlying material to scour until a fixed distance from a subsea structure. As the underlying material scours the rock berm material falls down and covers the resulting slope, thus halting the scour of the underlying material. Figure 4 presents the falling apron concept.
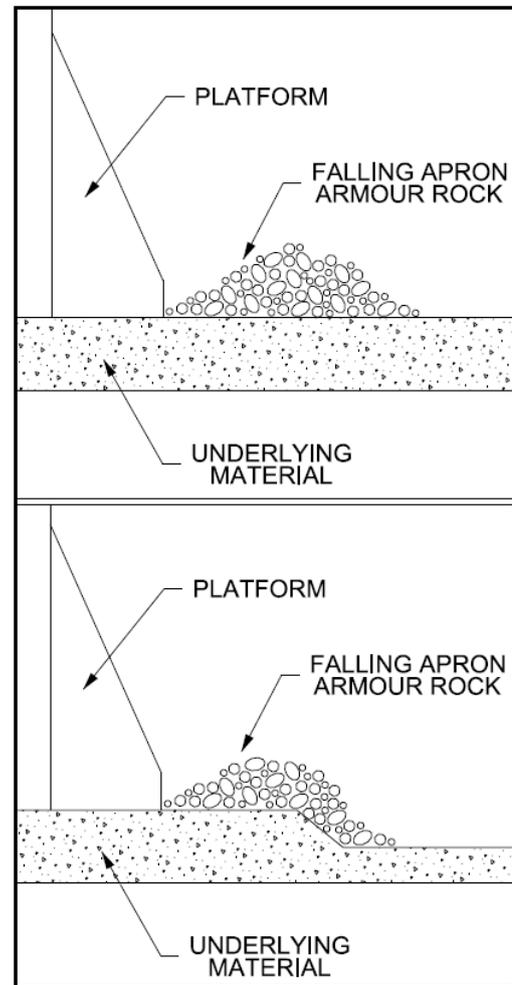

Figure 4 – Falling Apron Concept.

As this falling apron design has not been extensively used within the offshore industry continual monitoring of the rock berm performance is recommended, as stated in Whitehouse et al (2008).

3.2 Subsea Mattresses

Subsea Mattresses are widely used within the offshore industry for both secondary stabilisation and scour control. Although subsea mattresses can be constructed from a variety of materials concrete is usually chosen for the following reasons:

- Concrete is a low cost material
- Concrete is readily available worldwide
- Concrete has a high and flexible density and strength
- Concrete is easy to cast into the desired shape
- Concrete mattress are easy to install in most situations
- Concrete has longevity underwater.

There is currently no uniform industry methodology for the stability design of subsea mattresses. However, subsea mattresses are often designed by using the stability calculations presented in DNV-RP-F109 On-Bottom Stability Design of Submarine Pipelines (2010), which are then adapted to suit a mattress. The result is high factors of safety are applied to account for the uncertainty in the design and

therefore subsea mattresses are often over designed. The subsea mattress stability methodology presented in Godbold et al (2014) is adapted from the equations given in DNV-RP-F109.

The stability of a concrete mattress can be increased by altering a number of factors, including, but not limited to, block plan and elevation dimensions, concrete density, overall mattress dimensions, concrete additives and block connections. This paper does not discuss the stability of subsea protection options; however it is recognised as an important factor in scour protection design. Figure 5 presents a concrete mattress which has been placed over a pipeline.

Figure 5 – Concrete Mattress over a Pipeline

Subsea mattresses are an effective scour protection option for the following reasons:

- Subsea mattresses are able to be replaced in the event of movement.
- Subsea mattresses are versatile and can be used for most applications.
- The individual blocks embed into the seabed, increasing the stability of the system.
- Mobile seabed material becomes trapped within the mattress structure, increasing its stability.
- Can be easily installed in a number of different conditions and situations.
- Subsea mattress materials are available worldwide, decreasing the lead time on remedial works.
- Subsea mattresses have a proven track record.

However, it is important to note when used for scour protection around a subsea structure such as a platform, subsea mattresses are required to be installed accurately with little to no gap between them to ensure that the scour protection system works as designed.

3.3 Grout bags

Grout bags are widely used within the industry for scour control. Grout bags come in a variety of sizes, shapes and densities. Installation of a grout bag is undertaken when empty with placement on the seabed either by diver or ROV and then filled with grout pumped from a grout spread on the installation vessel. Grout bags are useful for scour protection as they can be placed adjacent to subsea struc-

tures and due to the installation method, the grout bags are form conforming to the structure to ensure robust protection.

In areas where high hydrodynamic activity is expected grout bags may not be suitable as a stand-alone scour protection option due to self-stability issues; grout typically has a low maximum density (~1,900 kg/m^3). Due to their ability to mould to the environment in which they are placed, grout bags are ideal to fill scour holes which develop in difficult to reach locations, such as under goosenecks where a spoolpiece connects to a manifold.

Figure 6 – Diver Installed Grout Bags

3.4 Geotextile

Geotextile is often used as scour protection along banks and slopes (Niroumand et al 2012) by stabilising the underlying material. One advantage of geotextiles is they are produced in one sheet, Figure 7, allowing full coverage of an area without gaps.

Figure 7 - Geotextile

Geotextile can be incorporated into other scour protection systems, for example subsea mattresses. This is achieved by casting the geotextile into the subsea mattress so it protrudes creating a geotextile flap around the mattress, closing any installation gaps between adjacent subsea mattresses or the subsea structure it protects. Furthermore, Geotextiles can be layered under other scour protection options, for example engineered rock or subsea mattresses, as is commonly done along banks. The geotextile is an effective scour protection option as it provides a physical barrier between the seabed material and the hydrodynamic conditions. This is particularly help-

ful in areas where embedment of the scour protection system is not advisable.

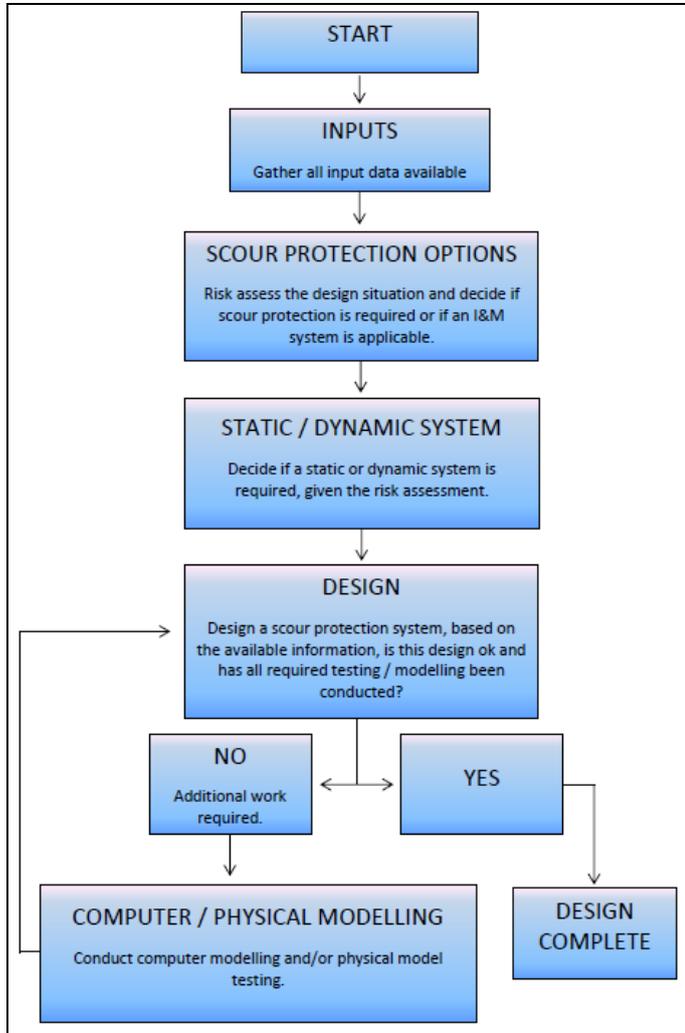# 4 DESIGN METHODOLOGY

4.1 Flow Chart

Figure 8 – Flow Chart

The proposed design methodology is an iterative process and is presented in Figure 8. The first step is to collect all the available input data for the design. Once collected, the second step is to perform a scour risk assessment to assess the type of scour protection system required and the protection option specific inputs. Once a scour protection system is chosen (static or dynamic) the preferred materials are selected. Multiple materials may be suitable, and often more than one scour protection design is carried forward. The next step is to assess the need for additional analyses; this is an outcome of the scour risk assessment and will vary between projects. Once any additional analyses have been conducted, if required, the iterative process begins and the original scour protection design is reassessed. This iterative process is repeated until a suitable design is found.

4.2 Input Data

Scour protection design for subsea structures requires a number of inputs; the following are the typically used:
- Functional requirements and design constraints.
- Metocean data.
- Seabed conditions.

The level of detail required within these inputs will be determined by both the level of design required (concept, FEED or detailed design stage) and the criticality of the subsea structure being protected. Typically a risk based assessment is undertaken in consultation with the Client.

4.2.1 Functional Requirements and Design Constraints

Each structure will have a range of functional requirements and design constraints which will need to be considered in the overall scour protection design. These include whether some scour around the structure is permitted (dynamic stability) or no movement (static stability) of the surrounding erodible material is a requirement.

In addition the design life of the structure needs to be considered. The scour protection system must be able to remain functional for the subsea structure's design life. In subsea applications typical consideration is given to the design Return Period (RP) hydrodynamic event in which the subsea structure is required to be stable.

Installation constraints need to be considered when considering scour protection, particularly for applications in locations of high risk such as around offshore oil and gas platforms. Installation in these locations will drive the type and class of installation vessel and will be limited by the sea state during the install so as to minimise the risk of damage to the platform from vessel collision, to as low as reasonably possible. Furthermore offshore platforms are connected to pipelines, umbilicals, risers and cables, all of which can be damaged during installation of the scour protection system.

Additional functional requirements which may require consideration are:
- Minimum required distance between the structure and scour protection.
- Support or protection of other subsea assets within the vicinity of the subsea structure (for example pipelines, flowlines or risers).
- Installation equipment capability.
- Installation accuracy.
- Full field architecture.
- Increase in the shear stress around a subsea structure.
- Interference with other structures/materials to be installed adjacent to the scour protection.

- Minimising installation cost by using simple and quick to install scour protection systems.
- The quality of the seabed material. In the event of a low strength or uneven seabed there may be a requirement to either clear the area or create a foundation blanket of graded engineered rock with known properties.

4.2.2 *Metocean Data*

Wave characteristics to calculate on-bottom wave induced particle velocities and on-bottom current velocities are required for scour protection design. This data shall represent the design RP metocean condition(s) for which the scour protection shall meet. .

As the initiation and propagation of scour is partly dependant on the metocean conditions, accurate data for the subsea structure's local environment is imperative for a successful scour protection system. Site specific, detailed metocean data of the local environment where the subsea structure is to be placed allows for a detailed scour protection system to be developed. In the event that detailed metocean information is not available, the available information should be used and an appropriate factor of safety (FOS) should be applied.

4.2.3 *Seabed Conditions*

A detailed understanding of the local seabed is important for scour protection design, as it is directly related to understanding whether scour is expected or not, how it shall propagate, and the expected depth of scour holes. Therefore any available information should be compiled, this includes Autonomous Underwater Vehicle (AUV) and Side Scan Sonar (SSS) data, soil samples, bathymetry data and geotechnical reports.

There are a number of visual indicators to determine if a seabed is mobile / erodible. In sand these include ripple marks, megaripples, sandwaves and obstacle marks such as scour and deposition around rocks or other debris on the seabed (Whitehouse et al 2010), all of which indicate a mobile seabed. In clay this may include longitudinal furrows or grooves and obstacle marks such as scour around rocks or other debris on the seabed (Whitehouse et al 2010). Any previous project experience within the locality of the design area should be utilised including surveys of nearby subsea infrastructure.

It is important to have detailed knowledge of the sub-structure of the seabed material to allow a detailed assessment of the likely extent of scour both prior to the installation of the structure and during the structures design life. In addition, when pipelines are placed in areas with a highly mobile seabed they tend to self-bury, increasing their stability and reducing the need for scour protection.

4.3 *Scour Risk Assessment*

The risk assessment looks at two parameters when determining the most appropriate scour protection system:
1. The likelihood of failure.
2. The consequence of failure.

In the event that a scour hole develops around a pipeline the likelihood of failure is relatively low. In most cases, once the scour hole has reached a critical length, the pipeline will sag into it. However, scour holes under a pipeline result in freespanning of the pipeline which can increase the stress and loading on the pipeline, potentially decreasing the life span of the pipeline in that location. Fatigue assessment on any section of a pipeline which is spanning over the allowable span length limit is recommended to ensure the pipeline is operating within the specified parameters and is not at risk of a fatigue failure. Scour around the footing of a subsea structure, left unchecked, has the potential to cause structure instability. As the hydraulic shear stress is amplified around the structure scour is likely to propagate faster, thus increasing the likelihood of failure. Especially, if the subsea structure is in a location which experiences large hydrodynamic events on a regular basis.

The consequence of failure for any subsea structure which carries hydrocarbons is likely to be high.

4.4 *Analytical Process*

An output of the risk assessment is the need for additional analysis. For a subsea structure which has a high likelihood and / or consequence of failure additional analysis is recommended, this can consist of computer modelling and / or physical model testing to assure the design. Before any further analysis is conducted a cost / benefit assessment of the options is recommended, considering the availability and location of testing facilities as well as the project budget.

The best scour information is field measurements taken from the site. However, these are not always available. Some comparison between field measurements and the calculations presented in DNV-OS-J101 Design of Offshore Wind Turbine Structures has been conducted by Haerens et al (2012) and Whitehouse et al. (2008). Whitehouse et al. (2008) found the observed scour, taken from wind farms in the North Sea, was higher than the predicted scour. Therefore, in situations where the scour protection system requires static stability, it is important to perform additional analysis to assess stability throughout the design life and to ensure the theoretical calculations do not underestimate the expected scour.

4.4.1 Computer Modeling

Computer modelling can greatly assist a scour protection design, allowing for a complex system to be modelled and the flow patterns to be studied (Whitehouse et al 2011).

There are a number of computer modelling programs used to predict scour and study the seabed conditions around offshore structures. Harris et al (2010) investigated the use of the STEP model for predicting scour around subsea structures, Hogedal & Hald (2005) used the modelling program Optipile to assess scour around monopoles and Rudolph et al (2009) evaluated the merits of OSCAR for complete scour management. Each program has its own benefits, limitations and applicability and it is important to understand these before using them within design. This paper does not investigate the various scour modelling software available.

Aside from modelling the expected scour, computer modelling can assist with the design of scour protection systems by providing a greater understanding of the hydrodynamic conditions around a structure. These outputs directly relate to the stability of the scour protection design and therefore the effectiveness of the chosen system. One such program is SCOUR-3D, developed by the University of Western Australia (UWA). SCOUR-3D is a Computational Fluid Dynamics (CFD) package, which has been utilised in numerous stability and scour studies. The SCOUR-3D package is a finite element program and simulates the turbulent flow field around any structure by solving the Reynolds-Averaged Navier-Stokes (RANS) equation with a k-ω turbulence model (Zhao et al 2009). The parallel computing capability of SCOUR-3D allows large scale simulations to be conducted efficiently. SCOUR-3D has been validated for use in a wide range of applications; these are documented within Cheng & Zhao (2010), Zhao et al (2010a) and Zhao et al (2010b).

CFD allows for the hydrodynamic conditions around a subsea structure to be modelled and consequently the shear stress amplifications can be determined. Increased shear stress around the footing of a subsea platform has the potential to destabilise the chosen scour protection system by causing an increase in the hydrodynamic conditions applied.

Another use of computer modelling within the scour protection design is using programs such as PROBED to assess the stability of an engineered rock berm. PROBED uses the concepts presented in The Rock Manual to assess the minimum required nominal D_{50} of engineered rock to achieve stability using the hydrodynamic conditions.

4.4.2 Physical Model Testing

Physical model testing can provide valuable insight into scour around subsea structures (Bos et al 2002) and is the most effective method for validating a scour protection system.

Before embarking on a physical model testing program the value of the tests must be considered, not all physical model testing will add value to a project. It is important to ensure the chosen facility is capable of performing the tests and achieving the desired result. Some things to consider when choosing a physical model testing facility:

- Scale. If the tests have to be performed at a small scale (greater than 1:20), then scaling effects become more prominent and the information gained is not always transferable to prototype scale.
- Model. When modelling complex structures it is important that an appropriate scaled model is able to be created, otherwise the results obtained are not relevant to the prototype situation.
- Scenario. The testing facility must be able to replicate the metocean and geotechnical scenario required.

A number of physical model testing facilities exist worldwide which are capable of reproducing numerous scenarios with an acceptable scale, for example the facilities at The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and those at UWA.

BMU have developed offshore physical model testing facilities in 30 m water depth, for testing scour (Stahlmann & Schlurmann 2011). This facility allows for large scale testing of scour around foundations / footings to be completed in real world conditions.

UWA have developed the O-Tube facility, a hydrodynamic testing facility which allows for testing near-seabed conditions during cyclonic events (Cheng et al 2014). The O-Tube operates using an electric powered propeller to circulate or oscillate 60 m^3 of water though a closed loop system. It has several advantages over other facilities including:

- Simulates high oscillatory and steady currents.
- Simulates the mobility of seabed material.
- Simulates the interaction between seabed material and the test piece.
- Ability to use a large scale of around 1:10 for scour protection stability testing, reducing the inaccuracies inevitable due to small scaling.

The O-Tube facility has been utilised for a number of projects, allowing for the verification of designs when analytical / theoretical methods have been unable to provide conclusive results. The O-Tube allows for on bottom conditions to be modelled while still maintaining an acceptable scale. In addition, the O-Tube has been used to model over 10,000 year RP cyclonic oscillatory conditions for recent platform scour protection projects.

4.4.3 *Evaluate*

Once all input data has been collected, a preliminary scour protection design has been done and additional computer and physical model testing has been conducted the scour protection design system restarts. This step takes the current design and compares it to the results of the computer and physical model testing. If the scour protection system design is acceptable then the process may end. However, if the system is deemed un-acceptable it is necessary to modify the scour protection design using the additional knowledge. This may result in the need to conduct more computer and physical model testing to validate the new design.

5 CASE STUDY

The scour protection for subsea structures design methodology, Figure 8, has been implemented on a project in the NWS of WA, which is presented as the case study.

The case study looks at the design of the scour protection system for the foundation of an offshore platform. Due to the metocean conditions in the NWS, and the likelihood of cyclonic activity the platform had stringent functional requirements for scour control. Any scouring of the platform's foundation material around the footings is unacceptable. As a result the theoretical calculations adapted from DNV-RP-F109 were not considered to provide an adequate amount of assurance of the scour protection system.

In addition, to create a flat seabed for the platform a foundation layer of engineered rock has been installed. This engineered rock must be considered within the scour protection design and was therefore considered as an erodible seabed of known material properties.

The platform required static stability of the foundation material under and around the footings in order to ensure stability of the platform over the design life. To achieve static stability a scour protection system has been implemented, designed to the extreme design conditions due to large RP tropical cyclones (10,000 year RP event) in combination with increased free flow hydrodynamic loading caused by flow amplification around the base of the offshore platform.

The initial scour protection method was to use engineered rock around the entire platform to protect the foundation material from scouring. Due to installation constraints engineered rock was unable to be placed around some sections of the platform. Therefore, the design iteration process began and subsea mattresses were added to the design.

The subsea mattresses and engineered rock are designed using the falling apron concept. As the foundation material is expected to scour under the hydrodynamic conditions the engineered rock and subsea mattresses will cover the exposed slope, halting the scour of the foundation material, as detailed in Figure 4.

From the platform scour risk assessment the need for additional analyses was established. Any potential effects of the platform on the hydraulic shear stress around the footings were analysed. To achieve this CFD modelling was utilised to assess the expected shear stress amplifications expected around the platform in order to ensure the correct metocean input data has been used. This data was then used to assess the stability of the scour protection system and determine areas of potential instability around the platform. As a result of the CFD modelling it was deemed necessary to conduct further investigations to assess the stability of the scour protection engineered rock and concrete mattresses and ensure their performance will be within acceptable limits.

According to the amended theoretical equations the subsea mattresses and engineered rock were expected to be unstable for the required design RP cyclonic event in some areas around the platform. Therefore physical model testing was conducted in UWA's O-tube. The engineered rock and subsea mattresses were tested within the O-tube to assess their stability. It was proven that not only were the mattresses stable for the required RP cyclonic event, but for most of the expected amplifications as well, providing savings for the project. It was a project decision that the small areas where the subsea mattresses and engineered rock are potentially unstable will be specifically monitored and maintained as required.

It is noted that not all projects will require as detailed analysis and testing as this case study; however further testing is recommended in areas of either high likelihood or high consequence of failure to ensure certainty in the scour protection design.

6 SUMMARY

When designing a scour protection system for a subsea structure there are a number of factors which must be considered to ensure an effective solution. Each case should be evaluated separately and the individual risks and benefits assessed.

Each of the scour protection systems (static and dynamic) impact the capital expenditure (CAPEX) and operational expenditure (OPEX) of a project and the long term scour protection requirements must be considered when choosing an option. A dynamic system may result in reduced CAPEX for the project but if the asset does not have adequate access or is in an area prone to scour, then the long term OPEX costs may escalate.

Scour protection for subsea structures is an iterative process and it is important this process is com-

pleted for each design taking in to account all considerations discussed herein. The iterative process increases the likelihood of problems being identified before installation, therefore decreasing the likelihood of issues later in life.

Subsea structures, especially offshore oil and gas platforms, are large, long-term investments and to ensure the longevity of the asset and success of the project, adequate analyses must be performed before the scour protection design can be finalised.

7 FURTHER WORK

Scour around subsea structures, and the most efficient way to protect the structures from scour is an area of interest for the offshore industry. Areas which may benefit from additional research are:
- Scour around unusual shaped foundations and footings.
- Falling apron design.
- Effects of amplifications around different shaped subsea structures on varying seabed material.
- Failure behaviour of scour protection systems.
- Alternative scour protection options / materials / systems.

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